BIRZEIT UNIVERSITY

Faculty of Engineering and Technology
Joint Master in Electrical Engineering (JMEE)

Impact of Integrating Photovoltaic Systems on Distribution Network Harmonics

Submitted By

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Supervisor

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January, 2019

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تأثير ربط الأنظمة الكهروضوئية على التوافقيات في شبكات التوزيع الكهربائية

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This Thesis was submitted in partial fulfillment of the requirements for the Master's Degree in Electrical Engineering From the Faculty of Engineering and Technology at Birzeit University, Palestine

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January 12, 2019

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DECLARATION

I declare that this thesis entitled "Impact of Integrating Photovoltaic Systems on Distribution Network Harmonics" is the result of my own research except as cited in the references. It is being submitted to the Master's Degree in Electrical Engineering from the Faculty of Engineering and Technology at Birzeit University, Palestine. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature: ………………………………

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Date: ……………………………………

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January 12, 2019

ABSTRACT

In this new epoch, the accelerating in technological innovation and strong worldwide tendency toward energy efficiency represented by increasing use of power electronics, and increased reliance on renewable energies have propelled the development of the entire world to its new prospects and challenges. Moreover, advent of high efficiency Distributed Generators (DGs), parallel with the increased attention toward environment, has led to increasing renewable energy based DGs in distribution power systems. But, from the other hand, these rising equipment over power networks can destabilize the system stability and reliability, as this creates a lot of troubles and malfunctions. In this context and whereas power quality problems inevitable in distribution systems, the aim of this study is to highlight an important issue concerning power quality problems in presence of Photovoltaic (PV) systems connected to it. Harmonics resulted from various sources have a considerable impact on system operation and performance. It also becomes increasing concern to both power suppliers and user. For this purpose, an existing PV system of small scale capacity (300 kW), and another proposed large scale one (of 7.5 MW capacity) had been tested. The first system was monitored along different periods of time. A detailed assessment and analysis of the measuring periods are performed for the purpose of monitoring the behavior of these systems during their work, and study their impact on electrical system mainly harmonic distortion. Moreover, both test systems are applied for a real existing system within Jerusalem District Electricity Co. (JDECo) network, for the purpose of studying the impact of PV systems on total system losses. The outcomes demonstrate a significant impact of large scale grid connected DG units on electric system parameters, due to their aggregated harmonic distortions. The system was tested simulated and verified using NEPLAN simulator.

المستخلص

في هذه الحقبة الجديدة، أدى التسارع بالابتكار التكنولوجي والإتجاه العالمي المتمركز نحو كفاءة الطاقة التي تمثلت بزيادة استخدام إلكترونيات القدرة فضلاً عن زيادة الإعتماد على مصادر الطاقة المتجددة إلى دفع العالم بأسره نحو آفاق وتحديات جديدة. وعلاوة على ذلك، أدى ظهور أنواع جديدة من المولدات الموزعة (DGs) ذات الكفاءة العالية، بالتوازي مع الإهتمام المتزايد نحو قضايا البيئة، إلى زيادة الإعتماد على مصادر الطاقة المتجددة في شبكات التوزيع. لكن من ناحية أخرى، يمكن لهذه المعدات المتزايدة عبر شبكات الطاقة أن تزعزع استقرار النظام وموثوقيته، الأمر الذي يخلق الكثير من المشاكل والأعطال.

في هذا السياق وفي حين أن مشكلات جودة الطاقة تعتبر موضوعاً حيوياً لايمكن تجنبها في أنظمة التوزيع، فإن الهدف الأساسي من هذه الدراسة هو تسليط الضوء على قضية مهمة تتعلق بمشاكل جودة الطاقة في ظل وجود أنظمة كهروضوئية (PV) متصلة بها. التوافقيات الناتجة من مصادرمختلفة لها تأثير كبير على تشغيل النظام وأدائه. وبالتالي أصبحت مصدر قلق متزايد لكل من موردي الطاقة والمستخدمين على حد سواء. ولهذا الغرض، تم إختبار نظامين الأول نظام كهروضوئي قائم ذو سعة صغيرة الحجم (300 كيلوواط)، ونظام آخر واسع النطاق ذو سعة 7.5 ميجاواط. تم رصد النظام الأول في فترتين مختلفتين من الوقت، من أجل إجراء تقييم وتحليل مفصل لفترات القياس لغرض مراقبة سلوك هذه الأنظمة أثناء عملها، ودراسة تأثيرها على النظام الكهربائي ككل وبشكل رئيسي على التشويه التوافقي. علاوة على ذلك، تم تطبيق نظامي الاختبار على أنظمة موجودة بالفعل ضمن شبكة شركة كهرباء القدس (JDECo) لغرض دراسة تأثير الأنظمة الكهروضوئية على إجمالي خسائر النظام. أظهرت النتائج وجود تأثير كبير من وحدات DG المتصلة بالشبكة واسعة النطاق على عناصر النظام الكهربائي، وذلك بسب وجود التوافقيات المجمعة. تم عمل المحاكاة والتحليل باستخدام محاكي NEPLAN .

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DEFENITINOS

System Voltages

- Low voltage (LV) refers to $V_n \leq 1$ kV;
- Medium voltage (MV) refers to 1 kV < $V_n \leq 35$ kV;
- High voltage (HV) refers to 35 kV < $V_n \leq 230$ kV;
- Extra high voltage (EHV) refers to 230 kV < V_n [IEC 61000-3-6].

Distorting Installation

An electrical installation as a whole (i.e. including distorting and non-distorting parts) which can cause distortion of the voltage or current into the supply system to which it is connected [IEC 61000-3-6].

Emission Level

Level of a given electromagnetic disturbance emitted from a particular device, equipment, system or disturbing installation as a whole, assessed and measured in a specified manner [IEC 61000-3-6].

Emission Limit

Maximum emission level specified for a particular device, equipment, system or disturbing installation as a whole [IEC 61000-3-6].

Maximum Demand Load Current

This current value is established at the point of common coupling and should be taken as the sum of the currents corresponding to the maximum demand during each of the twelve previous months divided by 12 [IEEE 512- 2014].

Normal Operating Conditions

operating conditions of the system or of the disturbing installation typically including all generation variations, load variations and reactive compensation or filter states (e.g. shunt capacitor states), planned outages and arrangements during maintenance and construction work, non-ideal operating conditions and normal contingencies under which the considered system or the disturbing installation have been designed to operate [IEC 61000-3-6].

Planning Level

level of a particular disturbance in a particular environment, adopted as a reference value for the limits to be set for the emissions from the installations in a particular system, in order to coordinate those limits with all the limits adopted for equipment and installations intended to be connected to the power supply system [IEC 61000-3-6].

Point of Common Coupling (PCC)

Point in the public supply system, which is electrically closest to the installation concerned, at which other installations are, or could be, connected. The PCC is a point located upstream of the considered installation [IEC 61000-3-6].

Harmonic Frequency

Frequency which is an integer multiple of the fundamental frequency. The ratio of the harmonic frequency to the fundamental frequency is the harmonic order (recommended notation: “h”) [IEC 61000-3-6].

Harmonic Component

Any of the components having a harmonic frequency. For brevity, such a component may be referred to simply as a harmonic [IEC 61000-3-6].

Total Demand Distortion (TDD)

The ratio of the root mean square of the harmonic content, considering harmonic components up to the 50th order and specifically excluding inter-harmonics, expressed as a percent of the maximum demand current. Harmonic components of order greater than 50 may be included when necessary [IEEE 512-2014].

Total Harmonic Distortion (THD)

The ratio of the root mean square of the harmonic content, considering harmonic components up to the 50th order, and specifically excluding inter-harmonics, expressed as a percent of the fundamental. Harmonic components of order greater than 50 may be included when necessary [IEEE 512-2014].

Ratio of the rms. value of the sum of all the harmonic components up to a specified order (H) to the rms. value of the fundamental component [IEC 61000-3-6].

$$THD = \sqrt{\sum_{h=2}^{H} \left(\frac{Q_h}{Q_1}\right)^2}$$

Where

Q: represents either current or voltage,

Q_1: is the rms value of the fundamental component,

h: is the harmonic order,

Q_h: is the rms value of the harmonic component of order h,

H: is generally 40 or 50 depending on the application.

LIST OF ABBREVIATIONS

Abbreviation	Full word
ac	Alternating Current
AHF	Active Harmonic Filter
BSPs	Bulk Supply Points
CFLs	Compact Fluorescent Lamps
dc	Direct Current
DG	Distributed Generator
DISCos	Distribution Companies
DSTATCOM	Distribution Static Compensator
GA	Genetic Algorithm
HC	Hosting Capacity
HHF	Harmonic Hybrid Filter
HVAC	Heating Ventilation Air Conditioning
IEC	International Electrotechnical Commission
IECo	Israeli Electric Corporation
IEEE	Institute of Electrical and Electronics Engineers
JDECO	Jerusalem District Electricity Co.
JICA	Japan International Cooperation Agency
LCL	Inductor Capacitor Inductor
LL	Load Losses
LV	Low Voltage
MRC	Multiple Resonant Control
MV	Medium Voltage
NLL	No Load Losses
PCC	Point of Common Coupling
PENRA	Palestinian Energy and Natural Resources Authority
PETL	Palestinian Electricity Transmission Company
PFCC	Power-Factor Correction Capacitors
PHF	Passive Harmonic Filter
PQ	Power Quality
PSO	Particle Swarm Optimization

PU	Per Unit
PV	PhotoVoltaics
PWM	Pulse Width Modulation
rms	root mean square
SCADA	Supervisory Control and Data Acquisition
SMPS	Switch Mode Power Supplies
TDD	Total Demand Distortion
THD	Total Harmonic Distortion
VUF	Voltage Unbalance Factor
XLPE	Cross-Linked Polyethylene

CHAPTER 1: BROAD PROBLEM AREA

1.1 Introduction

By the mid of 19^{th} century, the advent of industrial revolution brought a major shift in energy sources with the wide usage of coal and oil, for steam engines and power plants operation. During the 20^{th} century, the prevalence of petroleum products as the main source of energy played a key role in the neoteric global economic market. One of the most important achievements of modern science was the discovery of access to atomic energy. Besides advancement in energy sources, and by the relentless efforts, power electronics has recently emerged as a sophisticated and multidisciplinary technology, which took control of the growing potential of new efficient forms of energy sources under a new concept known as Distributed Generators (DGs). DGs cover a wide range of power generation units including both conventional and renewable types. The presence of these generators has been contributing into the formation of the decentralized energy market and the end long ages of monopolies in energy sector. Beside the numerous advantages of technology advancement; now the main challenge with power generation and distribution is the intermittency of DGs, in addition to emergence of a considerable number of low power nonlinear components connected to the power system grid.

In recent years, there is a global direction towards energy efficiency and power quality issues. The end user achieves energy efficiency at the expense of increased system losses and reduced system reliability, stability, and safe operating conditions for utilities. The problem in this study will highlight an important issue concerning power quality problems arising from the proliferation of harmonic with presence of DG system. A detailed assessment and analysis for harmonic impact on system operation, including assessment of technical losses caused by harmonics for different operating conditions will be performed in order to take important decisions about medium and long term of the electric energy distribution network planning.

1.2 Research Problem

This research will focus on studying the harmonic impact of PV systems connected to a typical distribution system, to consider the effect of such systems on both power quality issues, as well as total system losses.

1.3 Significance of the Study

DG integration realizes a lot of benefits which have been closely followed in various research papers. These benefits enface the advantages that will be gained. However, this integration of PV units introduces certain challenges in the systems. Some basic information of common benefits of such unit integration have been listed below

1- Technical benefits

- ✓ Integration of PV systems at strategic locations and sizes leads to reduced line losses, improving power quality, and enhance voltage support thereby improving voltage profile
- ✓ Enhancement system reliability, stability, and security

2- Economic benefits

- ✓ Prolong equipment’s life, and thus avoiding equipment failure due to miss operations
- ✓ Reducing waste of energy, thus increasing overall system efficiency
- ✓ Enhancing overall productivity due to diversification of resources and risk allocation
- ✓ Deferred investments for upgrading traditional generating units

- ✓ Lower operation and maintenance cost required compared to traditional generation units
- ✓ Reducing reserve requirements and related cost
- ✓ Potential employment opportunities
- ✓ Indirect monetary benefit in terms of reduced health care cost

3- Environmental benefits

- ✓ Generation of electricity without toxic pollutants such as CO_2
- ✓ No effect on global warming

1.4 Research Questions

The research questions are summarized as follows:

1- What are the harmonic sources in modern power system?

2- What is the problem of harmonics in modern power system?

3- What are the international standards for harmonics?

4- What are the mitigation techniques used to reduce harmonic effects?

5- What is the impact of integrating PV on power system harmonics?

6- How do harmonics affect system losses?

7- Should waveform distortion be considered when connecting large scale of PV projects?

1.5 Target Beneficiaries

1- Jerusalem District Electricity Co. (JDECo).

2- Distribution Companies (DISCos).

3- Palestinian Electricity Transmission Company (PETL)

4- Renewable energy investors.

5- State based regulatory authorities.

6- Power quality researchers.

1.6 The Organization of the Study

The remaining divisions of this study are structured as follows. Chapter two introduces a literature review of what has been done in the same field area. The following Chapter three presents the system under study, statistical information and figures regarding electric system in Palestine. In addition, Chapter four introduces the methodology used in the study, and data collection criteria. Moreover, Chapter five discussed the results obtained for the test system, as well as analysis of harmonic impact on total system losses using NEPLAN simulator. Finally, conclusions and future works are presented in Chapter six.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

A significant increase in the penetration level of PV systems has been noticed during the past 15 years due to rapid development in the PV technology [1]–[3]. According to [4], In near Future, PV systems have the potential of general applications as an alternative safe and clean energy source. The target of some utilities is to penetrate around 20% renewable energy of total required energy by 2020, while other utilities expect 50% by the year 2050 [2]. For many world countries PV systems are considered as a practical unconventional and clean source of energy.

In the past, the DG units connected to the power were weaker to cause a significant effect in the power system. Nowadays, with the tangible progress in systems integration with dispersed generation units, this situation is changing [4]. In addition, although the main concern in PV development and application was focused on the improvement of cells efficiency, several researchers got attention to the integration of these systems with electric grid [5], [6]. Studies show that having an inter-tie between DG systems and utility grid may have a significant impact on the system itself, as well as equipment operation in terms of dynamic as well as steady state operations, power quality, reliability, safety and stability for both network operators and end users. According to [7], higher levels of PV penetration has resulted in replacing conventional generating units with the DG units at lower voltage levels, and on locations much closer to the load centers. This situation can limit the availability of reactive power; in addition, increase injection of PV systems will affect the static performance as well as transient stability of large power system, mainly at disturbances when reactive power supply to the loads is interrupted. In this way, bus voltages are expected to be more perturbed during the system transients. voltage control, and on the associated reactive power flow through the distribution system is discussed in [8]. Another important issue regarding connecting of PV to the distribution system is protection system; the interconnection of DGs into distribution systems has significant impacts on the traditional protection scheme because the distribution system is no longer radial in nature. Thus, the protection system with overcurrent protection scheme becomes a challenging issue to system operators due to the change in fault levels and direction; mis-operation and malfunction of protective equipments may also occur [9]–[11]. Moreover, the DG is usually a converter-inverter type, thus, the conversion of direct current (dc) to alternating current (ac) results in injection of harmonic in electric networks; these units can therefore be treated as a nonlinear load injecting harmonics into the distribution system [12], [13]. Furthermore; the connection of large scale PV systems to the distribution grid will significantly increase Total Harmonic Distortion (THD) level and will augment the problem of distribution system performance [14]–[16]. Higher harmonic levels of such systems can cause problems and disturbances in the performance of sensitive and electronic devices as well as load controllers. Harmonic distortion is a growing concern for Power Quality (PQ) as it will degrade the performance of the power systems [1], [17]. This impact may manifest itself either positively or negatively, depends on both DG characteristics itself and distribution network operating characteristics [7], [17]–[20].

The severity of these issues depends on the penetration level of PV, network configuration, and the location of the PV system in the distribution system. According to [15], the Hosting Capacity (HC) which represents the maximum penetration level of the DG units decreases with increasing in utility side voltage distortion and load side's nonlinearity values. The HC level was influenced more by the nonlinearity of the load side than by the utility side voltage distortion. Chidurala et al. [17] introduce a potential issue of increased harmonic distortion levels on LV distribution system; with high penetration levels of PV systems, the investigation has been carried out at different cases, simulation results show that the harmonics generated from PV systems are additive in nature and are subject to the concentration of harmonic levels from non-linear loads. Results likewise affirm that both voltage and current distortions are affected by the number of PV systems as they increase with system penetration increases. In [21], the effect of solar irradiance to voltage and current waveforms distortion is discussed through the simulation model developed in simulink. The outcomes based on field measurement demonstrate that solar irradiance affects the current THD profiles significantly.

Amongst these impacts, the proliferation of harmonic becomes a major interest for the utilities as various kinds of nonlinear loads and DGs are connected to the network. This interaction of harmonics affects the system in different ways. The following section presents the state-of-the-art and literature survey on harmonic impacts, limits and mitigation techniques used to control harmonic levels within the system.

2.2 Harmonic Problems in Modernistic Power System

Most power systems can accommodate a certain level of harmonic currents but will experience problems when harmonics become significant components of the overall load. These impacts levels are affected by type of harmonic source, its location on the power network, and the network characteristics that promote propagation of harmonics. As these higher frequency harmonic currents flow through the power system, they can cause communication errors, overheating and equipment damage in some cases [22], [23]. In addition, the effects of such exposure does not have to be visible or observed instantly in the short term, but may have serious consequences in the medium and long term [22]. The major harmonic impacts to other equipment include performance degradation, increased losses and heating, in addition to resonance problems. In extreme situations, it can lead to high thermal stresses and early ageing of the operating equipments. Furthermore, harmonic currents when combined with high grid impedance increases voltage distortions in the network [24]–[28]. Voltage distortion directly affects loads; it can cause motors to overheat and vibrate excessively and may damage the motor shaft. Although non linear loads are prey to voltage distortion, equipment include computers, electronically-ballasted fluorescent lights, other sensitive electronic loads may be affected directly and deteriorate by voltage distortion [25]. Another indirect problem caused by current distortion is called "resonance"; certain current harmonics may excite resonant frequencies in the system. This phenomenon can cause extremely high harmonic voltages, potentially harming delicate electronic hardware. Moreover, as the current distortion is passed through the system wiring, it creates voltage distortion as indicated by Ohm's Law. While current distortion travels only along the power path of the non-linear load, This distortion affects all loads connected to that particular bus or phase [25].

Research and development regarding harmonic issues are underway, and several methodologies and algorithms have been proposed in order to reduce harmonic impacts and meet its challenges, as well as making power grid transition towards smart one in a powerful manner. Neaguet al. [29] Investigated the additional power losses for a real distribution network that operates in distortion state using complex analytical approach for determining the active power losses. The simulation results demonstrate that the power losses can be increased to more than 25% due to harmonic current flowing in real low voltage (LV) distribution networks. In [30], the researchers tried to estimate the amount of the harmonics produced by nonlinear loads in residential, commercial and office loads in distribution feeders and determine the energy losses caused by these harmonics. The outcomes show that the losses can be up to 18% of the feeder power usage, while the share of harmonics in causing these losses is dependent to the THD of the feeder current. Some works have used the curve fitting approaches and the simplified feeder models and to estimate the losses [31]–[33]. A comprehensive loss estimation method using detailed feeder and load models in a load-flow program is presented in [34]. A combination of load flow methods and statistical methods is used to find different types of losses in a particular power system in [35]. Simulation of distribution feeders with actual information evaluated from typical consumer loads is performed in [36].

2.3 Harmonic Effects

Below is a short summary of most effects caused by harmonic.

2.3.1 Effects on Transformers

Transformers serving nonlinear loads exhibit increased both no load losses (NLL) and load losses (LL) as shown in (1). No load or iron loss can be divided into two components: hysteresis loss (due to non-linearity of the transformers) and eddy current loss (varies in proportion to the square of frequency). These losses are affected mainly by voltage harmonics, and the overall increase of this loss with harmonics is relatively small [27]. On the other hand, the LL, as a function of load current, consists of I^2R loss (P_R) due to the ohmic resistance of windings, and stray losses. The stray load losses are caused by eddy-currents that produce stray electromagnetic flux in the windings, core, core clamps, magnetic shields, tank walls, and other structural parts [26], [27]. Because the load losses of a transformer is directly related to square of load current; for harmonic-rich current these losses will increase sharply due to the increase in rms current as shown in the below equations (2) [26], [27] :-

$$P_{loss} = P_{NL} + P_{LL} \tag{1}$$

and, $$P_{LL} = P_R + P_{EC} + \mathrm{P_{ST}} \tag{2}$$

where

P_{NL}: No load losses

P_{LL}: Load losses

P_{EC}: Eddy current losses

$\mathrm{P_{ST}}$: Stray losses in the structural parts

The power loss for non-sinusoidal load currents, the can be obtained by the sum of the squares of the fundamental and harmonic currents, as shown in (3) [31].

$$P_R = 3\sum_{h=1}^{n} {I_h}^2 R_h \tag{3}$$

where

I_h: rms value of harmonic current at the hth harmonic

R_h: Resistance at the hth harmonic

As mentioned before, eddy current loss in transformers winding vary directly to the square of the product of harmonic current and its corresponding frequency. Given the winding eddy current loss at the fundamental frequency, the total eddy current losses including harmonic frequency components can be represented by :-

$$P_{EC} = P_{EC-1}\sum_{h=1}^{h_{max}} {I_h}^2 h^2 \tag{4}$$

Equation (5) gives total load losses (PT) of a transformer when harmonics are present in the network [27].

$$P_T = P_{CU}.\left(\frac{I_L}{I_1}\right)^2 + P_{WE1}.\left[\sum_{h=1}^{n}\left(\frac{I_h}{I_1}\right)^2.h^2\right] + [P_{CE1} + P_{SE1}].\left[\sum_{h=1}^{n}\left(\frac{I_h}{I_1}\right)^2.h^{0.8}\right] \quad (5)$$

where

P_{CU}: Copper loss

P_{WE1} : Total eddy current losses at full load (at 50 Hz)

P_{CE1}: Additional eddy current losses at full load (50 Hz)

P_{SE1}: Stray losses in construction parts at full load (50 Hz)

I_h : rms value of harmonic current at the h^{th} harmonic (per unit ‘‘PU’’)

I_L : rms value of the total load current (PU)

I_1: rms value of load current at the fundamental frequency "50 Hz" (PU)

h: Harmonic order

It is worth mentioning that with a MV/LV transformer of Δ/Y configuration; triplen-currents circulate in the closed delta winding. Due to delta connected primary. The triplen harmonic currents (i.e. 3^{rd}, 9^{th}, 15^{th}…) cannot penetrate downstream but circulate in the primary closed delta winding of the transformer causing localized overheating. In this type of transformers only the ‘non triplen’ harmonics pass to the upstream network [26], [27], [37].

Another important point to note about harmonic currents in three phase system is that when loads are equally distributed between the phases, then no net current flows in the neutral conductor. However, in practice, systems rarely have perfectly balanced loads. So with unbalanced loading of the three phase and with nonlinear loads, the triplen harmonics in the phase currents do not cancel out (predominately 3^{rd} harmonic), and therefore will add together in the neutral. This is because the triplen harmonics produced by these loads show up as zero-sequence components for balanced circuits, overheating the transformers and sometimes causing thermal stress and burning of neutral conductors [23], [37]. A typical transformer is not capable to withstand with high harmonic currents generated by non linear loads. It will overheat and fail prematurely when connected to these loads.

When harmonics propagated into electrical systems at levels that showed significant effects, in this situation, the transformer rating is derated using a K-factor. The reason behind transformer derating is due to additional eddy current losses caused by harmonic current and these losses are proportional to the square of the corresponding frequency. The aim of these K-rated transformers is not to eliminate harmonics but to handle the heat generated by harmonic currents; It measures transformer capability to supply varying degrees of nonlinear load without violating the rated temperature rise limits [22].

Traditionally, power transformers are designed for their utilization in sinusoidal voltage and current conditions. However, the non-linear loads are largely proliferated in the modern power systems. Derating ratio of transformers is generally determined via K factor method [38]. Now, manufacturers design special K-factor transformers. Standard K-factor ratings are 4, 9, 13, 20, 30, 40, and 50. For linear loads, the K-factor equals one. And For nonlinear loads, if harmonic currents are known, then the K-factor is calculated and compared with the transformer's nameplate K-factor. As long as the load K-factor is equal to, or less than, the transformer K-factor, the transformer does not need to be derated [23]. The following equation used to calculate the transformer derating.

$$Transformer\ Derating = \sqrt{\frac{1+P_{ec-r}}{1+\frac{\sum_{h=1}^{n} {I_h}^2 h^2}{\sum_{h=1}^{n} {I_h}^2} x P_{ec-r}}} = \sqrt{\frac{1+P_{ec-r}}{1+KxP_{ec-r}}} \qquad (6)$$

where

P_{ec-r}: Maximum transformer eddy current loss factor typically, between 0.05 and 0.10 per units for dry-type transformers (PU)

I_h: rms value of harmonic current at the h^{th} harmonic

h: Harmonic order

The K-factor can be calculated according to the following equation [39] :-

$$K - factor = \sum_{h-1}^{h=max} I_h^2 x h^2 \qquad (PU) \tag{7}$$

where

h: Harmonic order

I_h: rms value of harmonic current at the h^{th} harmonic

It is important to note that transformer size is directly proportional to the K-factor, higher K-factor transformers are typically larger in size than those with lower K-factors. The higher the K-factor, the more significant the harmonic current content, so the optimal K-factor should be chosen based on the harmonic profile of the data center to optimize the tradeoff between size, efficiency and heat tolerance [22].

In order to analyze the harmonic distortion impact on a three-phase transformer loss, the analytical simulation and experimental results show that losses increase with the increase of harmonic distortion level of the transformer. When a transformer is supplying a nonlinear load the full load losses increased by 13.26% compared with case of linear load. The percentage increase of ohmic loss was 31.4%, while the increase of eddy current loss was 63.4% and increase of other stray loss was 5.2% compared with the case of linear loads [40]. According to [35], in the analysis of three phase load profile and corresponding neutral current in a 500 kVA transformer, the triplen Harmonics are most often responsible for high neutral currents, and they represent more than 70% of the rms current in the neutral conductor. In addition, the variation of this current is less than variation of the fundamental current in the neutral conductor due to unbalanced load conditions and frequent load changes in the three-phase supply. This is a very sophisticated issue, because of safety issues prohibit neutral conductors from having overcurrent protection, and thus there is no provision for automatic interruption of these high currents [41]. Various studies discussed in details the effect of harmonics on power system transformers, transformer derating, as well as derating of transformers using K- factor [23], [26], [27], [37], [38].

2.3.2 Effects on Cables

Because of elevated I^2R losses in the cable, the resistance (R), is determined by its dc value plus ac skin and proximity effects. The resistance of a conductor is dependent on the frequency of the current being passed through it. The eddy current, which is generated due to the relative motion of the electromagnetic field and circulating current in a conductor, is the root cause of skin effect. Skin effect is a phenomenon whereby current tends to flow near the surface of a conductor where the impedance is least, it increases the effective resistance of the conductor and eddy current losses. An analogous phenomenon, proximity effect, is due to parallel arrangements of conductors which caused a mutual inductance between them. Both of these impacts are reliant on resistivity, permeability, conductor size, and frequency. For small conductors, and at fundamental frequencies, both skin and proximity effects are usually negligible. The related losses can increase significantly with frequency due to changes in resistance and thus increase the overall I^2R losses [27], [37], [42].

The presence of harmonics in the cables influences conductor's resistance and further increases its operating temperature. This can in the long run cause early aging of the conductors. Moreover, Harmonic currents along with the grid impedances cause harmonic voltages across various components of the network. This harmonic voltage increases the dielectric stresses on the cables and can shorten their valuable lifetime [26], [27], [37], [43].

Generally, THD, is defined by [23] :-

$$THD_I = \frac{\sqrt{\sum_{h=2}^{\infty} {I_h}^2}}{I_1} \tag{8}$$

$$I = \sqrt{\sum_{h=1}^{\infty} {I_h}^2} = \sqrt{{I_1}^2 + {I_2}^2 + {I_3}^2 + \cdots + {I_h}^2} \tag{9}$$

Manipulating (8) and (9) yields the total rms current

$$I = I_1\sqrt{(1 + THD^2)} \tag{10}$$

where

I: rms value of the current including harmonic components at different frequencies

I_1: rms value of the current at fundamental frequency

I_h: rms value of harmonic current at the hth harmonic

Without harmonics, in pure sinusoidal wave the total rms current is basically the value of the fundamental component. The power loss in pure sinusoidal wave for all conductors (W_S) of the cable is given by [18] :-

$$W_S = \left[{I_1}^2 R_{ac\,(1)}\right]_{L1} + \left[{I_1}^2 R_{ac\,(1)}\right]_{L2} + \left[{I_1}^2 R_{ac\,(1)}\right]_{L3} + [0]_N = 3.\,{I_{p(1)}}^2 R_{ac\,(1)} \tag{11}$$

Where the ac resistance of the cable conductor per unit length at the permissible maximum operating temperature according to IEC std. 60287-1 is given by :-

$$R_{ac} = R_{dc}(1 + y_s + y_p) \tag{12}$$

where

R_{dc}: is the DC resistance of the cable conductor per unit length at the permissible maximum operating temperature.

y_s and y_p: are respectively skin and proximity effect factors and as mentioned before they are frequency dependent factors.

In non-sinusoidal conditions (i.e. when, $I_h \neq 0$), power loss in all conductors of the cable is given by :-

$$W_{Ns} = \left[I_1{}^2 R_{ac\,(1)} + \sum_{h=3}^{49} I_h{}^2 R_{ach}\right]_{L1} + \left[I_1{}^2 R_{ac\,(1)} + \sum_{h=3}^{49} I_h{}^2 R_{ach}\right]_{L2} + \left[I_1{}^2 R_{ac\,(1)} + \sum_{h=3}^{49} I_h{}^2 R_{ach}\right]_{L3} + \left[\sum_{h=3}^{45} I_h{}^2 R_{ach}\right]_{N} = 3.W_p(h) + W_N(h) \qquad (13)$$

where

W_{Ns}: Total power loss in non sinusoidal conditions

W_p: Total power loss in phase conductor

W_N: Total power loss in neutral conductor

On the other hand, heat generated in a cable consisting of ‘m’ conductors and harmonic component ‘n’ is given by equation (14) [27] :-

$$Q(m) = \sum_{h=1}^{n} m.I_h{}^2.r_{ac}(h) \qquad (14)$$

where

Q(m): Heat generated in a cable per unit length

m: Number of conductors in the cable

$r_{ac}(h)$: Conductor resistance for nth harmonic per unit length

I_h: rms value of harmonic current at the h^{th} harmonic

Basically, thermal degradation of electric equipments is mainly caused by temperature rise beyond the rated value. When the operating temperature deviates from the rated temperature, the life expectancy of a cable is changed and can be calculated by equation (15) [27].

$$\rho = \rho_{rat}. e^{-\left(\frac{E}{K}\right)\frac{\Delta\theta}{\theta_{rat}(\theta_{rat}+\Delta\theta)}} \quad (15)$$

where

ρ : Lifetime referred to $\theta = \theta_{rat} + \Delta\theta$

ρ_{rat}: Lifetime referred to $\theta = \theta_{rat}$

$\Delta\theta$: Temperature rise in relation to θ_{rat} in Celsius

θ_{rat}: Cable rated temperature in Kelvin

K: Boltzmann constant

E: Material's activation energy

Cable losses, dissipated as heat, are substantially increased when carrying harmonic currents due to elevated I^2R losses, causing catastrophic failure of cable operation that lead to great inconvenience to consumers and loss of system reliability and money.

For the purpose of introducing a reasonably accurate method for evaluating effects of harmonics on the power loss in Cross-Linked Polyethylene (XLPE) cables, Gandhare & Patil [18] presented a computational method using MATLAB for power loss calculations in XLPE power cables. Another study targeted by looking at the harmonic-related losses in a specific electrical system representing a commercial building, the investigation demonstrates that building wiring losses identified by operating nonlinear electronic load equipment might be more than double the losses for linear load equipment. Current-dependent power losses such as I^2R, proximity of conductors, and transformer winding eddy currents (I^2h^2) are considered [26]. Moreover, another case study discussed the impact of nonlinear loads on feeder harmonic distortion level and losses. The simulation results demonstrate that harmonic distortion in distribution systems can increase power losses up to 20% [30].

2.3.3 Effects on Power Factor Correction Capacitors (PFCC) and Resonance

Shunt capacitors that are usually used for power factor correction are mainly installed in industrial commercial facilities to improve power factor. These capacitors are installed to draw currents with a leading phase angle to offset lagging currents drawn by the inductive loads such as induction motors. The harmonic currents can interact with these capacitances and system inductances; they substantially change the system impedance variation with frequency and sometimes excite parallel resonance creating voltage harmonics which can overheat, disrupt and in some cases damage the equipment [23], [24], [37], [42]. In addition, with the widespread use of capacitors installed in the power system for reactive power compensation and with the presence of the inductance of the lines and transformers, severe L-C resonances may be excited by the harmonic current generated from nonlinear loads. Resonances occurred between transformer and line reactance, and capacitors in the system can result in amplification of voltage and/or current harmonics. Their operation depends on the "resonance phenomenon" which occurs due to variations in frequency in inductors and capacitors. The resonant frequency for a series resonant circuit as a result, even small harmonic sources can cause high levels of harmonic current flow between the utility grid and a customer cause unexpected troubles in locations far removed and unconnected with the harmonic source. Further, as loads behavior changes, system impedance changes, which can cause resonances and harmonic problems where none existed before. Such problems require a detailed system analysis in order to be correctly identified [23], [44], [45].

The impedance of a power factor correction capacitor reduces as the frequency increases, while the source impedance is generally inductive which increases with the frequency. The presence of voltage harmonics in the network increases the dielectric losses in the capacitors at high operating temperature and reduces the reliability [27]. While the inductive reactance of the components increases proportionately to frequency, capacitive reactance X_c decreases proportionately:

$$X_c = \frac{1}{2\pi f C} \tag{16}$$

where

X_c: Capacitive reactance

f: System frequency

C: Capacitance in farads.

The equivalent line-to-neutral capacitive reactance X_c at the fundamental frequency of a capacitor bank is found from

$$X_c = \frac{V^2}{Q} \tag{17}$$

where

V: System voltage (kV)

Q: Reactive power (MVAr)

Resonant problems likely to occur in the system could be series or parallel resonance. Series resonance offers low impedance to the flow of harmonic current, and parallel resonance offers high impedance to the flow of harmonic current. In the presence of harmonics, the resonance occurs when the source reactance (X_{sr}) is equal to the capacitor reactance (X_{cr}) at the tuned frequency, as follows [23], [24] :-

$$X_{cr} = \frac{X_{c1}}{h_r} \; and \; X_{sr} = X_{s1} x \, h_r \tag{18}$$

where

X_{c1} : Reactance of the capacitor at the fundamental frequency

X_{s1} : Inductive reactance of the source at the fundamental frequency

At resonance $X_{cr} = X_{sr}$ then, to find which harmonic order h_r cause resonance, the following equation (19) is used :-

$$h_r = \sqrt{\frac{X_{C1}}{X_{s1}}} = \frac{1}{2\pi\sqrt{L_{s1}C_1}} \tag{19}$$

where

L_{s1}: Inductance of the source at the fundamental frequency

C_1: Capacitance of the capacitor at the fundamental frequency

Series resonance can cause high voltage distortion levels between the inductance and the capacitor in the circuit due low impedance path to the harmonic currents. Series resonance oftentimes causes capacitor fuse failures due to overload. When parallel resonance exists on the power system, considerable harmonic volt-drops cause distorted bus voltages. The distorted bus voltage may result in distorted currents flowing in adjacent circuits [23], [24], [27].

The resonant frequency of the system inductive reactance and the capacitor reactance often occurs near the 5th or 7th harmonic. But, resonant problems occurring at 11th or 13th harmonic are not unusual; the resonance can cause nuisance tripping of sensitive loads and high harmonic currents in feeder capacitor banks. In severe cases, capacitors produce audible noise, and they sometimes bulge [23], [27].

It has been noted that the impact of DGs on electric grid is adversely affected with the presence of harmonics, and has several impacts on the network components. In order to analyze these effects, it is important to know how to model the DGs in a distribution system.

2.4 Modeling of DG in the Network

Because of the particularity of DGs, the model adopted in power flow calculation is different from traditional generators. Usually, DG can be viewed as a constant active power source because it does not concern frequency regulation [14].

Deng et al. [46] proposed an approach to model the PV output power generation from a prediction of solar irradiance. This method considers the input random variables such as clearness index and fraction of diffusion irradiance for prediction. Consequently, the harmonic emissions from PV system are altered for varying solar irradiance conditions. In [47] the PV system is modeled as a current source with harmonic frequencies, without operational impact of the control strategy. Pakonenet al. [48] proposed two basic models of the PV inverter with current control capability the first one is current regulated current source inverter (CRCSI) and the other one is current controlled voltage source inverter (CCVSI). In [30], a probabilistic PV harmonic model has been developed based on the measurements data for harmonic load flow studies. The statistical characterization of PV harmonic current emissions at different fundamental frequency output levels was discussed. In [49], [50], the harmonic characterization of solar PV inverters with respect to variations in solar irradiance and their aggregations has been analyzed. In addition, PV systems are usually treated as a negative load in some studies [41]. In reference [7], Utility Large scale PV systems is modeled in a way similar to conventional generators for steady state analysis. These units are represented as PV “buses” with appropriate var limit. However most of the residential PV systems are represented as negative active power loads which are fixed in power level. Only active power components are used. In other words, buses with residential PV systems are modeled as PQ “buses” with Q=0.

Besides modeling of PV systems, various load models were developed for the purpose of studying the harmonic impacts in the distribution networks [14], [34], [41]. The common approach used to model harmonic producing loads is to include a set of current sources for each frequency. Such modeling ignores the switching harmonics of non-linear loads and injects a constant harmonic pattern into the grid, which will not give realistic conditions. Dynamic aggregation of different types of domestic and commercial loads that inject harmonics, induce several complexities into the network. In [51], [52], a few different non-linear load models, such as compact fluorescent lamps (CFLs), computers, Televisions and other loads have been proposed for harmonic analysis in the distribution network. Reference [53], focused on the modeling of harmonic sources with nonlinear voltage-current characteristics such as the saturated transformer, the arc furnace, and the over-excited induction motor, different models were discussed including voltage source models, nonlinear resistance model, current source models and nonlinear time varying voltage source model. Ghorbani and Mokhtari [30] used the model following a “bottom-up” approach, starting from end users appliances Norton equivalent model and then modeling residential, commercial and office loads. The Norton model parameters for each appliance are calculated using the measurement results under different operating conditions.

In this work, the PV system will be modeled as source of harmonic currents represented as a current source in which harmonic currents are assumed to be independent of voltages. This model is relatively simple. The influence of harmonic voltage on the harmonic injecting current can be ignored.

Fig. 2.1 shows a schematic describing the modeling of non linear load for harmonic studies.

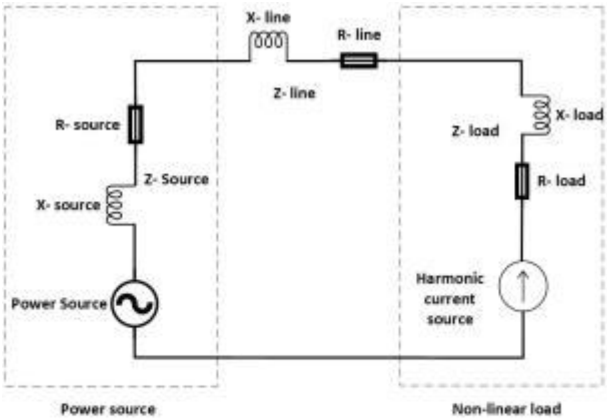

Fig. 2.1 Modeling of non linear load for harmonic studies

When penetration level of harmonic is far from negligible, this level should be mitigated in different ways. Section 2.5 reviews mitigation techniques used for this purpose.

2.5 Harmonic Mitigation Techniques

The main objective of harmonic mitigation and of all work on power quality is to avoid so-called "electromagnetic interference", i.e. to make sure that all equipment functions as intended. Interference can be avoided in three distinctively different ways:

- Reducing the emission levels from equipments
- Increasing the immunity of equipments against disturbances
- Reducing the transfer of disturbances from emitting equipments to susceptible devices

The first two mitigation techniques concern changes in installation or in the grid [54]. To mitigate the transfer of the above-mentioned PQ problems various technologies are available and constantly being advanced to control the harmonics at source. There are four main methodologies used for limitation of harmonics [23], [24], [42].

1- Passive Harmonic filters (PHF): Generally, passive harmonic filter configurations have a capacitive character as they are built with inductive, capacitive and resistive components arranged and tuned to be utilized to control harmonics. They make utilization of single-tuned components that provide a low impedance path to harmonic currents at a punctual frequency or as band-pass devices that can filter harmonics over a certain frequency bandwidth [49], [55], [56].

PHF involve the parallel or series arrangement of a tuned LC and high-pass filter circuit to achieve a low-impedance path for a specific harmonic frequency [57]. As eliminating harmonics at their source is the most effective method to reduce harmonic losses in the isolated power system. According to [58], [59], if a parallel-connected filter is connected further upstream in the power network, higher everyday costs will accumulate in the conductors and other plant items that carry the harmonic currents. However, losses are observed in the series-connected filter itself [54].

This mitigation technique represents the simplest traditional solution to control the harmonic distortion. Although simple, but they do not always respond accurately to the dynamics of the power systems [55]. What's more, PHF are that they cannot absorb other harmonics than they are designed for. They cannot automatically adjust to changes in the electrical system. Thus, they are an efficient and economical solution if specific harmonic frequencies, usually generated by a specific piece of equipment are intended to be mitigated [50].

Fig. 2.2 shows common types of passive filters and their configurations.

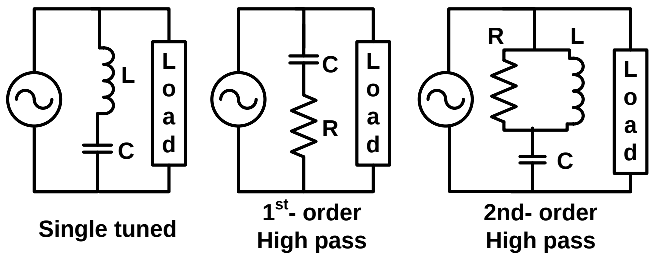

Fig. 2.2 Common types of passive filters [55]

2- Active Harmonic Filters (AHF): Due to the dynamic behavior of power system, the randomly varying amplitudes and harmonic content of the distortion power can make a PHF solution ineffective. Furthermore, the load conditions and different configurations nowadays are causing harmonics up to the 50th order. The more sophisticated active filtering concepts operate in wide range of frequencies, adapting their operation to the resultant harmonic spectrum. Active harmonic filters (AHF) are power quality devices that permanently monitor the nonlinear load and dynamically provide precisely controlled current components adjusting their operation to the resultant harmonic spectrum. In this way, they are designed to inject harmonic currents to counterbalance existing harmonic components as they show up in the distribution system [50], [55], [56].

AHF include shunt type, to prevent the transfer of harmonic current, or series type, to reduce the harmonic voltage [60]. However, for both, there is a need to calculate the required compensation current accurately and in real time [57]. In addition, these filers can be current or a voltage source Pulse Width Modulated (PWM) converters [61]. Many papers discuss active filters [62]–[64].

Fig. 2.3 shows active type parallel filter and its configurations.

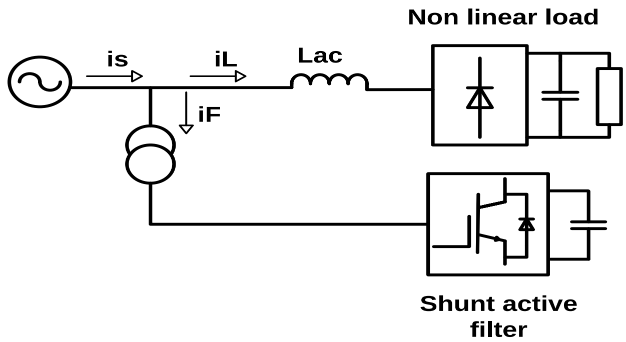

Fig. 2.3 single- phase shunt active filter [61]

3- Hybrid combinations of active and passive filters: The hybrid technique on the other hand incorporates both the active and passive [42]. In most cases, the best solution for an economical and effective harmonic mitigation solution is achieved by hybrid solutions (HHF), combining PHF and AHF. As the generation of harmonic components is part of the nonlinear components, a path must be provided for them to flow. The use of series-connected filters in isolation is not a solution and, normally, they have to be combined with some passive filtering. This solution avoids harmonic resonance as in the presence of harmonics, the resonance takes place when the source (or system) reactance X_{sr} is equal to the reactance of the capacitor X_{Cr} at the tuned frequency, as given in equation (18).

The main limitation of the PHF or AHF filter configuration is that it is limited to a fixed fundamental frequency [56]. HHF solutions have been developed to solve the problems of reactive power and harmonic currents effectively and it was observed that a combination of PHF makes a significant reduction in the rating of the AHF, decreasing or eliminating harmonic resonance [42], [55], [57]. Furthermore, no harmonic current flows in the supply. Some configurations of hybrid filters are described in Fig. 2.4. Their essential difference represents by whether they provide a (passive) filtering action within a selected bandwidth or as a result of a real-time (active) monitoring process that leads to the injection of real-time canceling harmonic currents.

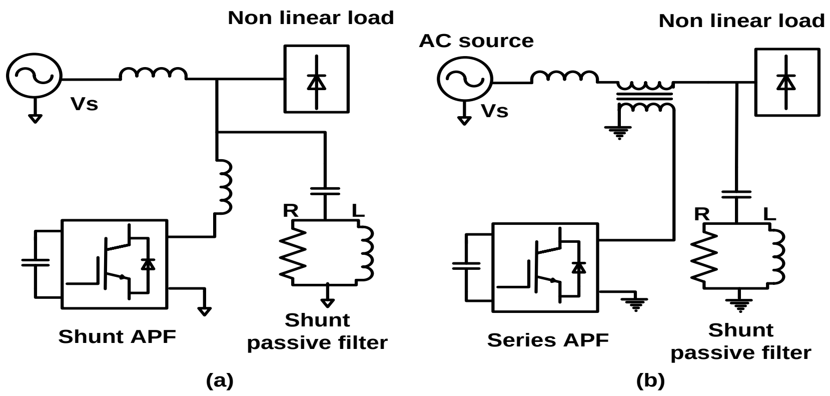

Fig. 2.4 Hybrid APFs: (a) combination of shunt APF and shunt passive filter (b) combination of series APF and series passive filter [55]

4- Alternative technologies can be used to control the harmonics at source, for example, phase multiplication, operation with higher pulse numbers, converters with interphase reactors, active wave-shaping techniques, multilevel converters, and harmonic compensation built into the harmonic producing equipment itself to reduce harmonic generation [58].

The problem of choosing optimal filter size, location, type, quality factor and filter's tuned harmonic order is highly non-linear and discrete in nature, selecting proper techniques is an engineering issue based on both technical and financial criteria [56]. In [56], [65], the optimal location and size for PHF design is proposed to minimize the maximum total harmonic distortion in radial distribution systems using Particle Swarm Optimization (PSO). The effect of probabilistic characteristics of non-linear load currents and harmonic impedances of the system on passive filter design is analyzed [14]. In [66], a genetic based algorithm (GA) was presented to solve the allocation and sizing problem of AHF using two algorithms.

Zadeh et al. [67] proposed that for a three-phase, four-wire distribution system a series AHF can simultaneously to be placed in neutral conductor to reduce current harmonics for the entire neutral conductor and the distribution transformer. This approach is applicable for both balanced and unbalanced systems. The simulation analysis demonstrates the effectiveness of the proposed approach and suitability of control strategy harmonic reduction in neutral conductor in three phase four wire systems.

For further improvement of the output current, a higher order Inductor– Capacitor–Inductor (LCL) filters with robust strategy are currently used to mitigate harmonics in the system [16], [68]. LCL filter has been used in place of the traditional ‘‘L’’ or ‘‘LC’’ filter. Recently, the LCL filter has been widely applied to the grid-interfaced inverters and active filters [69], [70]. It has been proved that the LCL filter offers a better smoothing output current [71], [72]. Moreover, this filter uses smaller inductance value that result in smaller harmonic voltage drop across the output filter [71]. Recently, a hybrid current and voltage control scheme is proposed for the LCL filter-based DG to compensate harmonics caused by nonlinear load nearby [73]. The proposed hybrid configuration can achieve PQ improvement without harmonic current extraction and guarantees smooth transition during the grid connected/ island mode transfer. Another technique used to mitigate the above-mentioned PQ problems, an integrated control of Distribution Static Compensator (DSTATCOM) described in [16], [74]. DSTATCOM is used for the mitigation of different PQ problems. DG inverter coordinates the active power sharing among DG, grid and load. DSTATCOM is connected at PCC where DG is connected and it acts as DG power quality conditioner. Moreover, DSTATCOM operation compensates the unbalanced currents flowing in the transmission line and hence, keeps the voltage unbalance factor (VUF) of PCC voltage within limit irrespective of unbalanced grid voltages and unbalanced loads. The injection of harmonic currents in the transmission line arose due to non-linear load is eliminated by DSTATCOM control. Furthermore, control of

DSTATCOM is designed in such a fashion that it provides reactive power demand of load locally and hence, neither grid nor DG inverter supplies the reactive power. DSTATCOM regulates the voltage at PCC by supplying reactive power during the condition of faults.

2.6 Nonlinear Loads, Power Quality Issues, and Standards

During the next 10 years, it is expected that more than 60% of the loads on utility systems will be nonlinear [49]. However, nonlinear loads draw a current that may even be discontinuous or flow in pulses for a part of the sinusoidal voltage cycle [37]. In this case, the total supply current will contain a distortion. These waveform deviations are described by the use of waveform distortion, usually called ‘‘harmonics’’. Various literatures were discussed nonlinear loads and harmonics [23], [29], [37], [49].

In power distribution systems, the sources responsible for the distortion state can exist both at the energy suppliers and in the consumers electrical networks [75]. The distortion state or harmonic distortion derives from the voltage wave distortion, so that the spectral analysis brings out multiple fundamental frequencies [76]. Voltages are not perfectly sinusoidal in a supply system, since certain electrical devices, absorbing non-sinusoidal currents, spread them by distorting, at the same time through power distribution network [60]. In the public electrical supply systems, the distortion state is produced by the distorting elements generating or amplifying harmonic voltages and currents. Such distorting elements can be divided into the following categories [37], [76].

- Elements which, supplied with mostly sinusoidal voltages or currents, produce distorting phenomena, such as welding machines, arc furnaces, and rectifiers. In general, any highly non-linear circuit components.

- Elements which do not generate distorting phenomena, but which, being supplied with distorting currents, amplify this distortion. This group includes electrical conductors when their own inductances and capacitances form oscillating circuits, whose frequency may coincide with the one of the harmonic currents produced by elements generating distorting phenomena.

In addition, distortion state sources can also be classified as follows [75]–[77].

a) Harmonic voltage sources, represented by sources producing non-sinusoidal electromotive voltages such as voltage source inverters (VSI).

b) Harmonic current sources, represented by distorting elements which, in a sinusoidal voltage state, usually introduce superior harmonics into the current absorbed from the power distribution network.

At present, a large portion of the non-linear electrical load on most electrical distribution systems comes from Switch-Mode Power Supplies (SMPS) equipment, as well as, TV-sets, printers, faxes, copying machines, Heating-Ventilation-Air Conditioning equipment (HVAC), dishwashers, dryers… etc. and more often, the whole range of domestic electrical appliances, including fluorescent lighting which representing the main sources of low power harmonics [22], [60], [75]–[77].

PV system generation depends extensively upon power electronic converters that are used to produce (ac) output from (dc) input for interconnection purposes. This output cause current harmonics as its output is not pure sine. The harmonics produced from inverters will be divergent, which relies on the type of control strategy and the size of PV systems and also on the grid voltage harmonics [78], [79]. PWM switching is the most efficient method to produce ac power, allowing for flexible control of both frequency and output magnitude. However, all PWM methods inherently generate harmonics and noise originating in the high dv/dt and di/dt semiconductor switching transients [78].

When both positive and negative half-cycles of the waveform are symmetrical around its time axis, the wave shape has half-wave symmetry and the harmonic frequencies will be odd integer multiples of the fundamental frequency, without the presence of even integer multiples. Odd harmonics are the characteristic harmonic components in today's power networks; in most nonlinear loads, and due to the usually three-phase symmetry of the present infrastructures almost all signals are symmetrical even though there is distortion. Therefore, even harmonics almost non-existent in three phase systems, even harmonics can only arise from waveforms that are not symmetric to the time axis. Three-phase systems, due to their configurations, have distinct harmonic signatures showing almost only odd harmonics [41], [43], [50], [80].

The concept of how the harmonic components are added to the fundamental current is obtained by the superposition of a fundamental sinusoidal frequency waveform with other waveforms of various frequencies and amplitudes. Generally, Fourier series used to describe a periodic function made up of the contribution of sinusoidal functions of different frequencies [43], [49], [58], [81].

The interconnection of DG units with the utility grid is subject to requirements as stated in the international standards as per the IEEE (the Institute of Electrical and Electronics Engineers, Inc.) in the United States, and IEC (International Electrotechnical Commission) in the European Union, standards. The location, type, and size of DG units are the three main factors that can affect the fault current levels, protection coordination of relays, stability, and power quality [42], [82], [83]. This also can limit the amount of DG penetration.

2.7 Harmonic Regulation, Limits, and Power Quality Indices Under Distortion

The most commonly used standards for harmonic and power quality regulations are IEC. The Codes set out the minimum requirements, the issues and considerations, recommendations and rules for power quality that the power utility must supply, as well as the permissible values for the harmonic current injection of each individual users which can be incurred in order to not cause voltage distortion to the interface junction between the utility and the customer [42], [50]. Both system operators and individual users must cooperate to keep actual voltage distortion below maximum permissible levels.

Harmonic emissions are subject to various standards and regulations:

1. Standards governing compatibility levels for distribution networks and products [80], [84].
2. Standards governing the quality of distribution networks [85]–[89].
3. Standards governing equipment causing harmonics [90]–[92].

In both IEEE and IEC, the ultimate target of harmonic emission control is to ensure voltage quality. IEEE Standard 519-1992 is a valuable document includes widely-adopted recommendations for harmonic control in electric power systems. It presents a joint approach between utilities and customers to limit the impact of non-linear loads. Moreover, utilities encourage preventive action in view of reducing the deterioration of power quality [93].

In this study, the evaluation criteria will be based on IEEE519 std. [85]. IEEE standard uses the wave shape (duration and magnitude) of each event to classify power quality problems. It sets the limits for converter systems including non-linear loads (e.g. static power converters, arc discharge devices and saturated magnetic devices). The limits in this recommended practice represent a shared responsibility for harmonic control between system owners (operators) and users. The philosophy underlying this standard is that the utilities and power producers must meet requirements of a certain voltage quality to the consumers; they should take action to modify system characteristics so that voltage distortion levels are acceptable in case the efforts by end-users are insufficient. Furthermore, end users should limit the harmonic current injection from their sides so that they will not cause unacceptable voltage distortion levels for normal system characteristics. It is a joint approach between utilities and customers to limit the impact of non-linear loads [23], [49], [50], [85].

The standard provides recommended harmonic indices:

- ✓ Depth of notches, total notch area, and distortion of bus voltage distorted by commutation notches, low-voltage systems
- ✓ Current distortion (individual and total)
- ✓ Voltage distortion (individual and total)

The limits are system design values for worst case for steady state operation, conditions not for transient or any abnormal conditions. The limits are applied to the interface between supply and load, which is called point of common coupling (PCC) The PCC is also the point where another consumer can be served from the same system [49], [94]. The PCC for industrial users (i.e., manufacturing plants) via a dedicated service transformer, is at the HV side of the transformer, while for commercial users (office parks, shopping malls, etc.) supplied through a common service transformer, the PCC is commonly at the LV side of the service transformer [49], [85], [94].

IEEE 519 std. does not lay down any limits of voltage distortion at the PCC which a consumer must adhere to. On the other hand, this standard doesn’t set the limits for higher order harmonic, or for cases in which ratio I_{sc}/I_L is much lower than 20 (minimum at which the harmonic limits are specified in [85]). In addition, this standard doesn't differentiate between single and three phase harmonics, it addresses the same values for both single and three phase systems [23]. Moreover, IEEE 519 std. does not specifically address even-order harmonics for voltage (all voltage harmonics are treated equally), but does recommend that even-order current harmonics be limited to 25% of the values for corresponding odd-order harmonics [93].

The maximum admissible current harmonics distortion that consumers must adhere to, for systems voltage (120 V- 69 kV), are shown in Table 2.1.

TABLE 2.1 Current Distortion Limits for General Distribution Systems (120 V–69 kV) [85]

$\lambda = I_{sc} / I_L$	Maximum Harmonic Current Distortion as % of I_L (Odd harmonics) [a,b]					
	$h < 11$	$11 \leq h < 17$	$17 \leq h < 23$	$23 \leq h < 35$	$35 \leq h$	TDD
$\lambda < 20$[c]	4.0	2.0	1.5	0.6	0.3	5.0
$20 < \lambda < 50$	7.0	3.5	2.5	1.0	0.5	8.0
$50 < \lambda < 100$	10	4.5	4.0	1.5	0.7	12
$100 < \lambda < 1000$	12	5.5	5.0	2.0	1.0	15
$\lambda > 1000$	15	7.0	6.0	2.5	1.4	20

[a] Even harmonics are limited to 25% of the odd harmonic limits above.
[b] Current distortion that result in a dc offset eg., half –wave converters are not allowed.
[c] All power generation equipment is limited to these values of current distortion, regardless of actual I_{sc}/I_L

The limits are dependent on the customer load in relation to the system short-circuit current at the PCC, this can be represented as Isc / I_L ratio, and it represents the ratio of the short-circuit current available at the PCC to the maximum fundamental frequency current. The maximum demand current value is established at the PCC and should be taken as the sum of the currents corresponding to the maximum demand during each of the twelve previous months divided by “12” [42], [49], [50], [94].

Several indices that have been used to measure electric power quality, the most widely used one is the total harmonic distortion (THD), known as the distortion factor (DF). IEEE 519 uses Total Demand Distortion (TDD) to describe harmonic distortion level in the system. This term and is similar to THD except that the distortion is expressed as a percentage of rated or maximum value, rather than as a percentage of the fundamental value [23]. TDD is a measure of the THD taking into account the circuit rating, as circuit rating versus load current rises, TDD drops. The current THD definition can be misleading because a small current can have a high THD but not be a significant threat. With the definition of THD, Distortions greater than 100% are possible, and a waveform with 120% does not contain twice the harmonic components of a waveform with 60% distortion because there is a nonlinear relationship between the magnitude of the harmonic components and percent [23], [95]. Therefore, $\mathrm{TDD_I}$ can be expressed as:

$$\mathrm{TDD_I} = \frac{\sqrt{\sum_{h=2}^{n} I_h^2}}{I_L} \text{ x } 100 \qquad (20)$$

where, I_L is the maximum demand load current in rms amps.

while, $\mathrm{THD_I}$ can be expressed as

$$\mathrm{THD_I} = \frac{\sqrt{\sum_{h=2}^{n} I_h^2}}{I_1} \text{ x } 100 \qquad (21)$$

Where, I_1 is the Fundamental load current in rms amps.

As a part of the shared responsibility concept, the utility or system operators is generally concerned with meeting the voltage distortion limits shown in Table 2.2 that indicates for voltage distortion at PCC, the voltage THD is limited to 5% for individual harmonic content and only 8% for electrical circuits rated < 1.0 kV. These values should be used as system design values or worst-case vales for normal system operation. At the higher voltages, more customers will be effective; hence, the lower limits [21], [49], [50], [96].

TABLE 2.2 Voltage Harmonic Limits [85]

Bus voltage V at PCC	V ≤ 1.0 kV	1 kV < V ≤ 69 kV	69 kV < V ≤ 161 kV	161 kV < V
Maximum Individual Voltage Division	5.0 %	3.0 %	1.5 %	1.0 %
Total Voltage Distortion (THD_v)	8.0 %	5.0 %	2.5 %	1.5 %

CHAPTER THREE: SYSTEM UNDER STUDY

3.1 Introduction to energy sector in Palestinian Territories

The Palestinian Territories depend primarily on Israeli imports to meet their electricity needs. More than 90 percent of electricity consumed in West Bank and Gaza is imported through the connection points to the Israeli Electric Corporation (Fig. 3.1). The situation varies significantly between the West Bank, where Israel Electric Corporation (IECo) imports represent 99 percent of electricity consumption in west bank, compared to only 64 percent in Gaza. Modest amounts of electricity are also imported from Jordan into the West Bank and from Egypt into Gaza [97].

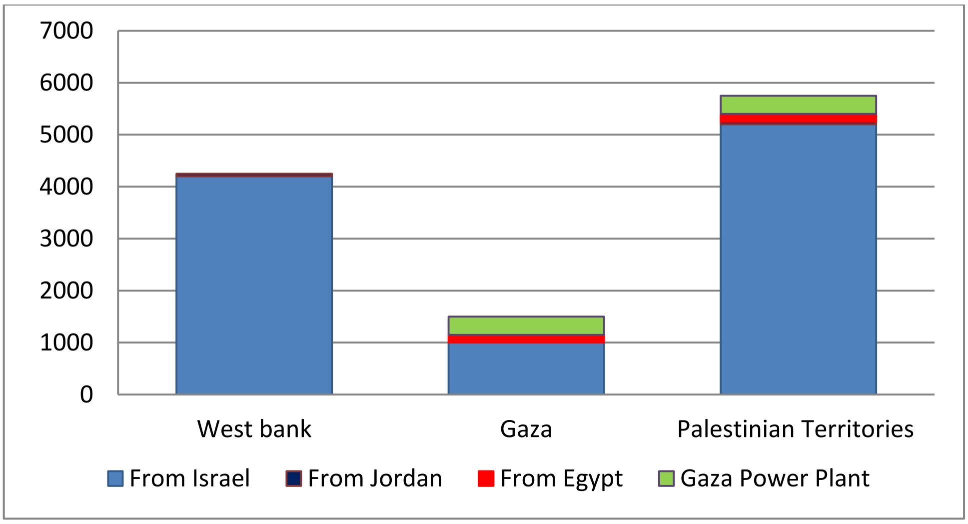

Fig. 3.1 Main sources of electricity in the Palestinian Territories (GWh), 2015 [98]

The Palestinian Energy and Natural Resources Authority (PENRA), established in 1995, launched key institutional reforms including the consolidation of hundreds of small Municipality and Village Councils (MVC) electricity services into six larger Distribution Companies (DISCos) to benefit from economies of scale. The distribution companies including one company in Gaza and known as Gaza Electricity Distribution Company (GEDCo). The rest companies are located in West Bank and include: Hebron Electricity Distribution Company (HEPCo), Jerusalem District Electricity Distribution Company (JDECo), Northern Electricity Distribution Company (NEDCo), Southern Electricity Distribution Company (SELCo) and Tubas Electricity Distribution Company (TEDCo) [97]. Amongst these DISCos, JDECO is the longest standing distribution company in the Palestinian Territories and is regulated by both Palestinian and Israeli authorities due to the nature of its service concession area.

3.2 Jerusalem District Electricity Co. (JDECo)

Jerusalem District Electricity Company (JDECo) is a Public shareholding company that holds monopoly over electricity distribution, and it is a longstanding utility that has been in existence since 1914 to supply customers with electrical power. JDECo purchases the bulk of its supply from IECo, supplemented by Jordanian imports (26 MW) when demand peaks or pricing rule differences prove advantageous.

JDECo’s concession area includes:

1- East Jerusalem (30%): falls under Israeli control with tariffs and regulations set by the Israeli Public Utility Authority (PUA).

2- The Central West Bank (70%): including Ramallah, Bethlehem, and Jericho, and falls under the control of the Palestinian Authority with tariffs and regulations set by the Palestinian Electricity Regulatory Council (PERC).

The Total number of Customers in the electricity company at the end of 2017 was 268,244 customers distributed as follows according to each province [97], [98]. Fig.3.2 shows general statistics about the electrical system in JDECo.

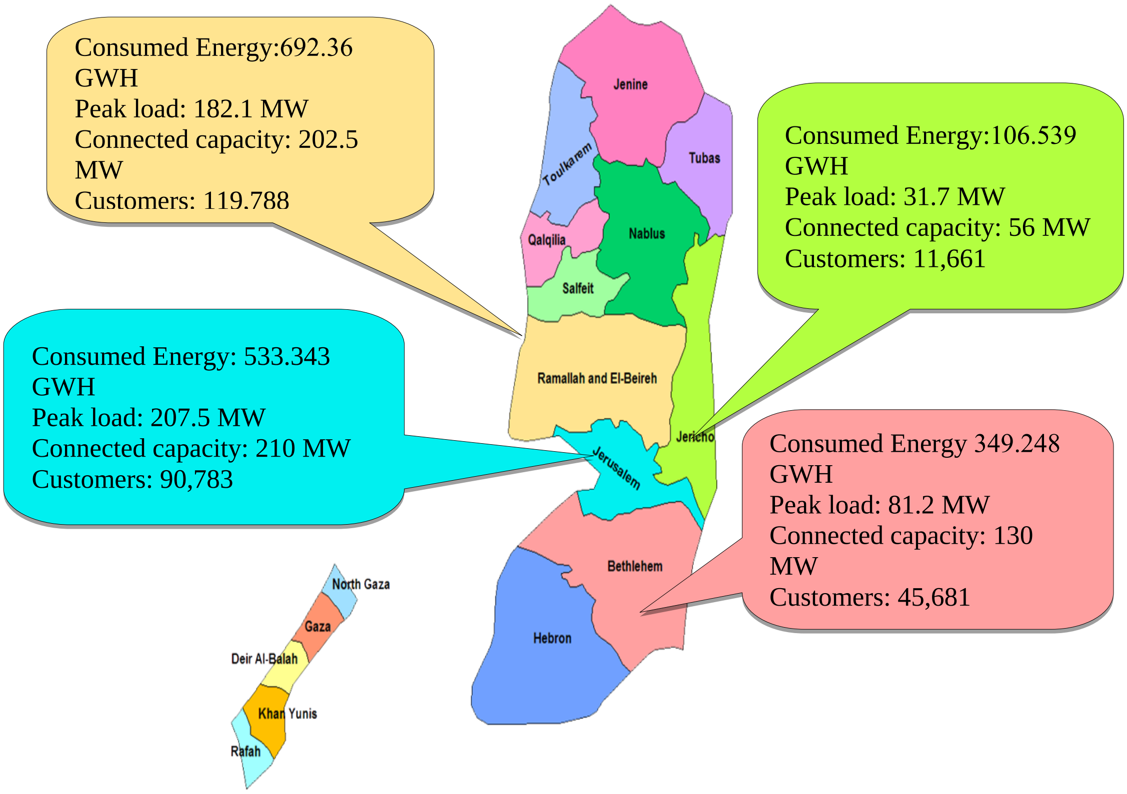

Fig. 3.2 General statistics about electrical system in JDECo [98]

Today and where Israel is becoming less able supply enough energy to cover Palestinian demand, and this dependency is very expensive, as Israel supplies electricity to the Palestinians at a cost of US$ 0.11 per kWh, while the Palestinian distributors sell it at an average of US$ 0.16 to the consumer. Using renewable resources in the production of energy is one of the strongest needs in Palestine [98], [99].

3.3 Renewable Energy Systems

Regarding renewable energies, Palestine has a renewable energy potential, it's characterized by the Mediterranean climate with long dry summers and cold short rainy winters, the perfect conditions for generating energy from renewable resources such as solar energy, wind energy, and biomass energy. The most type of these resources used on a large scale in Palestine generating electricity and heating water of domestic use is the solar energy, wind energy used in some location for small scale, biogas and geothermal [99]. The Palestinian Authority has set targets of 130 MW of renewable energy by 2020, but only 18 MW have been developed to date [97]. Within JDECO's concession area the use of renewable energy sources developed few years ago with cooperation with PENRA. Nowadays, the total installed capacities in JDECo's concession area are described in Table 3.1 [98].

TABLE 3.1 Total installed PV systems (MW) in JDECo

Area	No. of installed systems	Existing capacities (MW)
Jerusalem	11	0.128
Ramallah	91	1.466
Bethlehem	91	1.478
Jericho	24	3. 77
Total	**217**	**6.84**

3.4 System Under Study

3.4.1 General Overview

The test system chosen for this study is covering the whole electrical system in Jericho area within JDECo’s concession region.

The peak load in Jericho was around 34 MW in 2017, with normal annual increase on average is about 7.35% yearly [98].

Four main Bulk Supply Points (BSPs) feed Jericho network; two from IECo, and another two from Jordanian side, with overall connected capacity of 56 MVA. The capacity of these points is illustrated in Table 3.2 [98].

TABLE 3.2 Jericho BSPs

Connection point name	**Capacity (MVA)**
Mishour A. – Jericho	20
Vered - Aqbat Jabber	10
Jordan 1 & Jordan 2	13 +13
Total connected capacity	**56**

In addition, the system includes 5-main 33/11 kV step down substations, in addition to one 33 kV switching station. The total connected capacity for the stations is 73 MVA as shown in Table 3.3 [98].

TABLE 3.3 Jericho main S/S details

Station Name	Transformers Ratings (MVA)
Al-Oloom Al-A'mnyeh	5
Al-Moqata'a	7.5+10
Aqbet Jaber	3
Al-Maghtas	7.5+10
Industrial Zone	15+15
Dead Sea	0 (switching station)

Fig. 3.3 shows the locations of BSPs and main stations locations and capacities in Jericho.

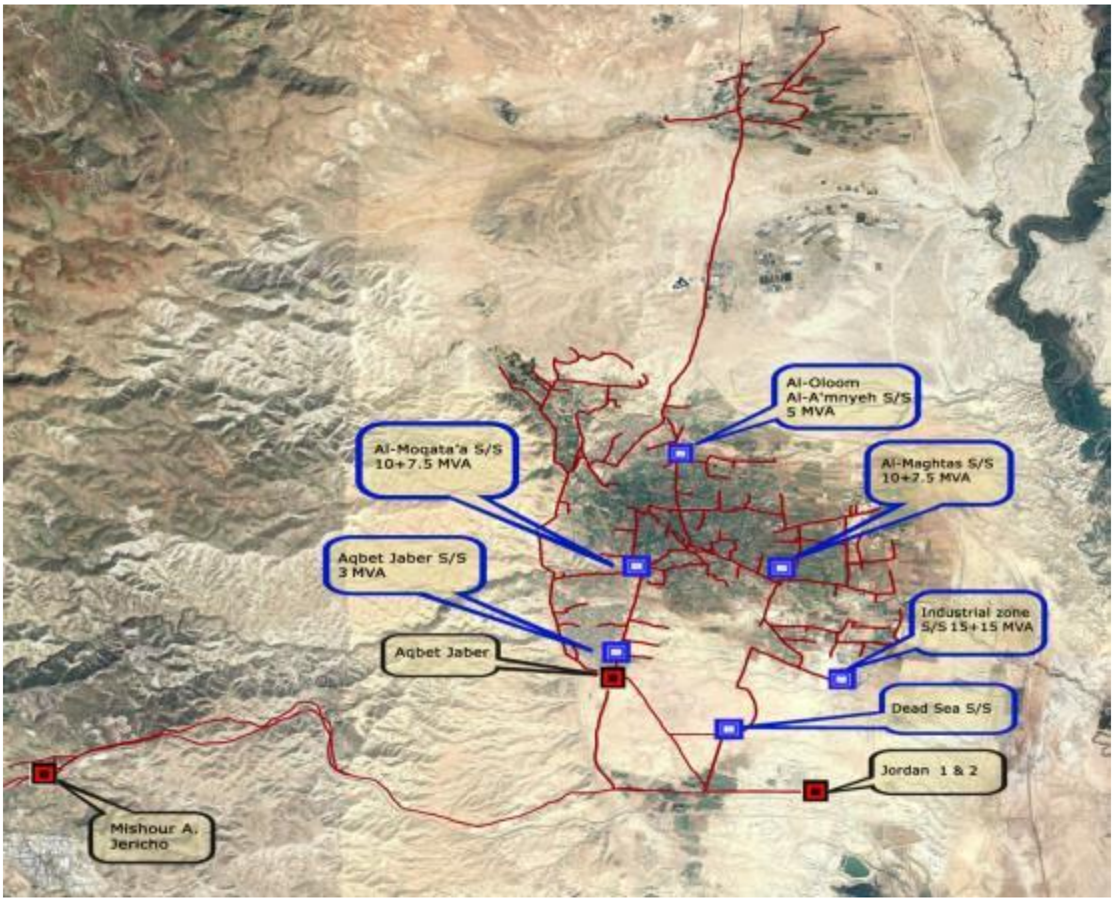

Fig. 3.3 Distribution of Jericho main stations and BSPs

All BSPs are controlled through Supervisory Control and Data Acquisition (SCADA) department; Fig. 3.4 shows the monthly loads (Min., Max., and Avg.) for the year 2017.

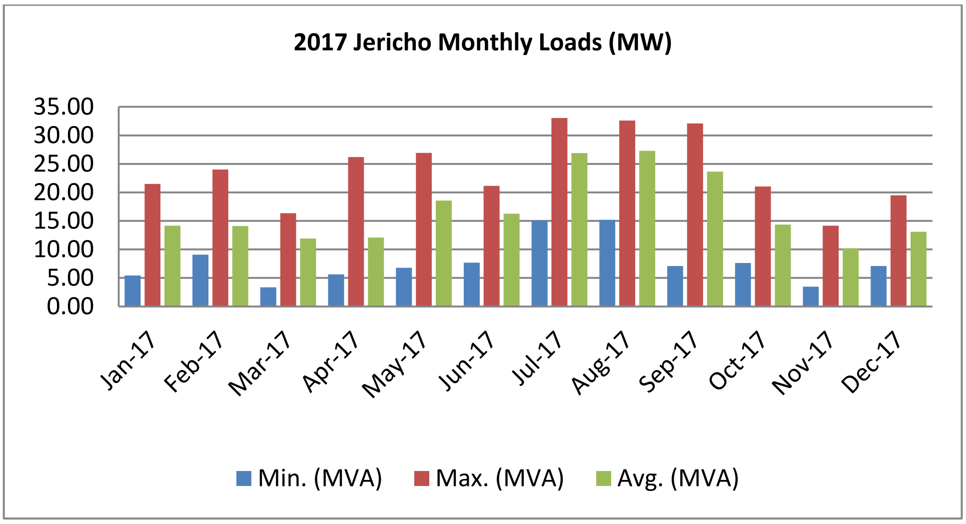

Fig. 3.4 Monthly loads of Jericho area (Min., Max., and Avg.)

It's clear from the above figure that the peak load occurs in summer days. In 2017, the peak load in Jericho was around 34 MW. While in winter it is around 24 MW and average load is about 14 MW. Autumn and spring have almost same behavior in which the average load is around 14 MW and peak load around 26 MW. The four seasons peak days loads are illustrated in the below Fig. 3.5 [98].

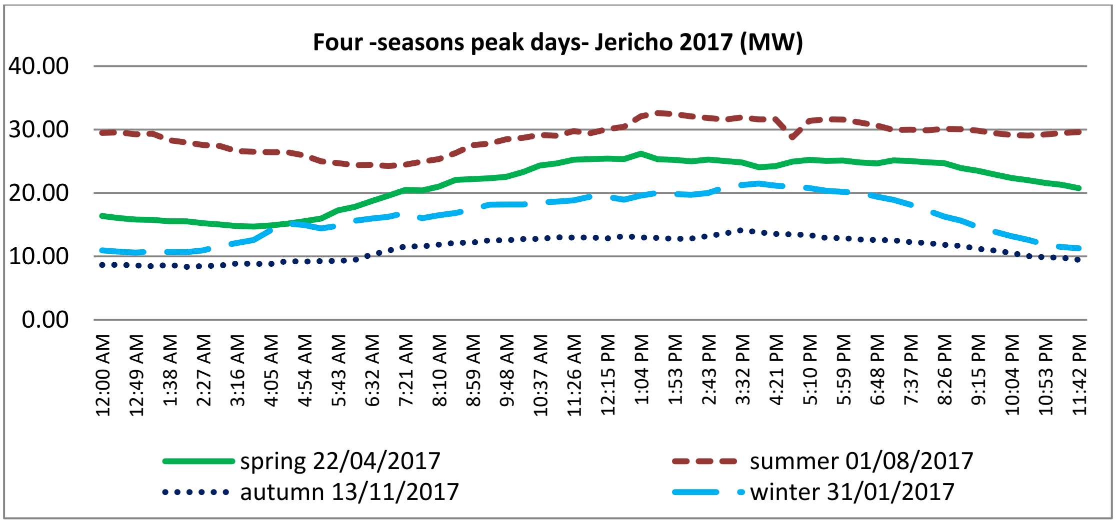

Fig. 3.5 Jericho four-seasons peak days

On average peak load increases about 6.5%-7% yearly [98]. Fig. 3.6 shows forecasted peak load of Jericho area based on historical information.

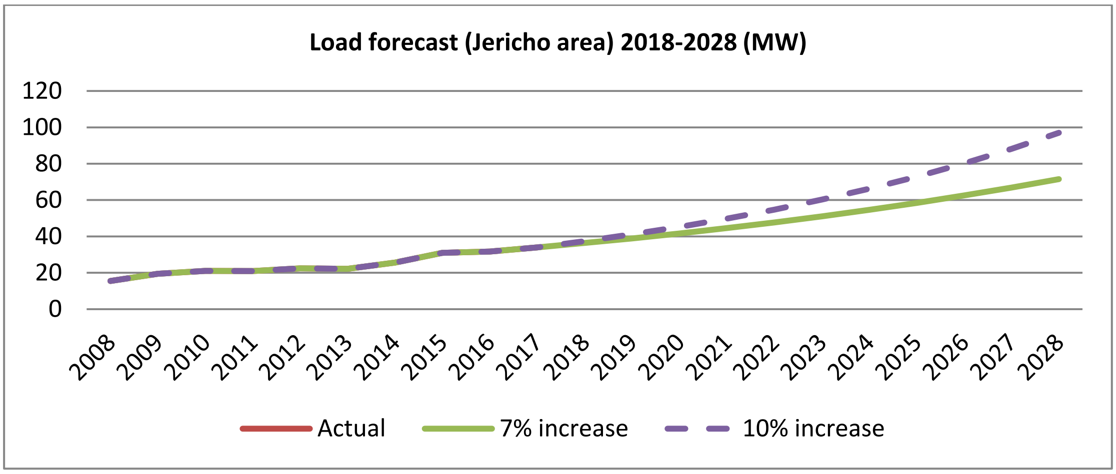

Fig. 3.6 Load forecast of Jericho Area

3.4.2 Lines and Cables

The electric power at MV level is transmitted and distributed within Jericho area via a mesh of overhead lines of 108.3 km length, and underground cables with total length of 40.3 km. Detailed specifications for medium voltage (MV) network are listed in Table 3.4.

TABLE 3.4 Technical Specifications of M.V Lines

	Conductor Type	Resistance Ω/km	Reactance Ω/km	Ground Capacitance (μF)	Rated current (A)	Length (km)
Overhead Lines	FEAL 1X50	0.395	0.415	0.0063	155	30.7
	FEAL 1X95	0.191	0.394	0.00654	230	49.5
	FEAL 1X120	0.151	0.386	0.0063	365	28.1
	Total					**108.3**
Underground Cables	DKBA 1X3X120 CU	0.153	0.088	0.25	305	11.8
	DKBA 1X3X150 CU	0.124	0.088	0.27	380	18.8
	DKBA 1X3X240 AL	0.125	0.19	0.21	380	3.2
	TSLE 3X1X150 CU	0.124	0.2	0.18	365	4.2
	TSLE 3X1X240 AL	0.125	0.19	0.21	380	2.3
	Total					**40.3**

3.4.3 Distribution Transformers (DTs)

Around 225 DTs are supplying JDECo's customers in Jericho region with required power. The transformers capacities are varied from 100-1000 kVA with voltage levels 33/0.4 kV or 11/0.4 kV as shown in Table 3.5.

TABLE 3.5 Statistical Information about DTs in Jericho

Rated power (kVA)	Voltage (kV)	Number of DTs
100	33/0.4	7
	11/0.4	5
160	33/0.4	23
	11/0.4	6
250	33/0.4	28
	11/0.4	30
400	33/0.4	20
	11/0.4	32
500	33/0.4	3
	11/0.4	8
630	33/0.4	18
	11/0.4	31
1000	33/0.4	4
	11/0.4	4

3.4.4 PV Systems

The electric system in Jericho includes existing PV systems with total capacities around 3.77 MW PV systems, in addition to 16 MW systems under construction, and around 35 MW proposed large scale ones. Table 3.6 summarizes PV connected capacities as well as proposed systems within the coming five years.

TABLE 3.6 Existing and proposed PV systems in Jericho

Existing systems (MW)	Systems under construction (MW)	Proposed systems (MW)
JICA (0.3)	Massader (7.5)	Industrial Area (13)
Dead Sea (0.708)	Dead sea "2" (1.8)	Paltel (10)
Hajleh& Al-Zor (1.6)	Aqbet Jaber (5)	Dead Sea "3" (12)
Other systems (1.158)	Other Systems (1.7)	
Total (3.766)	**Total (16)**	**Total (35)**

Fig. 3.7 shows a single line diagram for 33kV system in Jericho, including existing and proposed PV systems.

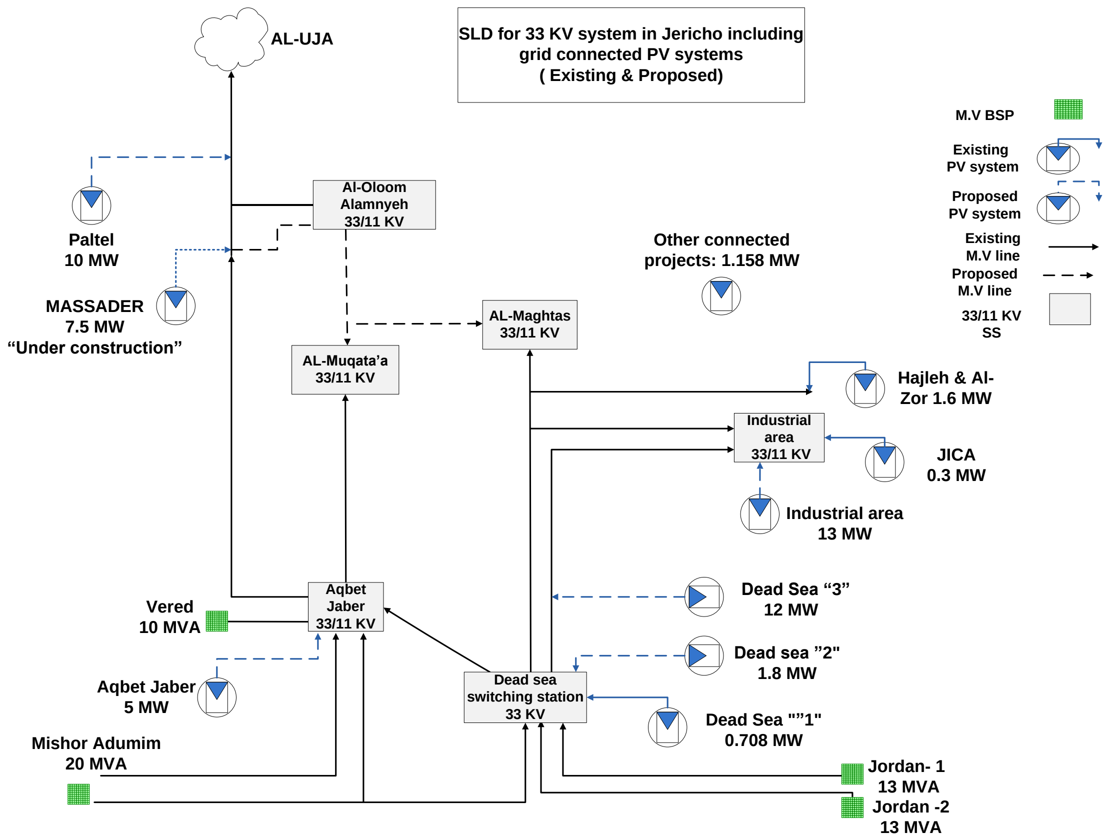

Fig. 3.7 Single line diagram for 33 kV system in Jericho including existing and proposed PV plants

CHAPTER FOUR: METHODOLOGY AND DATA COLLECTION CRITERIA

4.1 Methodology of the Study

In this work, NEPLAN Simulator is employed for analysis, and is developed to design suitable mitigation techniques if required. For simulation purposes, the electrical system of Jericho network will be considered as test system. In addition to existing PV system connected to it. Moreover, for harmonic analysis two test systems will be considered, one existing system with actual measurements from the site, and another planned one. The solution is solved using analytical methods and functions included in NEPLAN. As per NEPLAN system, for load flow analysis, the load flow can be calculated according to one of the following methods:

- Extended Newton Raphson
- Current Iteration
- Newton Raphson
- Voltage drop (only for radial weakly-meshed networks)
- DC Load Flow

The starting points of the load flow calculation are

- The network equation: $\vec{I} = Y * \vec{V}$ (22)

- The power equation: $\vec{S} = \vec{V} * \vec{I}^*$ (23)

where

$\vec{I}$: Vector of node currents

$\vec{V}$: Vector of node voltages

Y: Network admittance matrix

$\vec{S}$: Vector of node powers

For the Time Simulation module (Load Flow), the system makes a single Load Flow calculation (forecast) or a sequence of Load Flow calculations (Time Simulation). The P and Q power of consumers and generators with measurement data are determined before each Load Flow calculation.

Measured load data will be automatically applied. If measured data for a load at a certain date cannot be found in the database during a time simulation, the entered constant values for active and reactive power will be used. Missing measured values of a day profile will be linearly interpolated. This means that measured load values for a certain date (day) must be defined at least by one measured point. Otherwise the constant values of active and reactive power will be applied.

In case Scaling Types are used, the scaling of loads is done based on the load profiles defined in Day Characteristics and Long Term Characteristics, and the weakly/seasonal definition.

Regarding harmonic analysis, in NEPLAN, there are four different ways to make the addition of harmonics, which come from different sources. For each harmonic source and each harmonic, the network equation $I(f) = Y(f) * V(f)$ will be solved. The angle given in the harmonic sources are not considered for all calculations, except for vectorial sum calculation. After having calculated all voltages for each source and harmonic, the sum can be built up as follows:

1. Vectorially: The sum is built up vectorially

$$V_h = V_{h1} + V_{h2} + V_{h3} + \cdots + V_{hn} \qquad (24)$$

Mathematically correct sum, if angle is known.

2. Arithmetically: The sum is built up arithmetically

$$V_h = |V_{h1}| + |V_{h2}| + |V_{h3}| + \cdots + |V_{hn}| \quad (25)$$

It represents the highest value.

3. Geometrically: The sum is built up geometrically

$$V_h = \sqrt{V_{h1}^2 + V_{h2}^2 + V_{h3}^2 + \cdots + V_{hn}^2} \quad (26)$$

It represents the smallest value

4. IEC method: The sum is built according to IEC-1000-2-6

$$V_h = K_1.|V_{h1}| + K_2.|V_{h2}| + K_3.|V_{h3}| + \cdots + K_n.|V_{hn}| \quad (27)$$

In the above equations :-

V_h: Node voltage for harmonic order (h)

V_{hn}: Node voltage for harmonic order (h) caused by harmonic source (n)

K_n: Diversity factor for harmonic order (h) and harmonic source (n)

The size of k_n is dependent on the harmonic order (h) and the ratio between the node voltage V_{hn} caused by the single harmonic source i and the arithmetically calculated node voltage V_h.

The vectorial sum is mathematically the correct one, but may be very incorrect in practice because of unknown angles of the harmonics. The geometrical sum gives the smallest value and the arithmetic sum the highest value.

The methodology underlying the study focuses on:

1. Collecting data and information related power quality issues (Harmonics), daily load curves, and peak day loads
2. Analyzing of the measured data in order to provide illustrative image about the system behavior with presence of PV systems
3. Determining of whether or not the harmonic current and current distortions in step 3 satisfy IEEE 519-1992 recommendation limits

4. Defining of the PCC
5. Modeling the PV system using NEPLAN system
6. Running the load flow for initial case at peak load without the penetration of existing PV systems using current iteration method
7. Running the load flow time simulation for initial case without the penetration of existing PV systems
8. Simulate harmonic impact using IEC-1000-2-6 method
9. Taking necessary remedies to meet the guidelines

According to IEEE 519-1992, for newly installed non linear loads, the assessment strategy includes the following:

1. Defining of the PCC
2. Determining of the Isc, IL, and Isc/IL at the PCC
3. For the non linear load, defining the harmonic current and related distortion levels
4. Checking whether or not the harmonic current and current distortions in step 3 satisfy IEEE 519-1992 recommendation limits
5. Taking necessary remedies to meet the standard rated values

The following block diagram in Fig.4.1 1shows a general overview of the research.

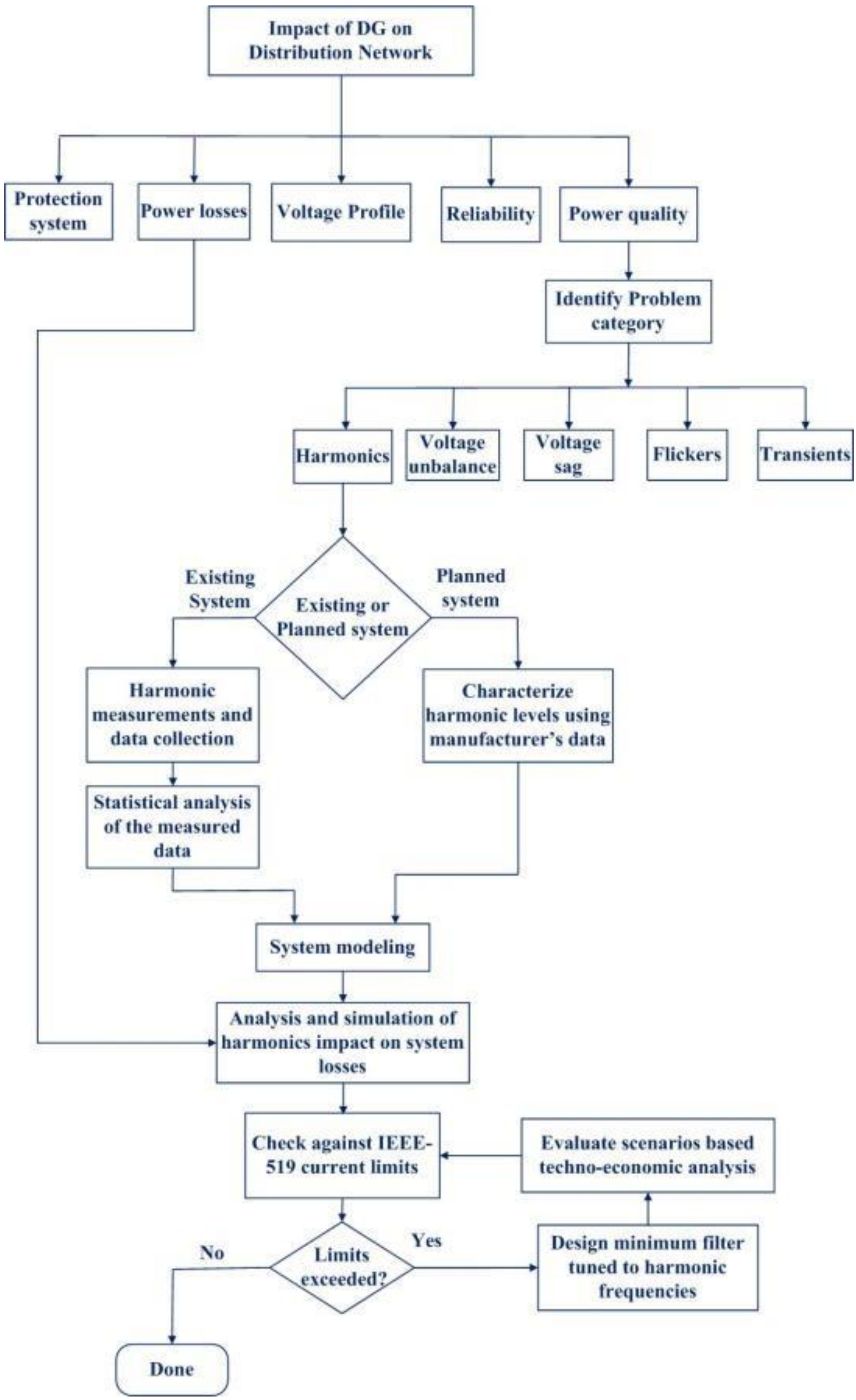

Fig. 4.1 System block diagram

In order to carry out the study, the collection of data and information, analysis criteria, and evaluation strategy are subject to international standard as described before. Gathering of the required information and technical data was performed to allow getting information on how the current distribution grid is operated, in addition to model and simulate the distribution grid under different operating conditions.

The data can be classified into:

- Available data and information describing the current situation of the system and collected based on historical data and information in JDECo's SCADA system, as well as Geographical Information System (GIS) department.
- Besides; statistical real-time data (mainly about Harmonics), were collected using energy analyzers in which this data are not available within JDECo's data mining system.

According to [28], [85], the power analyzer uses data acquisition hardware and inbuilt software algorithms to perform onsite measurements based on continuous mode within the monitoring period, in order to provide information regarding power quality phenomena causing electromagnetic disturbances such as (Flickers, voltage dip, voltage sag, Harmonics…etc.).

Power Quality (PQ) analyzers measure, record and analyze all variations in voltage, current and frequency from standard values. Common PQ analyzers come with built in waveform, vector, harmonics and flicker displays. It shows real time rms measurements of current, voltage and harmonic fluctuations. It also provide real time data about active (kW) and reactive (kvar) powers as well as displacement and distortion power factors. Moreover, PQ analyzers record sags and swells at 90% and 110% values and the interruptions at 10% values. Some types of PQ analyzers show sags and swells. Various types of power quality analyzers are offered in the market with different features and functions like smart phones [28].

In this study, the measurements were collected using energy analyzer (type HT-PQ824) for real time visualization of numeric values of electrical parameters of a three-phase 3-wire or 4-wire systems, harmonic analysis of voltages and currents up to 49 order, Voltage anomalies (surge and dips) with 10 ms resolution, Flicker (Pst, Plt) of input voltages, voltages unbalance, inrush current measurements and fast voltage transients analysis with 5ms resolution. The quality of electrical power for this device is referenced to IEC/EN 61000-4-30 class B.

The monitoring period is a direct function of monitoring objective. Usually the monitoring period tries to capture a complete power period that represents an interval in which the power usage pattern begins to follow specific trend by repeating itself. For example, in industrial plant, the pattern may repeat itself each day, or each operating shift. In addition, according to [100], the monitoring period is determined by the reasons for performing the power quality survey. For example, if the results are to be compared against power quality indices, there may be guidance in those indices regarding the monitoring period. It is often helpful to compare power quality measurements over time, for example comparing one year to the previous year. Some standards may specify minimum measurement periods. In any case, event measurements such as voltage dips and swells generally require longer measurement periods in order to capture enough events to provide meaningful statistics (months). Rare events such as interruptions may require even longer periods; in contrast, for harmonics and other steady state measurements, meaningful information may be captured in relatively short periods of time (minimum of one week).

As per [85], [100], the monitoring periods of 1 week for 10-min values (for long-term effects) and one day for 3-s values (for very short-term effects) and to allow taking into account daily work shift patterns and participation of different types of loads in the data collection. Long-term effects relate to thermal effects on different kinds of equipment such as motors, transformers, capacitor banks, and cables from harmonic levels sustained for at least 10 min. Very short-term effects related to disturbing effects on vulnerable electronic equipment by events lasting less than 3s, not including transients. Statistical handling of data is carried out in the form of 95 or 99 percentile of daily or weekly values [42].

According to [85], recommendations for short period measurements, in normal conditions, during any period in a week, 95% of the rms values of each harmonic voltage, mediated on 10 minutes, shall be lower than or equal to the values stated in Table 2.1. The total harmonic distortion (THD) of the supply voltage (including all the harmonics up to 40th order) must be lower than or equal to 8%.

In this study, the total harmonic voltage and current distortions are usually recorded, as well as a few individual harmonics (especially the 5th, 7th, 9th, 11th) where the strongest distortion is expected to appear. Single harmonic indices are usually evaluated. In order to reduce the amount of data, however, it is their mean values over 10 min integration periods that are recorded in the memory of the instruments during interval of measurements. Table 4.1 represents a brief description for test systems data collection.

TABLE 4.1 Monitoring periods for test system

Test system	**Period**	**Sampling rate (Measurement/ min)**	**From**	**To**	**Total days**	**Total No. of samples**
JICA	1	1/10	05-Apr-16	16-Apr-16	12	1566
	1	1/10	18-Apr-16	08-May-16	21	2877
	2	1/10	10-Apr-17	06-May-17	27	3723

In order to study the effect of PV system on network parameters mainly harmonic measurements, Japan International Cooperation Agency (JICA) system was intentionally shut down. Table 4.2 shows station amortization schedule:

TABLE 4.2 Shutdown schedule for JICA PV plant

Date	**Disconnection time**	**Reconnection time**	**Total disconnection period**
14/04/2016	09:55 AM	12:25 PM	02:30
19/04/2016	01:05 PM	03:15 PM	02:10
20/04/2016	03:05 PM	05:05 PM	02:00
21/04/2016	10:25 AM	12:55 PM	02:30
25/04/2016	11:55 AM	02:25 PM	02:30
26/04/2016	01:35 PM	03:15 PM	01:40

Fig. 4.2 shows a single line diagram for JICA PV test system.

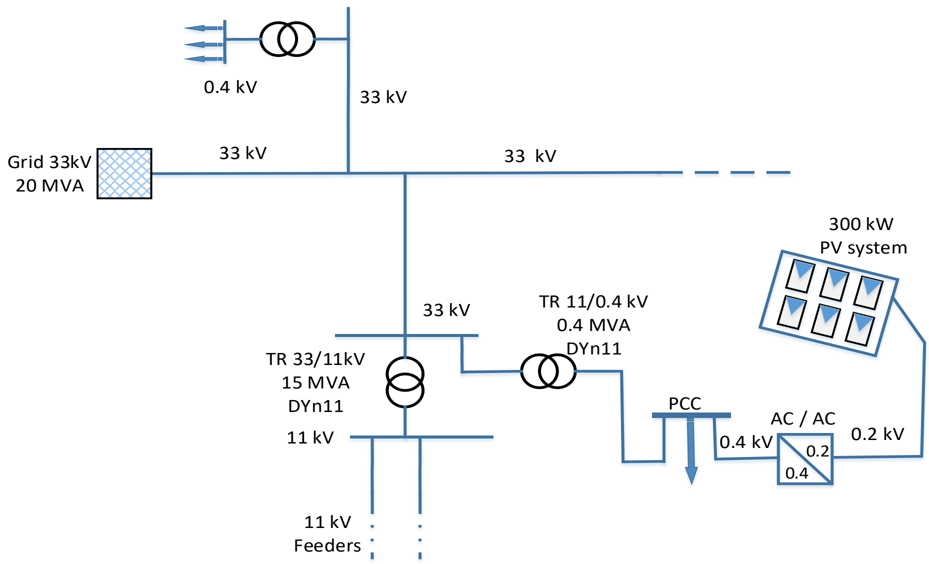

Fig. 4.2 Single line diagram of JICA PV test system

In addition, in order to assess the effect of Proposed PV system, a proposed 7.5 MW system is studied to determine the effect of such system on harmonic distortion levels, and its effects on total system losses.

Fig. 4.3 depicts the proposed system within Jericho electric network.

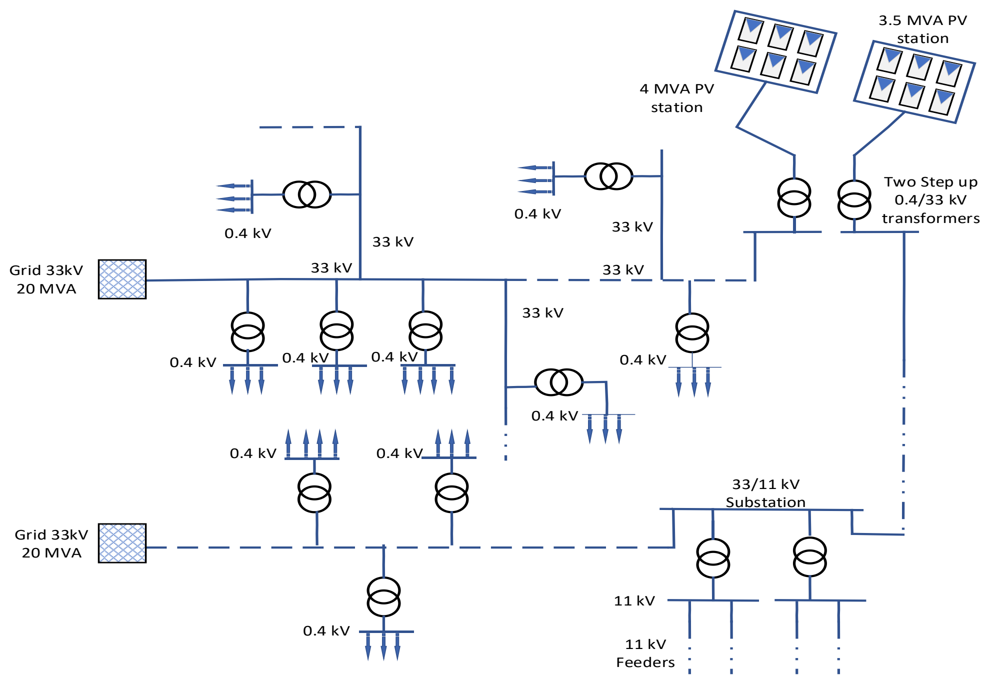

Fig. 4.3 Single line diagram of the proposed 7.5 MW PV system

It is important to note that the system is divided into two parts, the first one with total capacity of 4 MW connected to Al-Uja M.V line; while the second part of 3.5 MW is connected to AL- Maghtas proposed M.V line.

4.2 Statistical Analysis of the Measured Data

As per recommendation of [17], a suitable statistical analysis method should be chosen for the data. Different statistical methods may be selected, depending on the power quality parameter and measurement objectives, but the methods can be roughly divided into:

- Methods that count the number of events that exceed some threshold, and
- Methods that summarize large numbers of quasi-steady-state measurements into a single number, or a few numbers

For the latter method, various possible numbers may be chosen as the most useful summary value: maximum value, 99% value, 95% value, average value, minimum value, etc. In many references, the 95% probability value has been found to be useful. Data from multiple sites may be analyzed statistically to assess network performance.

Quasi-steady-state method is introduced in [17], [49]. And since the operation of power system is by nature dynamic, it is normally subdivided into well-defined quasi steady state regions for simulation purposes, field measurements are classified into sub-periods of time using quasi-steady state assumption [101].

In this research the same method will be used in order to analyze the effect of harmonic based on real data measurements. The day sub-periods are classified according to the Table 4.3.

Table 4.3 Division of daily hours based on quasi steady state regions

	Sub -Period 1	**Sub-Period 2**	**Sub-Period 3**	**Sub-Period 4**	**Sub-Period 5**
From	12:01:00	06:11:00	07:11:00	15:41:00	16:41:00
To	06:01:00	7:01:00	15:31:00	16:31:00	23:01:00

CHAPTER FIVE: RESULTS AND DISCUSSION

In this chapter, the statistical analysis of measured data and simulation results of the test systems were discussed in details. The results examined one of the most important issues regarding the integration of PV systems into electrical grid. Power quality issue represented in harmonic and its impact on total system losses are discussed for different situations and compared to standard values as discussed. The chapter includes four main sections: part one discussed PV test system during monitoring period “1”. Then part two illustrates the same system at different monitoring period “2”. Moving to part three which discussed the impact of test systems on total network losses, and part four discussed the impact of test systems harmonics on total system losses. Finally, a summary for the overall findings is presented.

5.1 Test System Under Measuring Period “1” (05/04/2016 – 08/05/2016)

This test system describes the behavior of existing 300 kW PV station connected via 0.4/33 kV step up transformer to Jericho M.V network. The system was monitored for two different periods of time; Period “1” during 2016 and period “2” during 2017, as will be discussed in details in the following section. The objective is to achieve actual information regarding impact of integrating such systems into the grid; in addition to compare the changes that may occur in the performance of these systems over different periods of time.

This measuring period “1” of the test system includes 33 days. During these days the PV system has been intestinally disconnected for couple of hours at randomly selected days, in order to show the effect of these integrated systems on the network behavior and power quality issues (mainly harmonics). In each day, line and phase voltages, line currents, active and reactive power, current and voltage harmonics, energy consumed, and other values were recorded each 10 minutes period. Through the information obtained several indicators such as: Avg. currents, Avg. voltages, THD_I, TDD_I, and THD_V, which used to analyze the obtained information and monitor the behavior of the system while connected to the network.

Fig. 5.1 shows average phase and neutral currents for randomly selected days of the test system during monitoring period “1” (disconnection days are excluded).

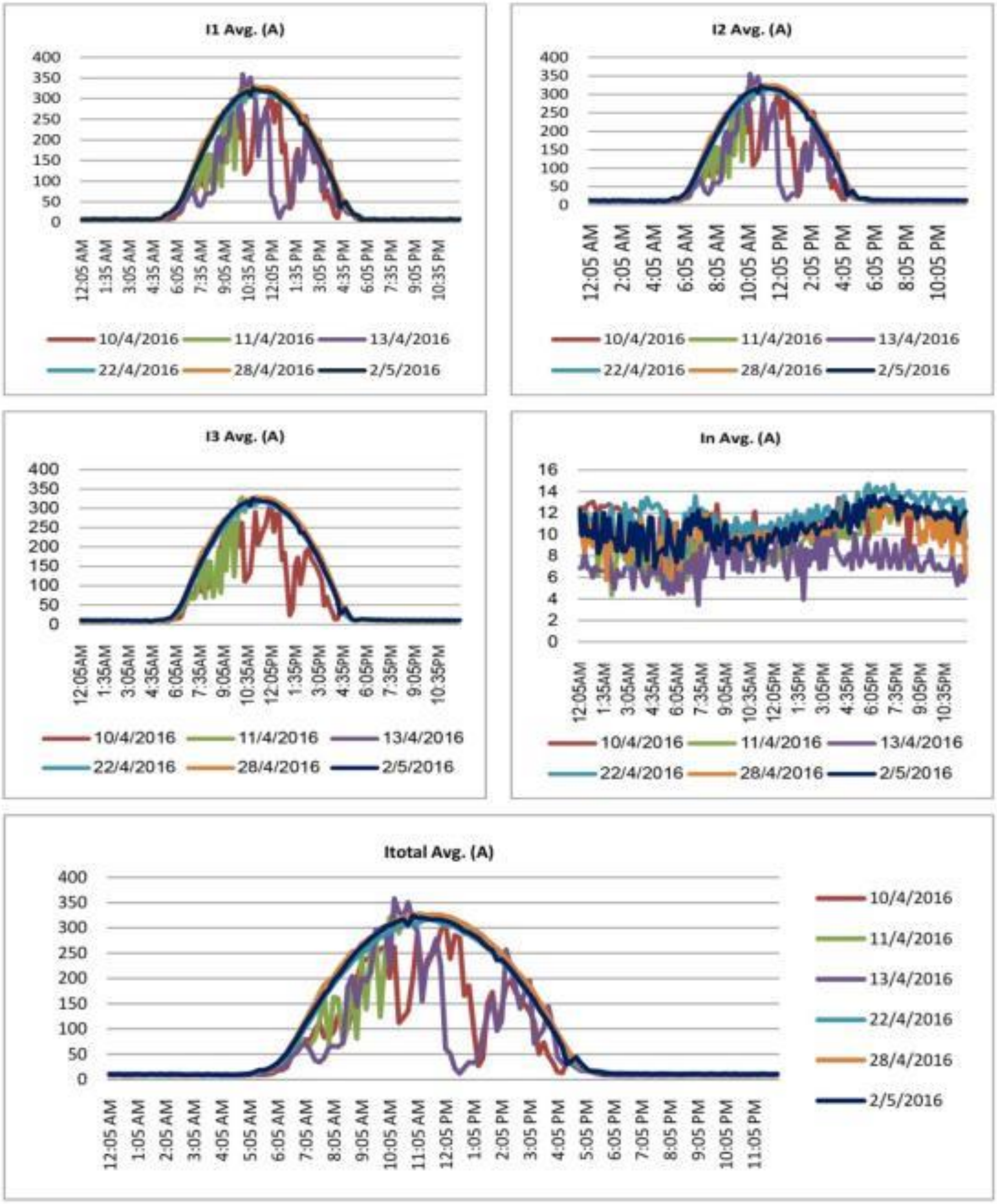

Fig. 5.1 Average phase and neutral currents of the test system during monitoring period “1” for randomly selected days (Disconnection days are excluded)

From the above figure, it is evident that the PV system begins injecting power to the grid around 6 am (sunrise) until 5 pm (sunset). During peak hours of generation, the maximum current is around 327 A; while the total avg. current during the same period is around 220 A and the neutral current is around 10 A. These values are dependent on climate and operating conditions.

During night and early morning hours the Avg. current dropped to around 11 A. This current represents the load current which is used for small power and lighting systems. Neutral current is around 10 A on Avg. for this period.

Regarding system voltage, the average phase voltages as shown in Fig. 5.2 were around 227 V-240 V and this is complying with values stated by IEC 60038 standard.

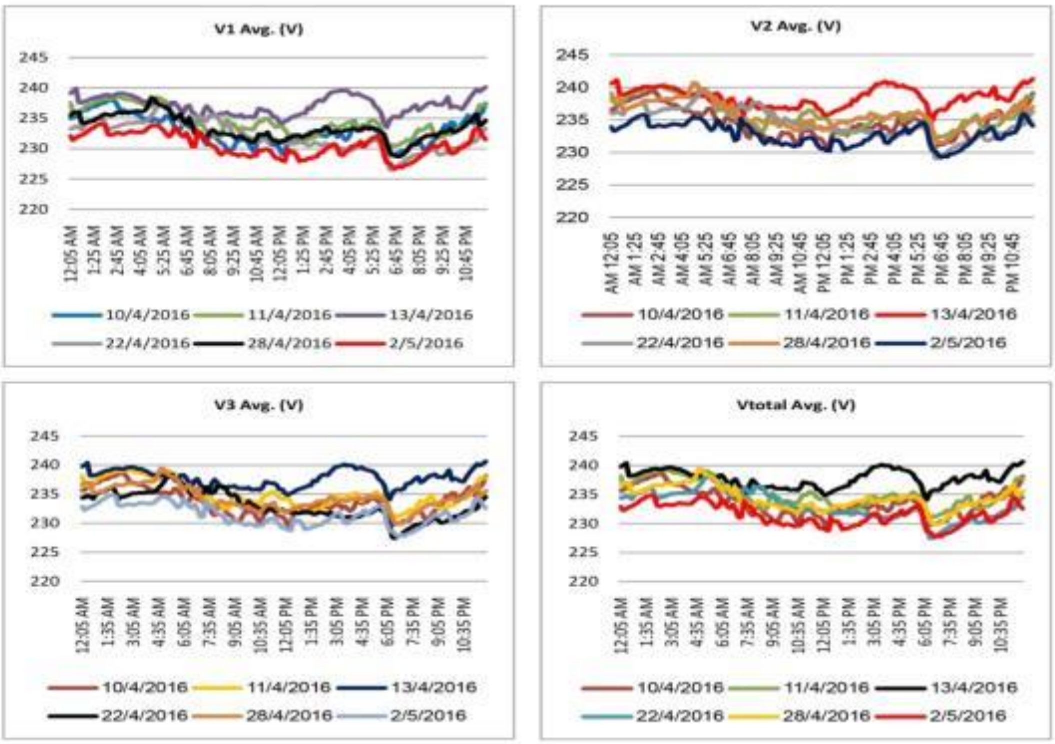

Fig. 5.2 Average phase voltages of the test system during monitoring period “1” for randomly selected days (Disconnection days are excluded)

In order to show the harmonic distortion during operation of the test system, the below Fig. 5.3 and Fig. 5.4, describe the behavior of harmonic distortion along randomly selected days during monitoring period “1”, with emphasis on the exception of the disconnection days in which the system was intentionally disconnected. The distortion level is expressed by the two indices forms (TDD and THD) as discussed earlier. Here, the aim is to decide which of indices is able to describe the distortion better. Fig. 5.3 shows TDD of phase and currents during period “1” for randomly selected days (Disconnection days are excluded).

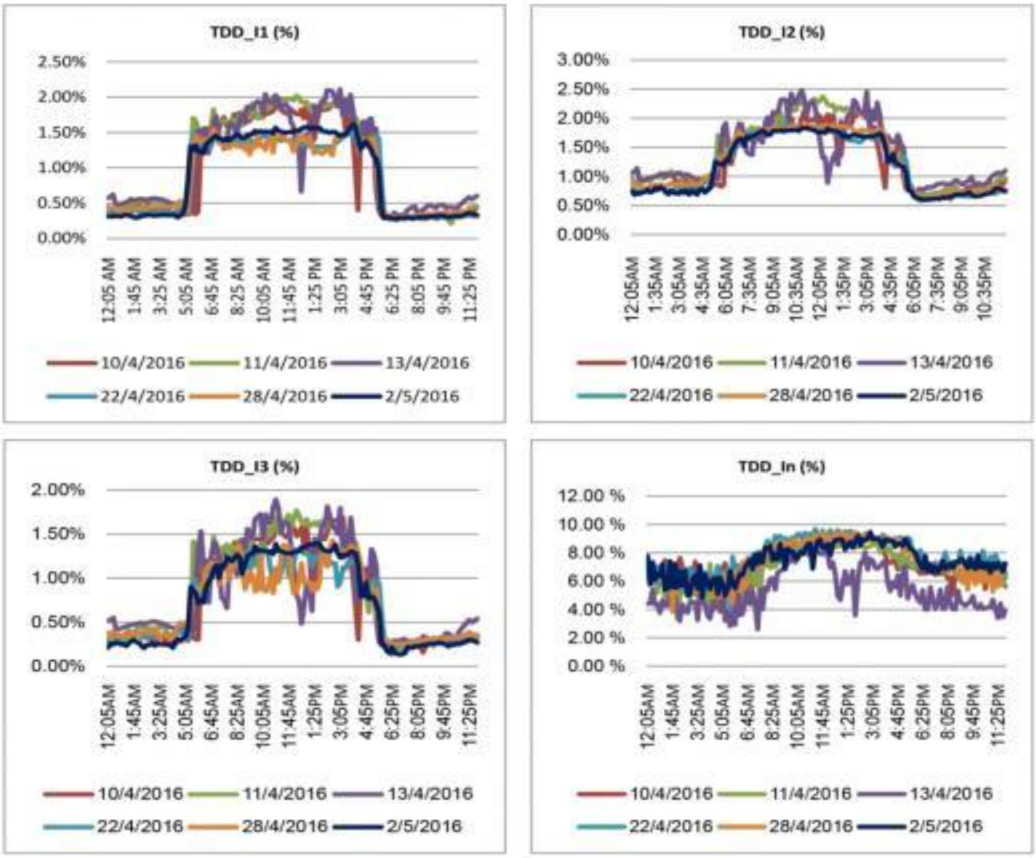

Fig. 5.3 TDD (%) of phase and neutral currents for randomly selected days during monitoring period “1” (Disconnection days are excluded)

It was apparent beforehand that TDD increased as PV generation increased. As detailed in Fig. 5.2, it seems that phase “2” shows max. distortion levels in which the distortion increased from 0.63% during night and early morning hours to more than 2.5% during peak hours of PV system. The Avg. value of TDDI2 at peak hours is around 1.86%. The distortion of other phases is ranging from 0.36% to 1.6 % on Avg. during same period, and then reduced to around 0.4% during off peak hours. The distortion for neutral current on avg. increased from 5.4% to more than 8% during operation of PV system. The detailed harmonic spectrum of current waveform up to 38th order is shown in Fig. 5.4. For more details see Appendix “A”

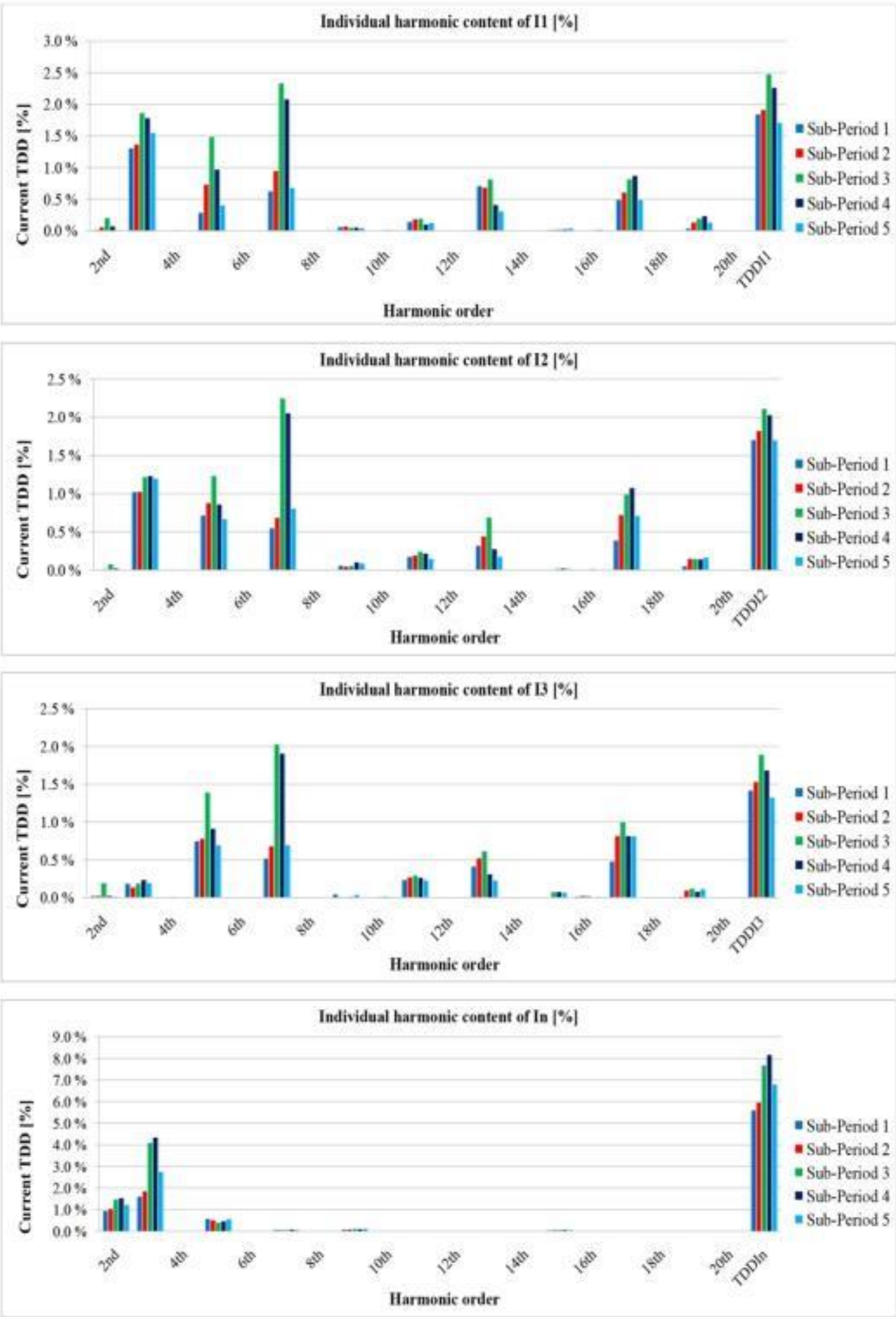

Fig. 5.4 Harmonic spectrum of phase and neutral currents for randomly selected days during monitoring period “1” (Disconnection days are excluded)

As mentioned before, the daily field measurements are classified into five periods of time using quasi-steady state assumption as presented in Table 4.3. It can be observed in Fig. 5.4 that 3rd, 5th, 7th, 13th and 17th harmonics are the most dominant harmonic in phases “1” and “2”. While, 5th, 7th, 13th and 17th harmonics represented the most dominant components in phase “3”. The neutral current mostly contained 3rd harmonic, in addition to 2nd and 5th spectrums. The appearance of the even harmonics in addition to appearance of other harmonics in the neutral conductor other than 3rd harmonic is due to the distortion coming from the load itself in addition to unbalance loading of the phases. Moreover, as can be noticed, the harmonic amplitude will increase when the output power of the inverter decreases. This is mainly caused by the DC-link voltage variation. The harmonic amplitude changes as the power level changes. The field measurement results show the same trend as the analysis results which are given Fig. 5.9. Hence, the analysis result is validated. DC-link voltage ripple variation due to MPPT is the major cause of the harmonic amplitude increase.

Here, it is important to reiterate that negative sequence harmonic (2nd, 5th, 8th, …) rotates in the opposite direction of the fundamental frequency. Whereas positive sequence harmonic (4th, 7th, 10th, …) would rotate in the same direction (forward) as the fundamental frequency. Another set of special harmonics called “triplen” displaced by zero degrees. Zero sequence harmonics circulate between the phase and neutral or ground.

It is also noticed from the results that mostly odd harmonics presented in the spectrum, here it is important to know that inverters only produce odd harmonics, because of the symmetry. This symmetry is regarding the process of producing 50 Hz-ac signal from a dc source. The process is achieved by put a switch between the dc (Vdc volts) and the load that switches on and off at a rate of 50 cycles per second.

This will generate a square wave of (0 or Vdc volts) alternating below and above a dc average level which is (Vdc/2). This waveform is very close to the fundamental 50 Hz sine wave except that it has a dc value and it is square wave. Square wave is a pure symmetric waveform when decomposed into their Fourier sine wave components can't have even harmonics components. All even harmonics will equal to zero. Therefore, what remains to get the inverted output in a form closest to a sine wave is to get rid of the dc (so square wave is now alternating positively and negatively) and to get rid of the higher order (odd numbered) harmonics. In addition, it can be seen that lower order harmonics are of more concern than higher order harmonics. Harmonics by default refers to current harmonics. The impedance of the device or circuit is mostly inductive and so is equal to $R + j \omega L$, where $\omega=2*pi*f$. Hence it can be observed from the equation that the impedance offered is directly proportional to frequency. The frequency of the 3^{rd} order is 3ω, 5^{th} order is 5ω. Hence as the order of the harmonics increases, the impedance offered to them increases and so they are less in magnitude compared to lower order harmonics. Hence the impedance of the device or the circuit itself blocks the higher order harmonics. While compared to TDD, THD shows different behavior for distortion state. Fig. 5.5 illustrates THD of phase and currents during period “1” for randomly selected days (Disconnection days are excluded).

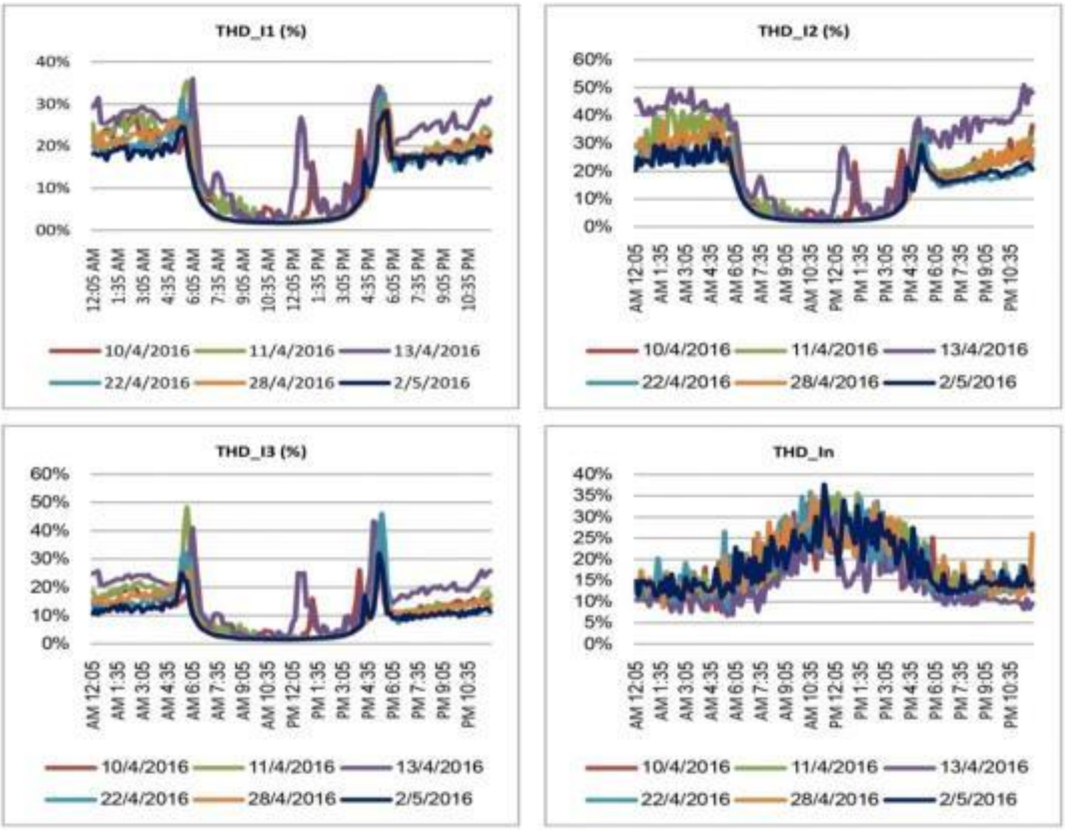

Fig. 5.5 THD (%) of phase and neutral currents for randomly selected days during monitoring period “1” (Disconnection days are excluded)

As can be noticed in Fig. 5.5, the effect of PV system on THD levels was seen clearly but with different trend compared to TDD. In addition, it is important to note that phase “2” has higher distortion values that are around 35% on Avg. during night hours. On the other hand it would appear that THD values for the same phase during operation of PV system, reduced to less than 4.5%. Other phase's distortion reduced to less than 3.8%. Moreover, it is also noticed that THD for neutral line varies between 13% -35% along day with a noticeable increasing during on peak hours.

The detailed results obtained for test system “1” for randomly selected day during monitoring period “1” are listed in Appendix “B”.

If THD used for representing harmonic distortion level, then the results will show a considerable decrease in distortion percent. The decrease in distortion level refers to the definition of THD in which the nominal current is used as a base instead of peak current which is used in TDD definition. For this reason TDD is more convincing for representing distortion state in the system.

In order to verify the performance of the PV inverters, measurements have been collected for randomly selected days in which the PV system was intentionally disconnected days during monitoring period “1”, to show how the distortion levels are affected with the presence of such distributed energy resources within the systems. Fig. 5.6 represents the average phase and neutral currents for the days in which the system was intentionally disconnected.

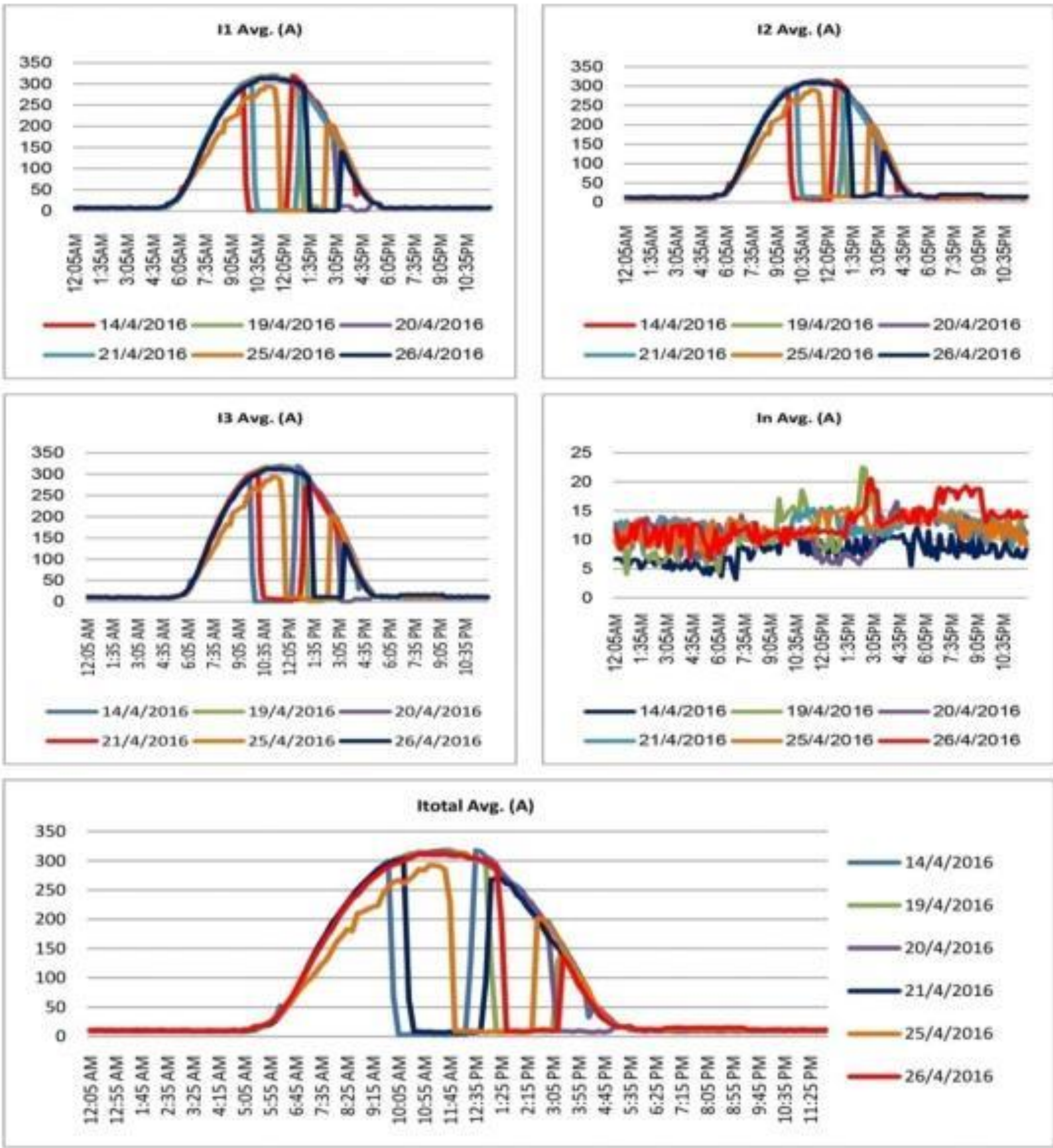

Fig. 5.6 Average phase and neutral currents for the days in which the system was down during monitoring period “1”

From the above figure, it is noticeable that the disconnection occurred at different periods of time. The maximum current is around 326 A, on average of 317 A. While during night times the current on avg. varies between 10.5 A and 12 A. The neutral current is changing from 10 A to 12A along the day. The detailed currents for each day are depicted in Fig. 5.7.

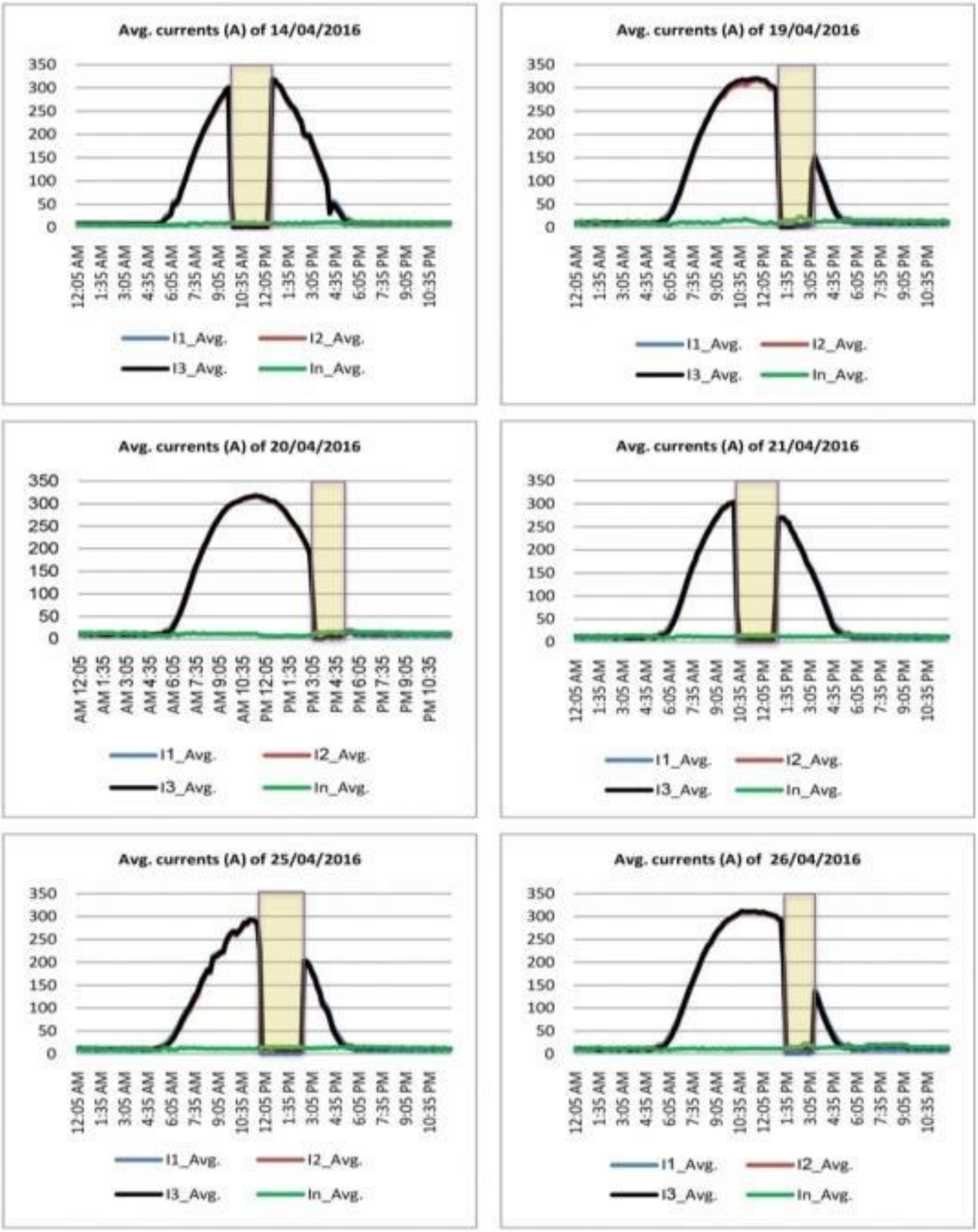

Fig. 5.7 Average phase and neutral currents for each single day in which the system was down during monitoring period "1"

There was a noticeable drop in the current as can be seen in the above Figure. This drop will cause significant impact on current distortion limits as shown in Fig. 5.8.

Fig. 5.8 TDD (%) of phase and neutral currents for the days in which the system was down during monitoring period “1”

As previously mentioned a reduction in PV injected current would cause reduction in TDD_I levels. During disconnection hours, TDD of phase currents dropped from around 2% on Avg. to less than 0.1%, and the same as for the neutral line in which the distortion dropped to around 25% of its previous value. The detailed harmonic spectrum of current waveform up to 38^{th} order is shown in Fig. 5.9. For more details see Appendix “C”.

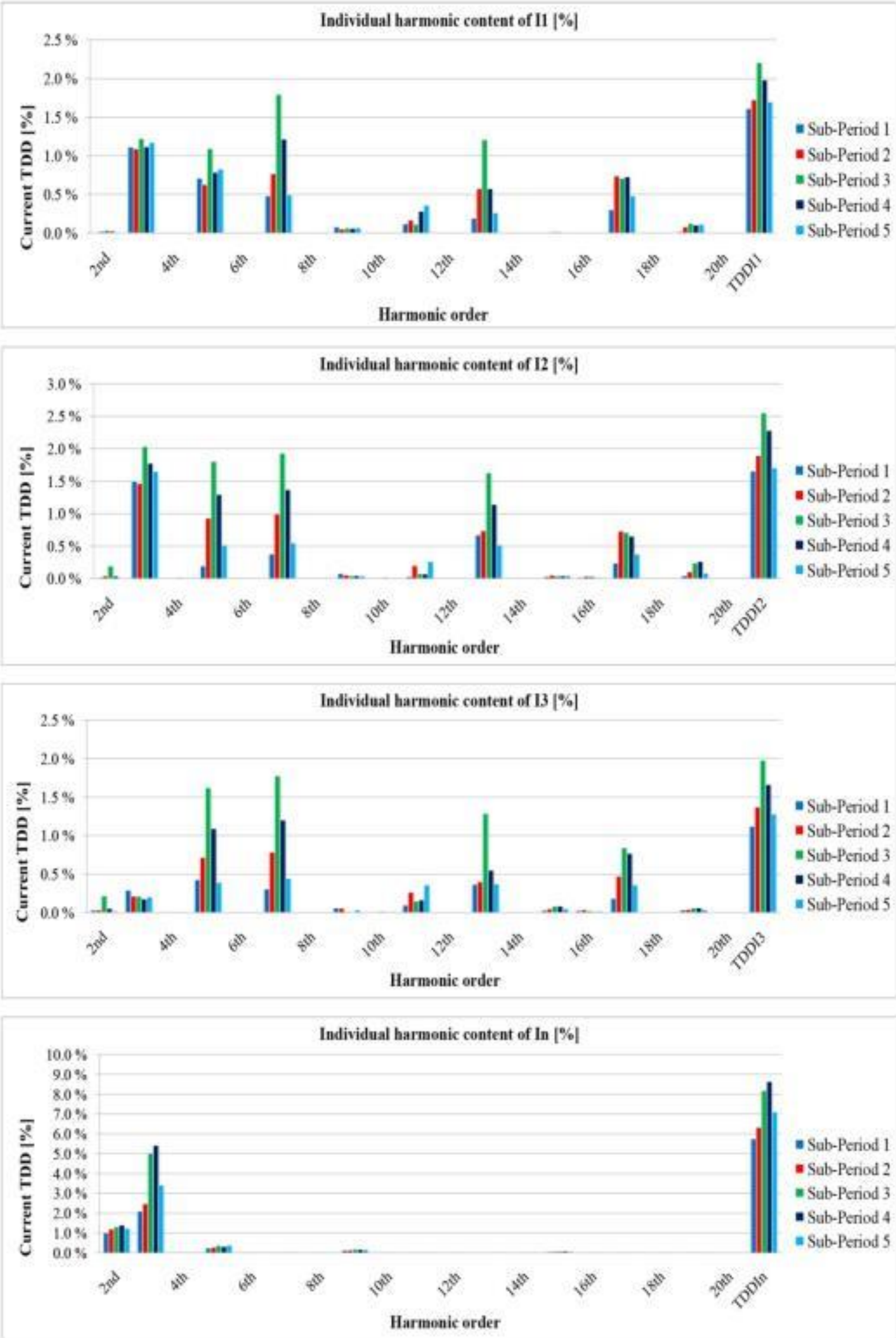

Fig. 5.9 Harmonic spectrum of phase and neutral currents for the days in which the system was down during monitoring period "1"

Results that are given in Fig. 5.9 are consistent to those presented in Fig. 5.4; the 3rd, 5th, 7th, 13th and 17th harmonics are the most dominant harmonic in phases "1" and

"2". While, the 5th, 7th, 13th and 17th harmonics represented the most dominant components in phase "3". The neutral current mostly contained 3rd harmonic, in addition to 2nd and 5th spectrums. The unbalanced loading of the phases, in addition to variation in the inverter output along the day hours affected the harmonic spectrum. More details about phase loadings when PV system is intentionally disconnected are listed in Appendix "D".

Meanwhile, THD_I will show different results compared to TDD for the reason previously discussed. Fig. 5.10 describes how THD_I levels are affected by the changing state of PV systems.

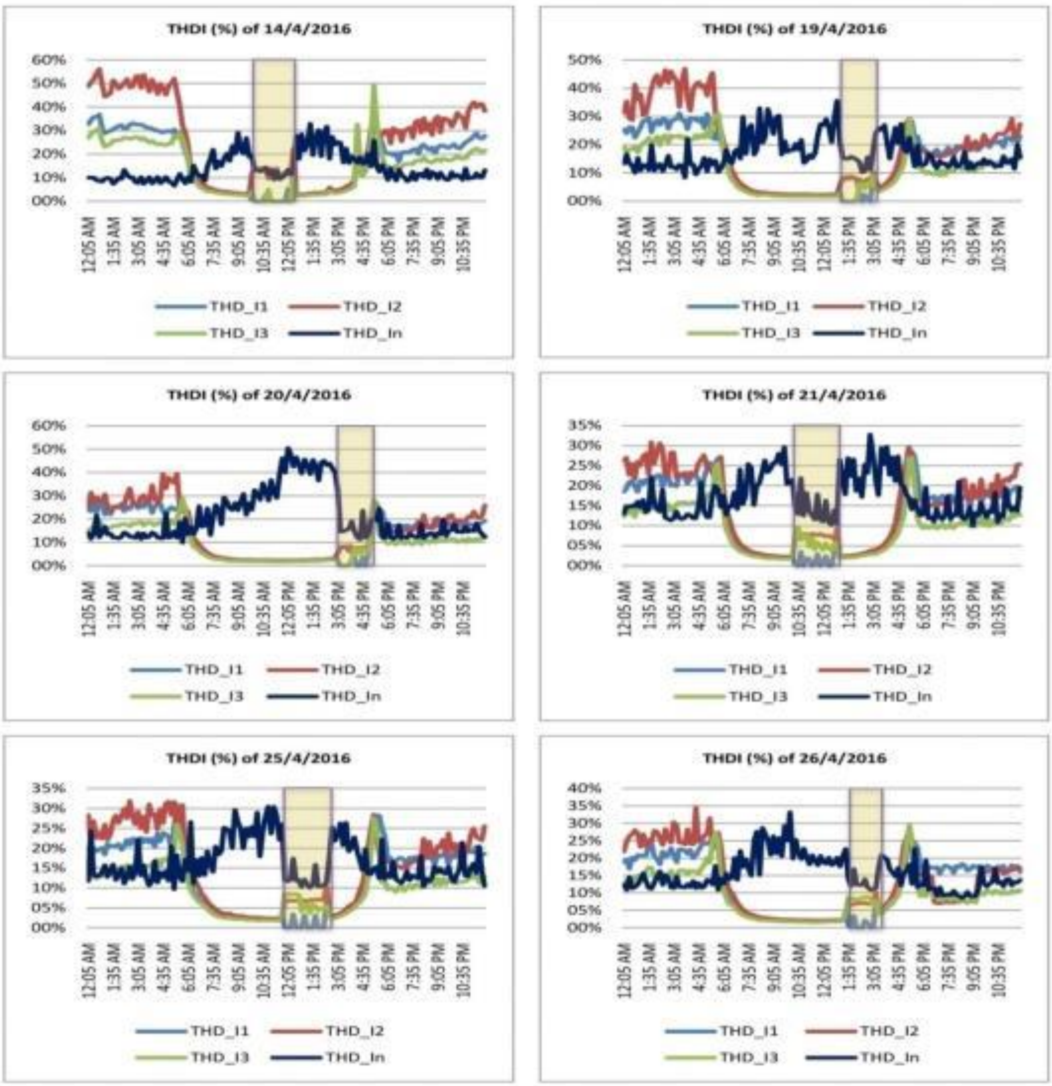

Fig. 5.10 THD (%) of phase and neutral currents for the days in which the system was down during monitoring period "1"

During this test, the phase voltages remained within acceptable limits as given in Fig. 5.11.

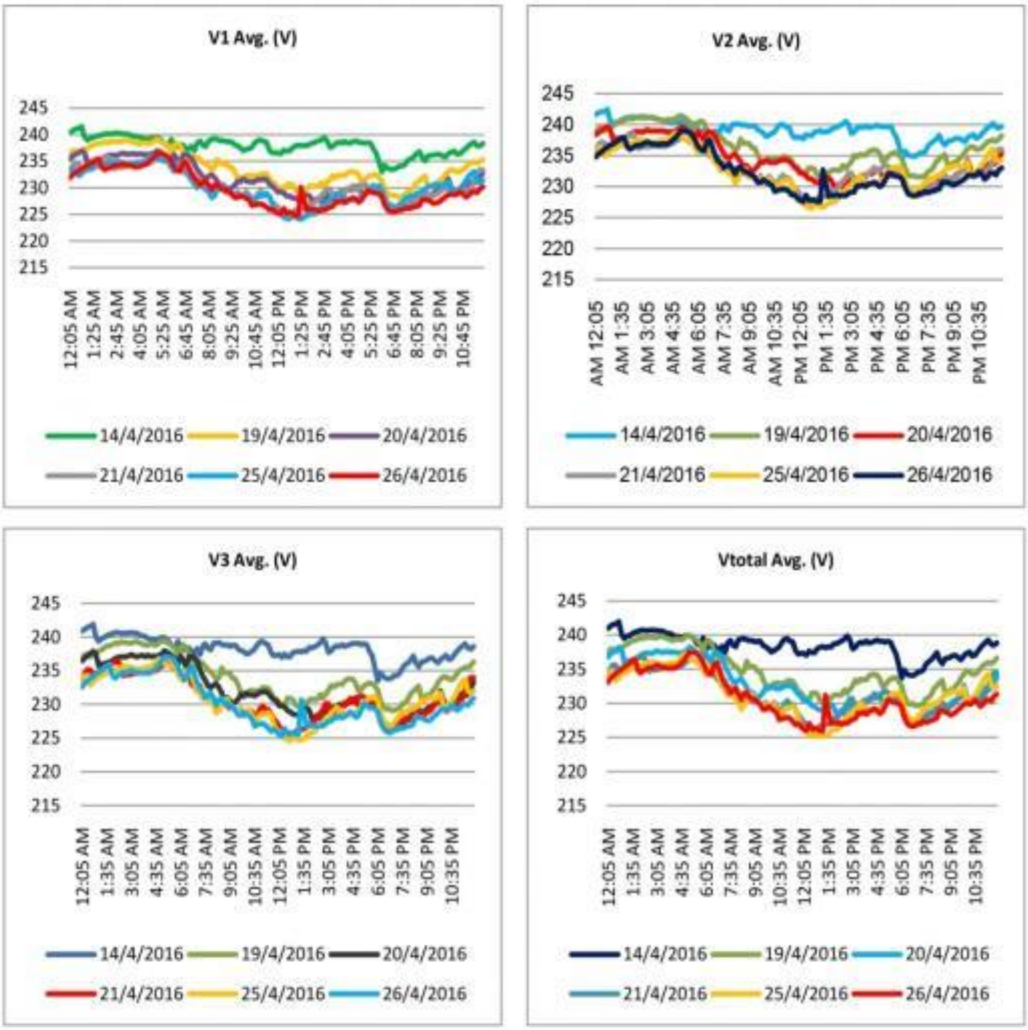

Fig. 5.11 Average phase voltages for the days in which the system was down during monitoring period "1"

The average phase voltages as depicted in last figure varies between 225 V-240 V. Besides, THD_V is also affected by the operation of PV system. The effect is shown in Fig. 5.12. THD_V is somehow reduced when PV system is disconnected. TDD_V is equivalent to THD_V because the rated (maximum) value is almost the same of fundamental value. The below Fig. 5.12 describes the changes in voltage distortion levels due to operation of PV system. It was apparent that the distortion level is less sensitive to changes in PV operation.

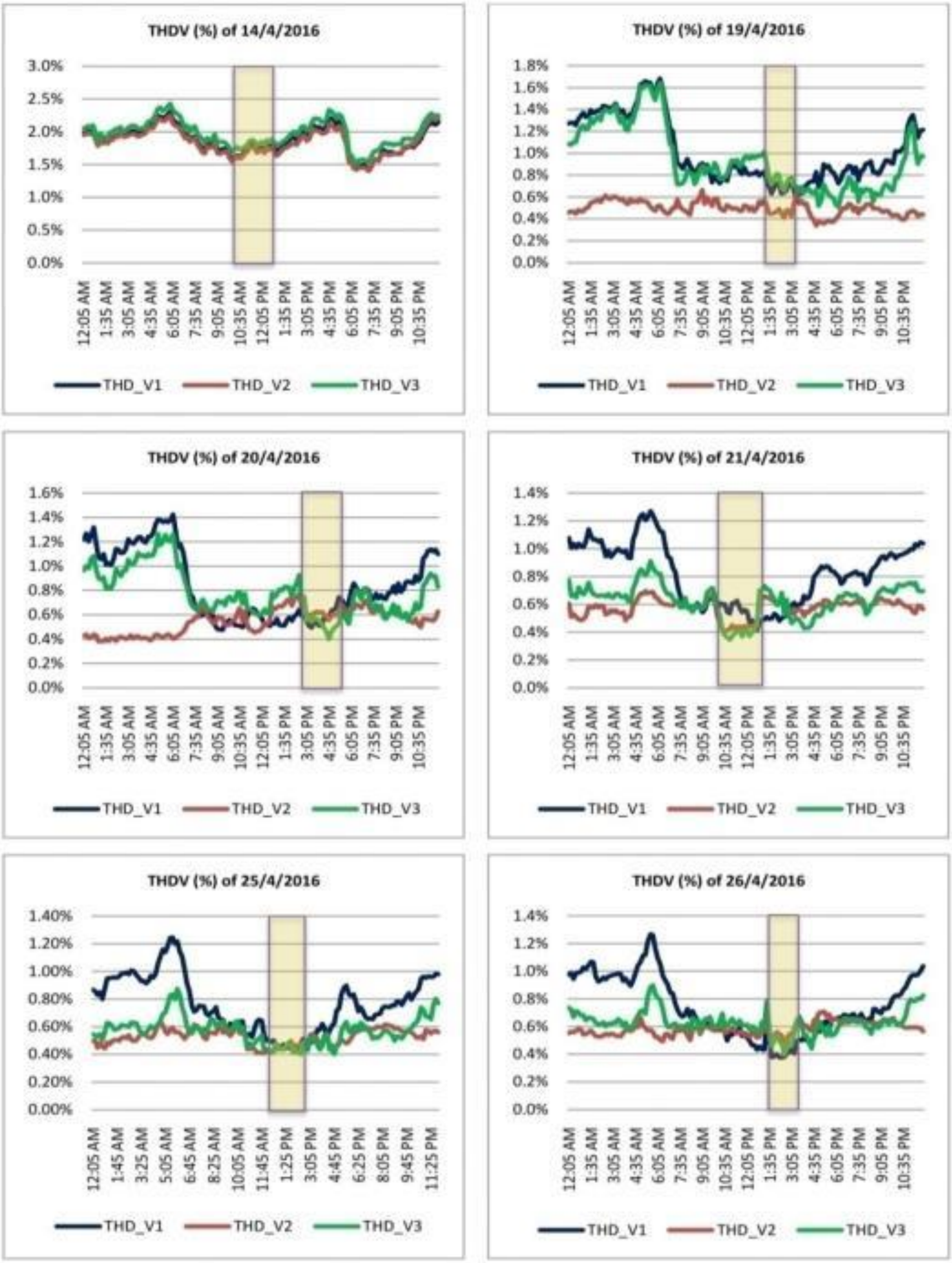

Fig. 5.12 THD (%) of phase voltages for the days in which the system was down during monitoring period "1"

In summary, during daylight times it is clear that TDD increased, while THD decreased this is due to concept of THD and TDD. In addition, PV system increases TDD_I as well as TDD_V (or THD_V) as depicted in the previous Figures. Compared to TDD, THD show different concepts for measurements as previously described, but

TDD seems more reasonable definition for harmonic distortion. Moreover, it was noted that some notches appeared in PV production curves; this is referred to temporary changes in PV production because of clouds or other unpredictable events.

The detailed results obtained for disconnection days during monitoring period “1” are listed in Appendix “E”. The general results obtained for whole days during monitoring period “1” can be found in Appendix “F”.

In the next section, the system is retested after one year in order to show the behavior of system parameters with presence of such dispersed units.

5.2 Test System Under Measuring Period “2” (10/04/2017 – 06/05/2017)

Beforehand, the quantitative analysis of the results obtained during measuring period “1” were discussed whilst the system behavior was monitored for a certain period of time in order to obtain practical information regarding the operation of these generation unit within electrical system. In this section, the same system was retested on different period of time in order to show how the behavior of PV test system is changing a long period of time, furthermore to compare the results obtained from period “1” at the same measuring period after one year. The measuring period “2” for the test system includes 28 days.

The slight differences in the monitoring period “2” outcomes compared to monitoring period “1”, is due to the changes in operating as well as network conditions as described hereafter. Some days were excluded from comparison due to misoperation of the system occurred in some days (transient changes, and disconnection of monitoring device itself).

Fig. 5.13 shows average line neutral currents for randomly selected days of system during monitoring period “2”. During these days, compared to period “1” the average currents are almost the same. The maximum current is ranging from 300 A-315 A, on average of 309 A while the avg. current during PV operation is around 210 A. Neural current is between 8 A-13 A. During night and early morning hours the current drops to 8 A-13 A, and it represents load currents

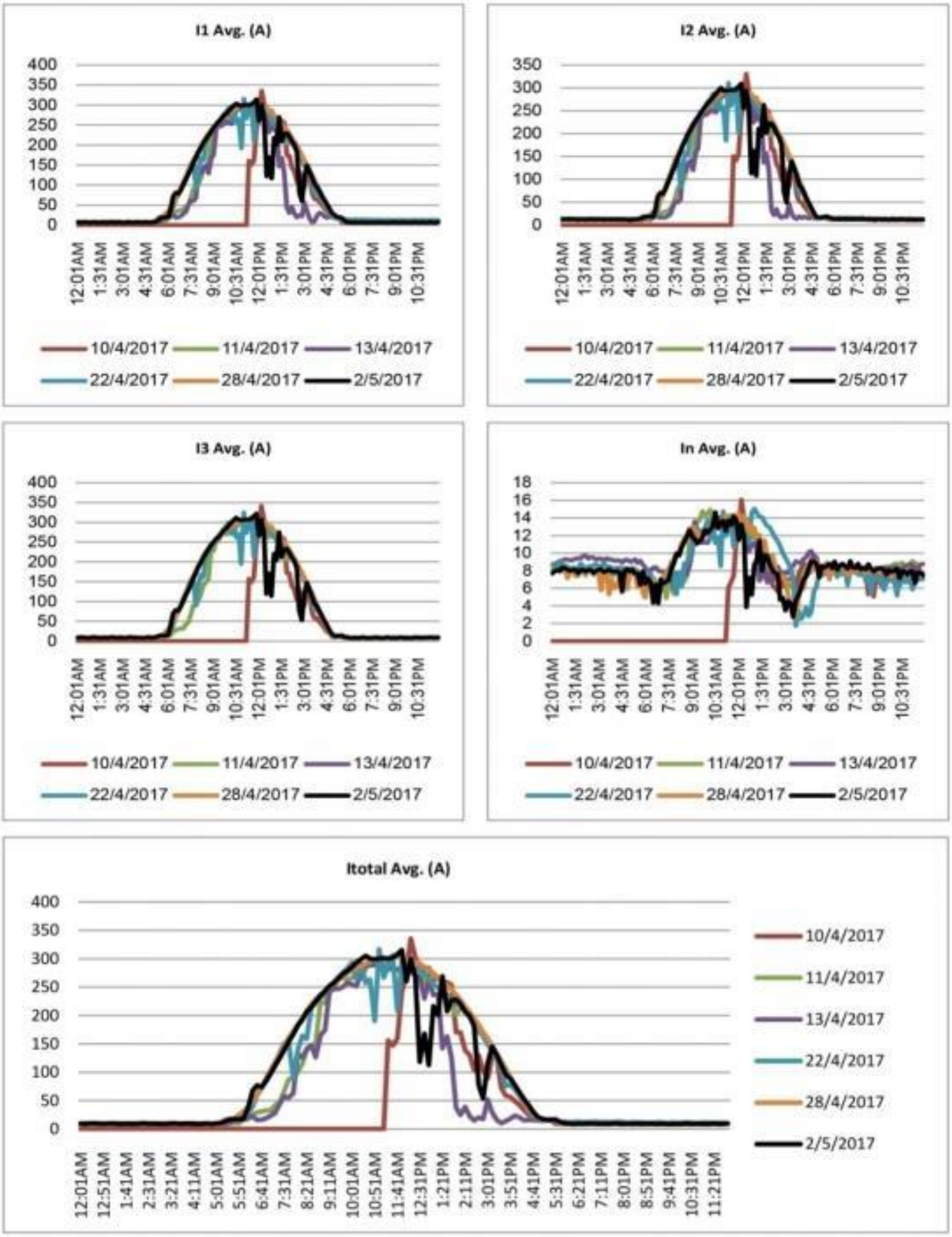

Fig. 5.13 Average phase and neutral currents of the test system for randomly selected days during monitoring period "2"

Regarding voltage variations, the phase voltages vary between 226 and 233 V, and also fall within the acceptable range as per IEC 60038. Fig. 5.14 shows the avg. phase voltages as well as avg. total phase voltages for randomly selected days during monitoring period “2”.

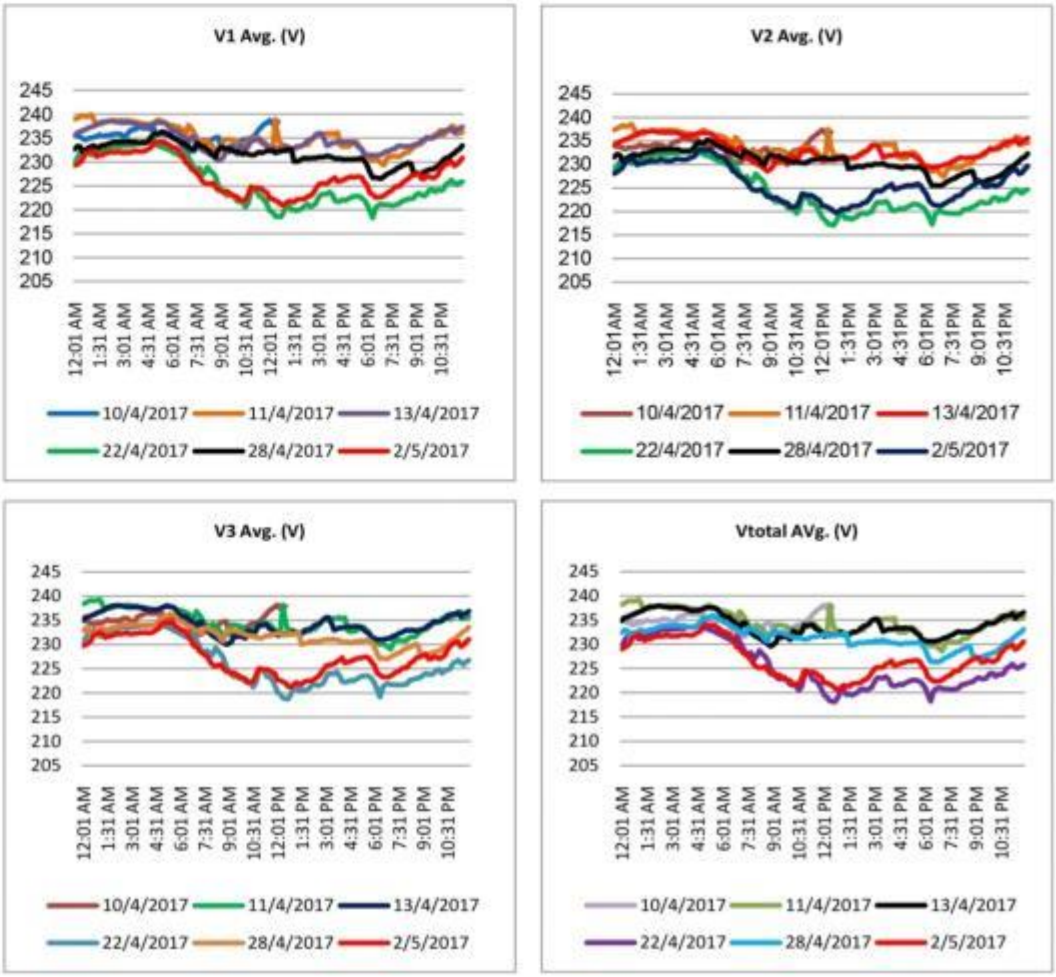

Fig. 5.14 Average phase voltages of the test system for randomly selected days during monitoring period “2”

For harmonic current distortion values, and compared to same monitored days in Period “1”. Fig. 5.15 and Fig. 5.16 show TDD_I and THD_I respectively. The avg. values of TDD_I of phase currents increased from 0.5% to 1.6%, whilst TDD for neutral currents varied almost between 13%-27% during sun hours which represents the maximum production of PV systems.

During this monitoring period; it would seem that phase “2” has the highest distortion value in which the TDD of the current on Avg. raised from 0.52% during night hours to more than 2% (on Avg. Around 1.9%) during peak hours. Other phases the distortion on avg. oscillates between 0.44% and 1.6 %. In contrast, there was increasing of TDD for neutral line during monitoring period “2”, here the neutral current distortion drooped to 19% during operation of PV system, Whilst, oscillates between 13% and 26 % during other day times.

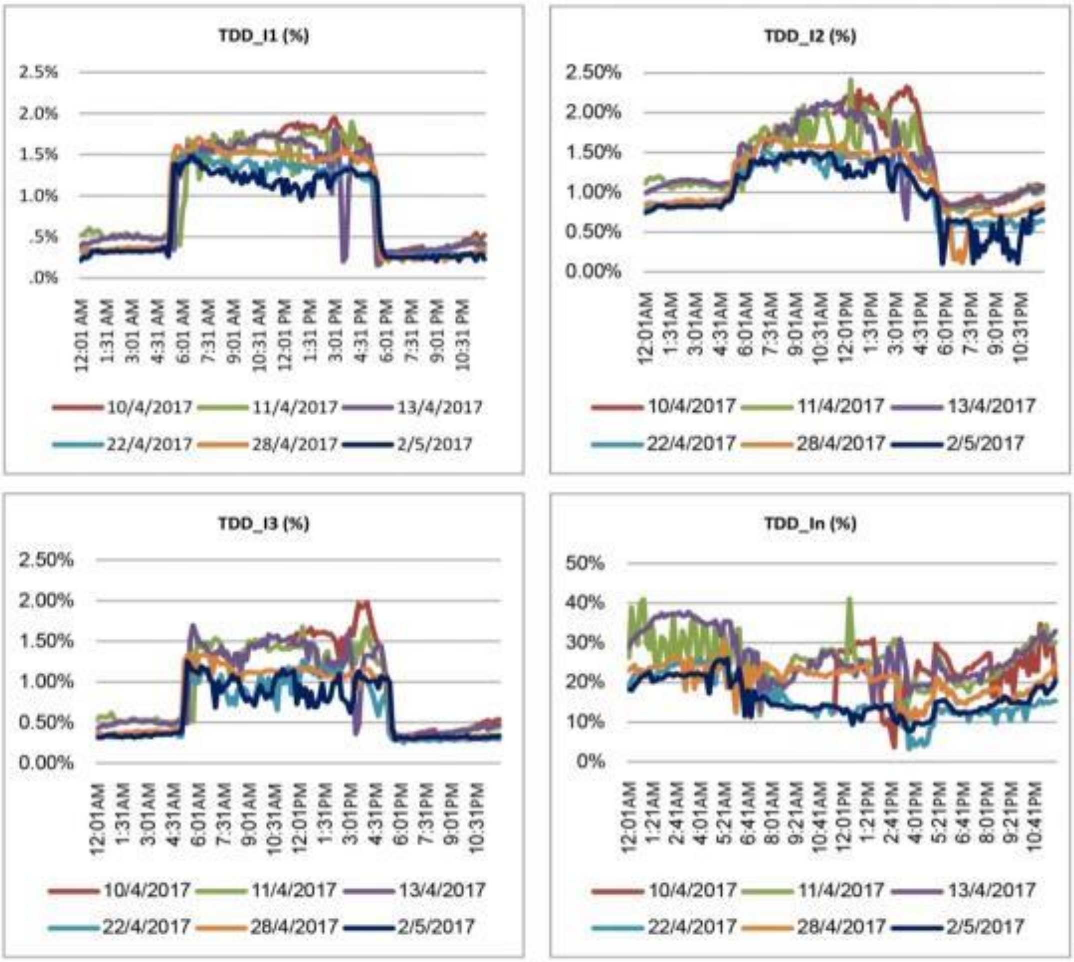

Fig. 5.15 TDD (%) of phase and neutral currents for randomly selected days during monitoring period “2”

The THD (%) for randomly selected days during monitoring period “2” of the test system are presented in Fig. 5.16

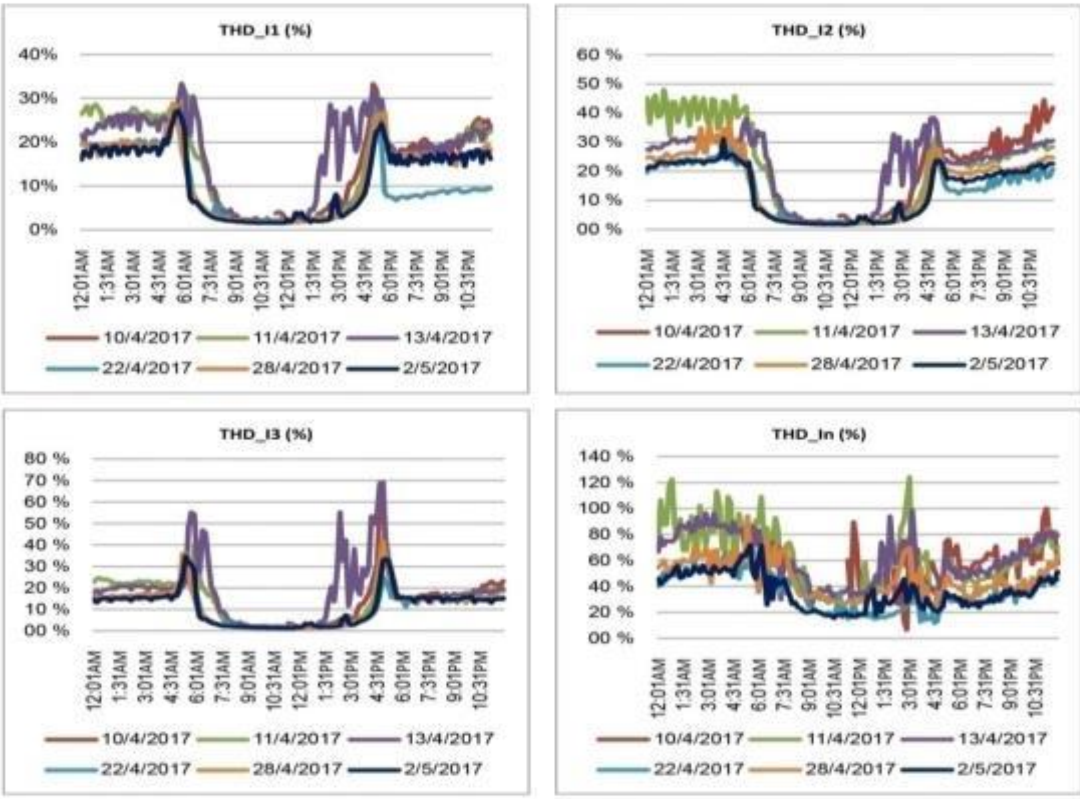

Fig. 5.16 THD (%) of phase and neutral currents for randomly selected days during monitoring period "2"

Regarding THD values, the phase current distortion dropped from 40% (max. value) during off peak hours of PV system to less than 4% during day hours. Phase "2" also still having max. distortion value compared to other phases. Although the distortion values of phase current during this monitoring period is close to that result obtained in monitoring period "1", but the neutral current distortion shows a noticeable jump in distortion levels which exceeds 100%, and it is also observed that neutral current distortion somewhat decreased during operation of PV system on contrary of monitoring period "1" in which the distortion increased for the same day hours. The detailed summery of the results obtained of randomly selected day during monitoring period "1" is presented in Appendix "G".

The harmonic spectrum of current waveform for 38th harmonic order can be illustrated with Fig. 5.17. The detailed values are listed in Appendix "H".

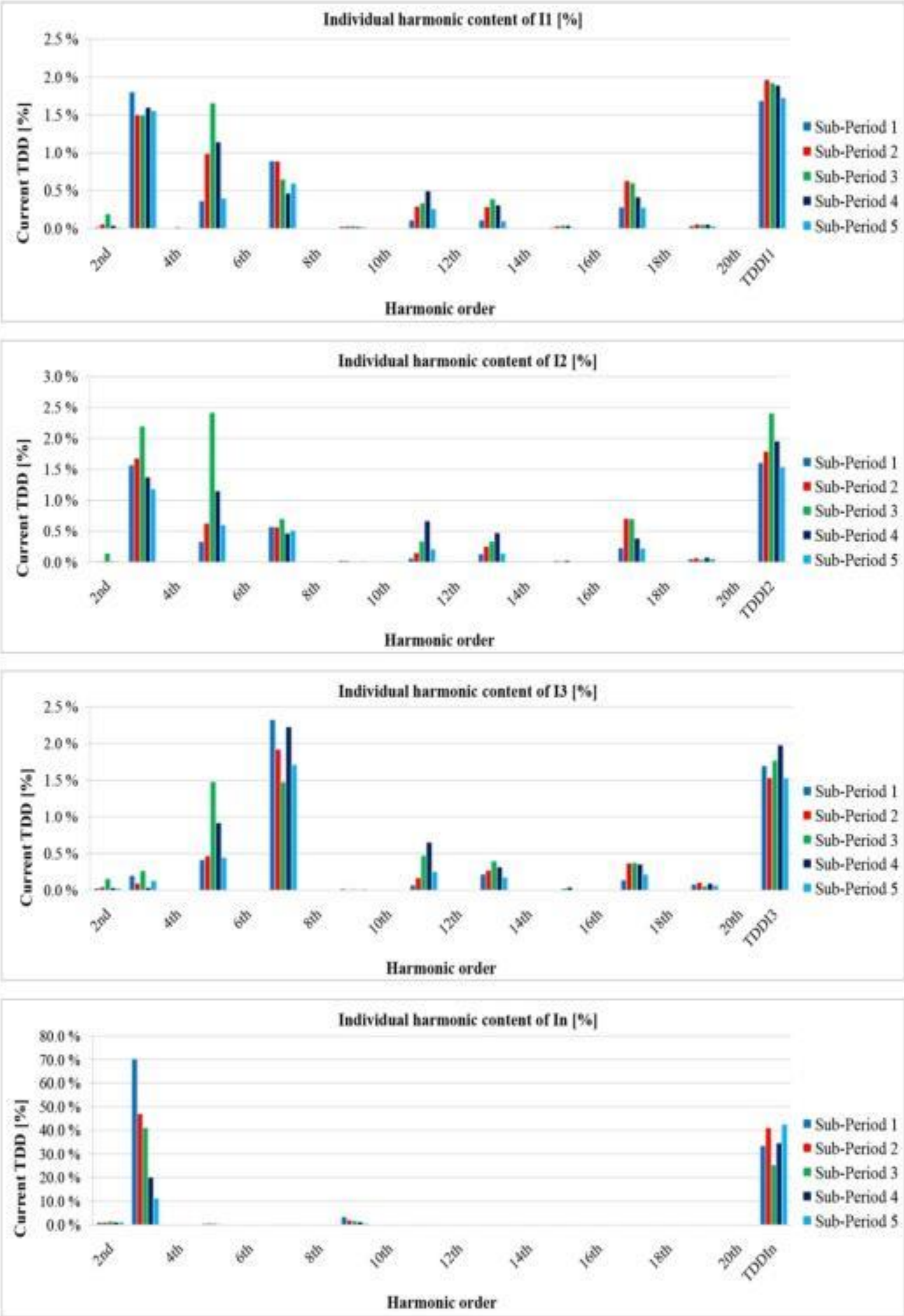

Fig. 5.17 Harmonic spectrum of phase and neutral currents for randomly selected days during monitoring period “2”

It is apparent that the harmonic spectrum during this monitoring period follows the same trend compared to test period “1” in which the 3^{rd}, 5^{th}, 7^{th}, 13^{th} and 17^{th} harmonics are the most dominant harmonic in phases “1” and “2”. While, 5^{th}, 7^{th}, 13^{th}

and 17th harmonics represented the most dominant components in phase “3”. The neutral current mostly contained 3rd harmonic, in addition to little amount of 2nd harmonic. Similarly, the distortion level is affected mainly by solar irradiance as the power level changes as previously discussed in monitoring period “1”.

In order to compare the same days in which the PV system was disconnected during period “1”. Fig. 5.18 shows the average phase and neutral currents during monitoring period “2” for the same disconnection days in period “1”. Here, the maximum current is ranging from 300 A-312 A, on average of 309 A. During night hours the current drops to 9 A-13 A this current represents load currents for small power and lighting systems. Neutral current on average is between 7A-11A.

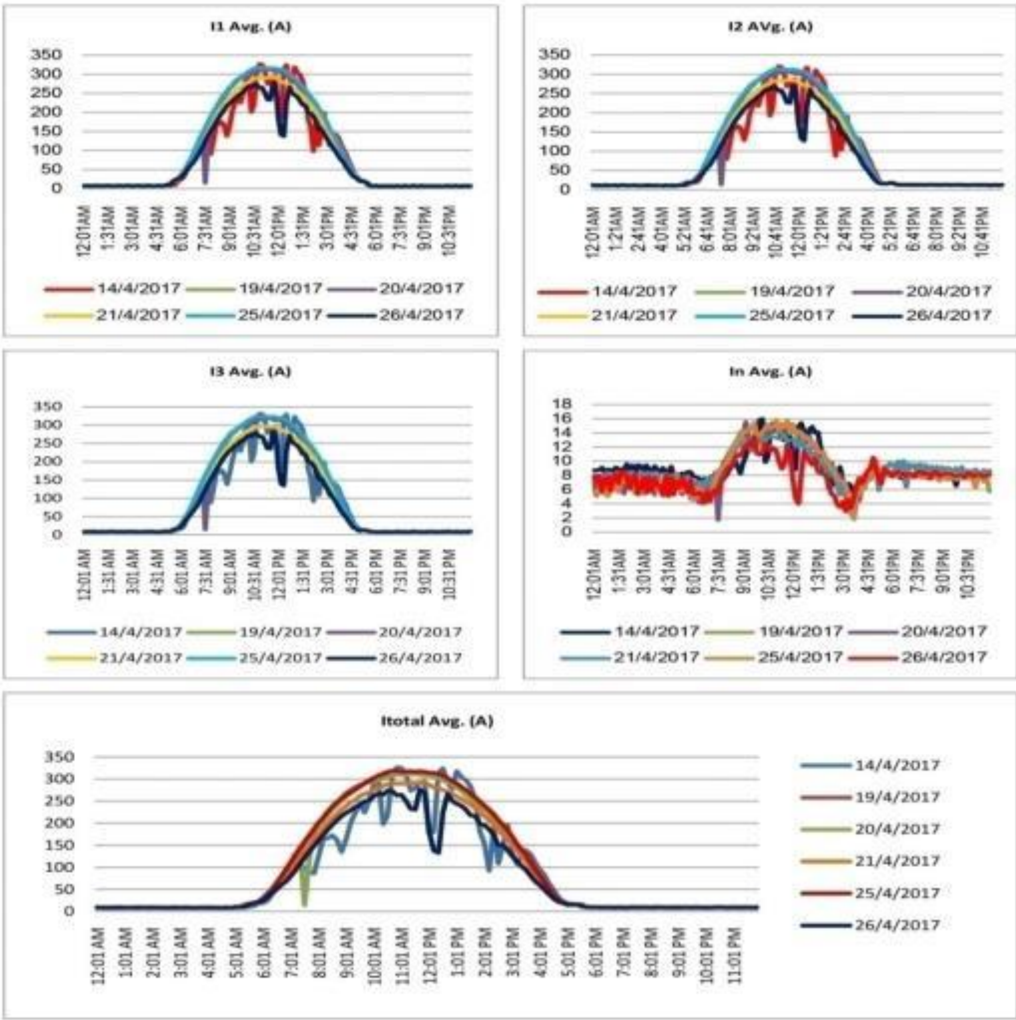

Fig. 5.18 Average phase and neutral currents during monitoring period “2” for the same days in which the system was down during monitoring period “1”

The average voltages for this period shown in Fig. 5.19. The voltages were varied between 220V and 237V which also falls within acceptable limits as per IEC standards.

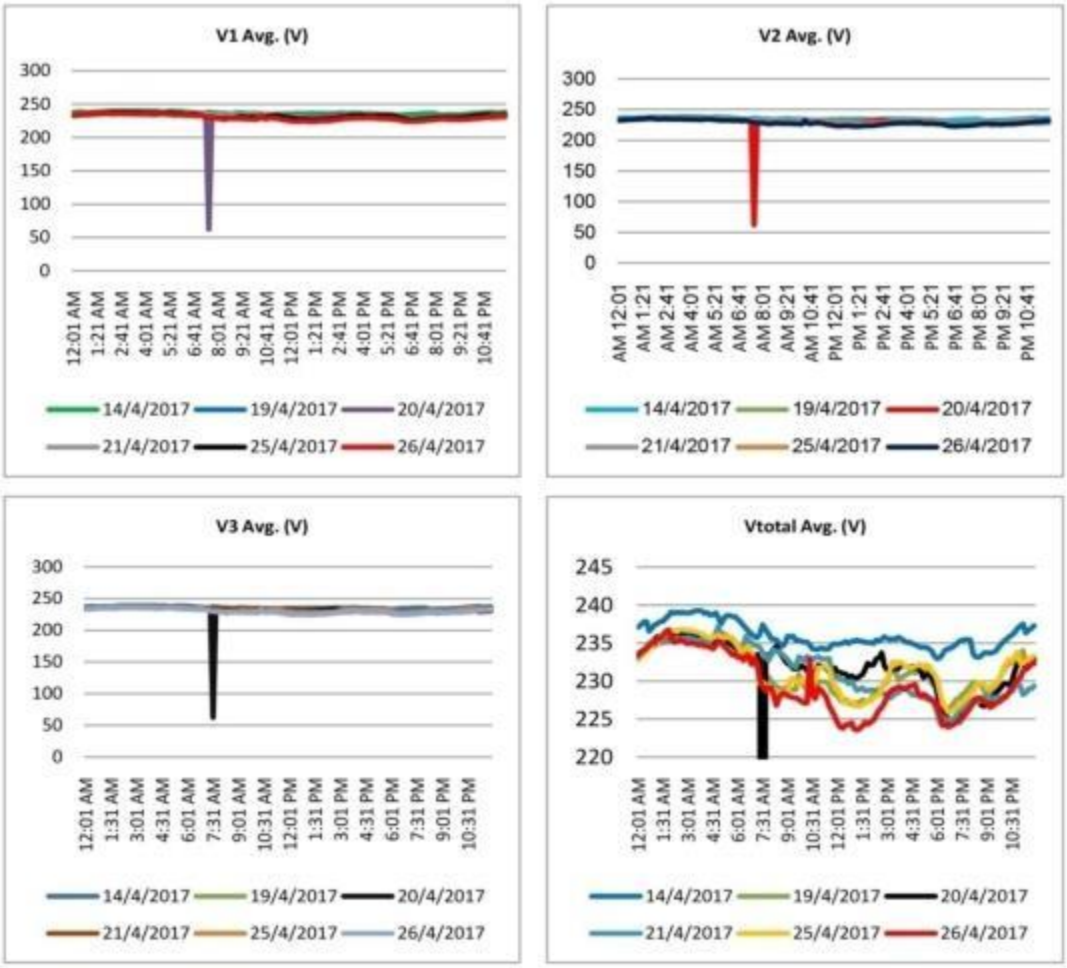

Fig. 5.19 Average phase voltages during monitoring period “2” for the same days in which the system was down during monitoring period “1”

Form the above Fig. 5.18 and Fig. 5.19; it is noticeable that during 20/04/2017 around 7:29 am the current dropped to around 14 A. In the same manner, the voltage dropped near 60V. This is appeared in voltage dips records that lasting for 0.06 s. This may occur due to sudden change in PV system operation that may have occurred as a result of transient operation of the system.

TDD_I and THD_I during these days also explained in Fig. 5.20 and Fig. 5.23. The values are close to those obtained in the previous days within the same monitoring period.

TDD_I of phase "2" was also varied between 0.35%-1.95% along day times, on avg. of 1.73% during generation of PV system. For other phases TDD increased from 0.52% to 1.57%. Neutral current distortion is around 20% during day hours and oscillates between 19% and 26% during night and early morning hours. The drop in distortion level is regards of voltage dip event as previously mentioned.

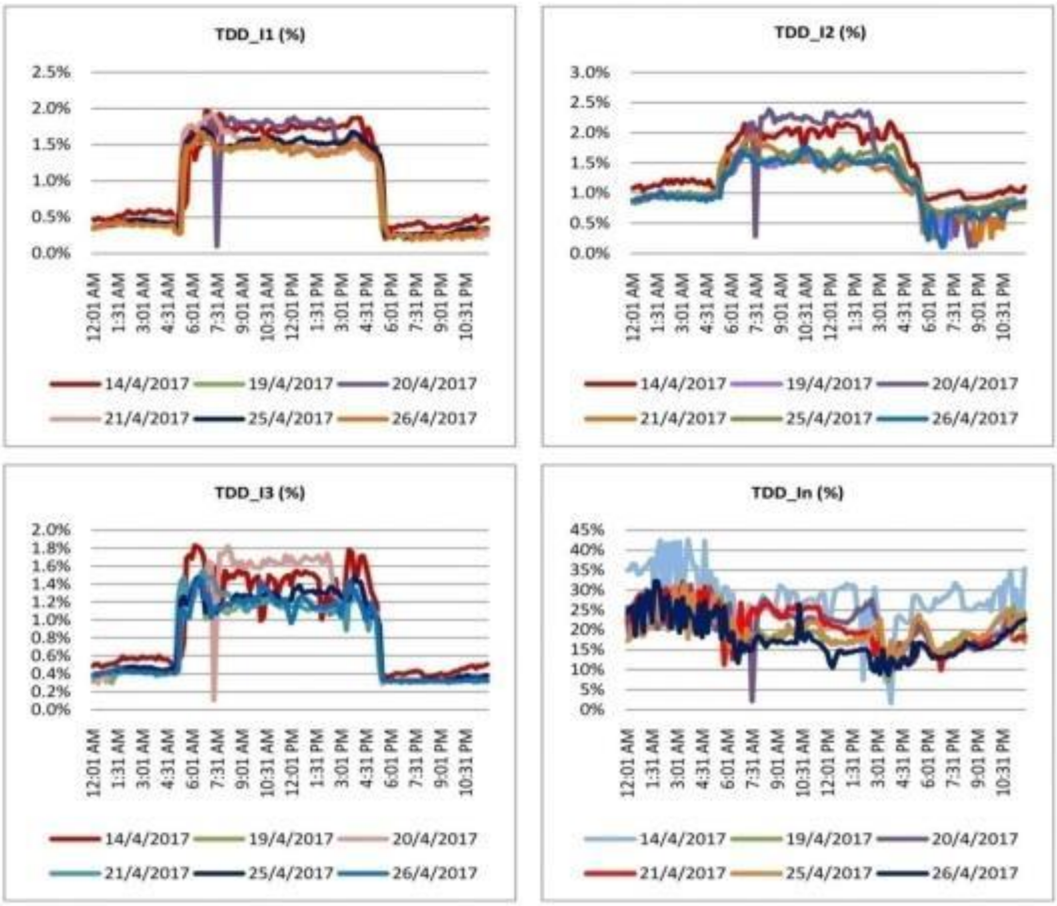

Fig. 5.20 TDD (%) of phase and neutral currents during monitoring period "2" for the same days in which the system was down during monitoring period "1"

If comparing the same period of time during monitoring period "1", it can be observed that the neutral current distortion during this period is doubled in value than before. The detailed results of current waveform distortion represented by TDD for each single day are depicted in Fig. 5.21.

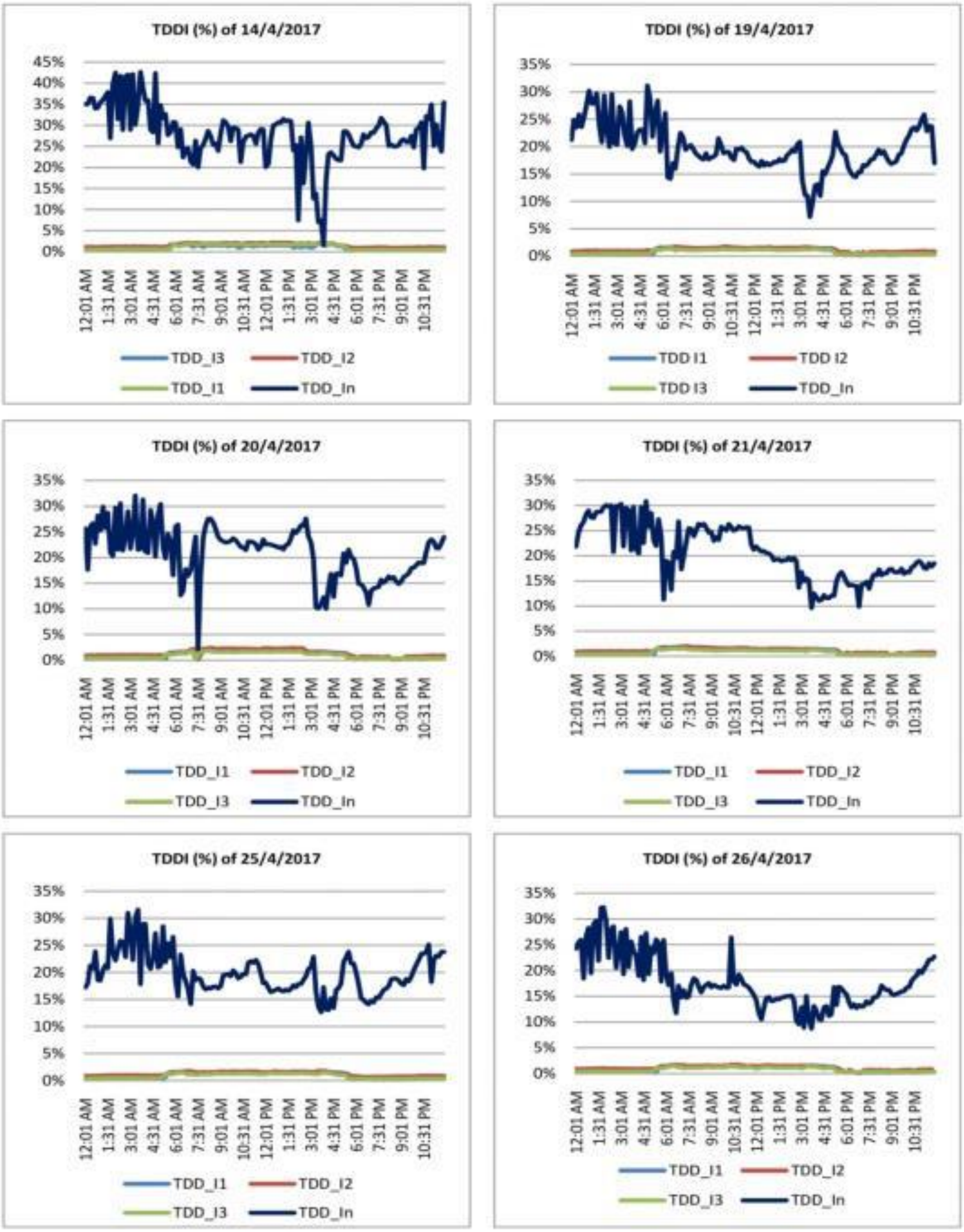

Fig. 5.21 TDD (%) of each single day during monitoring period “2” for the same days in which the system was down during monitoring period “1”

The harmonic spectrum of current waveform during these days can be observed in Fig. 5.22. The detailed values are listed in Appendix “I”

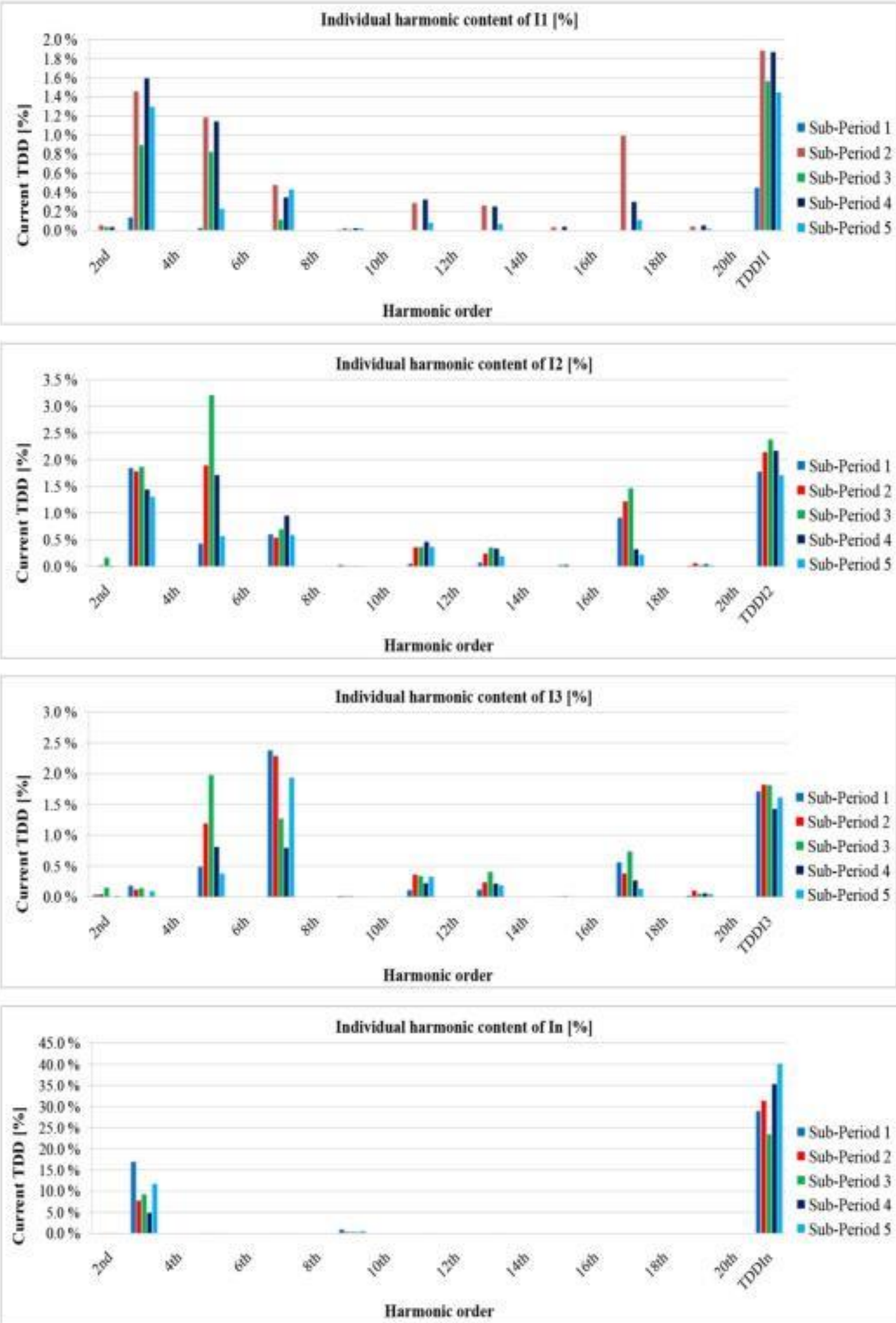

Fig. 5.22 Harmonic spectrum of phase and neutral currents during monitoring period “2” for the same days in which the system was down during monitoring period “1”

The obtained results are consistent with those obtained for the results illustrated in Fig.5.17 in which the 3rd, 5th, 7th, 13th and 17th harmonics are the most dominant harmonics in phases “1” and “2”. While, 5th, 7th, 13th and 17th harmonics represented the most dominant components in phase “3”. The neutral current mostly contained 3rd harmonic. However, during this monitoring period, the 2nd harmonic content faded from harmonic spectrum for neutral current waveform.

Furthermore, THD for current waveform during these days are displayed in Fig. 5.23

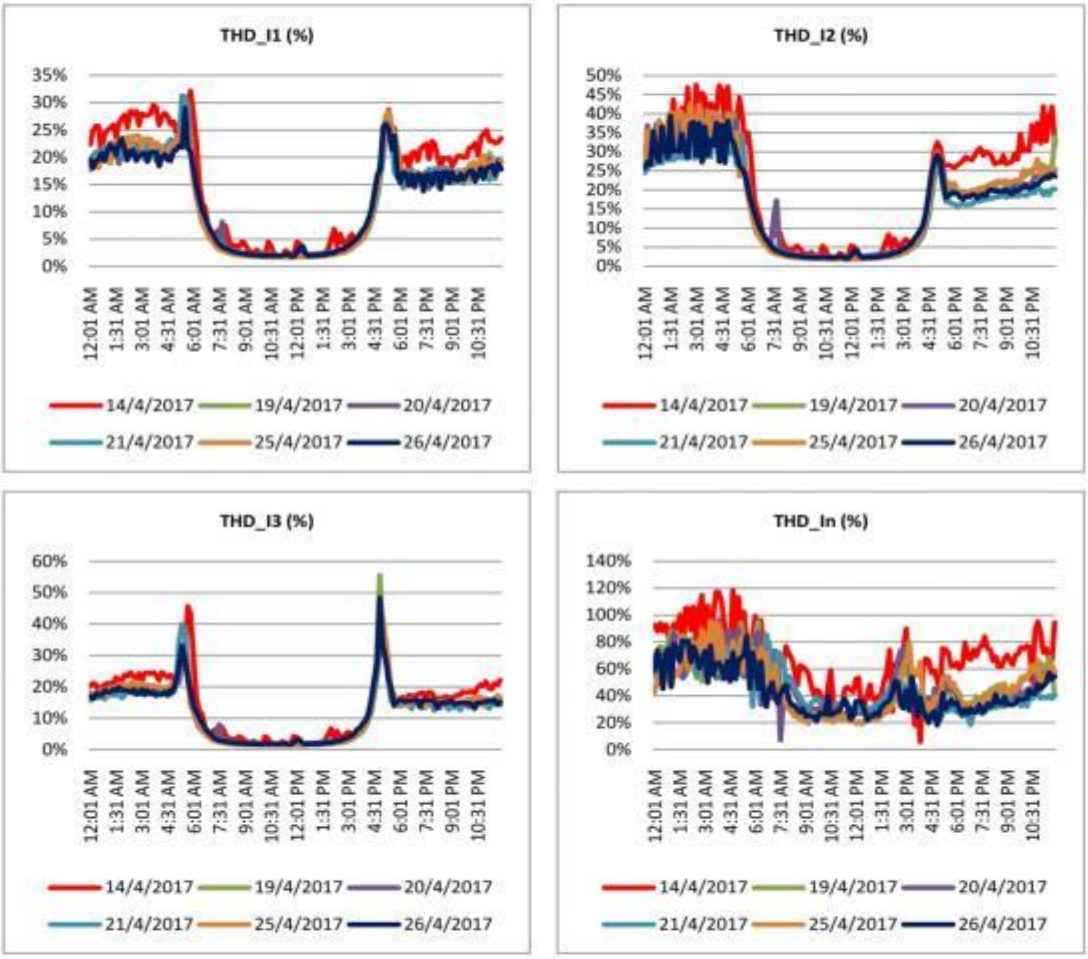

Fig. 5.23 THD (%) of phase and neutral currents during monitoring period “2” for the same days in which the system was down during monitoring period “1”

As illustrated by Fig. 5.23, the results are so closed to those obtained for the previous sample that discussed earlier in this monitoring period. THD of phase currents dropped from 44% (max. value) to less than 3.5% during PV generation hours. In addition, it was noticed that phase “2” has the largest distortion levels compared to other phases. Neutral current distortion also observed that exceeds 100% and obviously decreased during generation power of PV system to less than 60%. The detailed THD of phase and neutral currents during period “2” of each single day equivalent to disconnection day during monitoring period “1” are presented in Fig. 5.24.

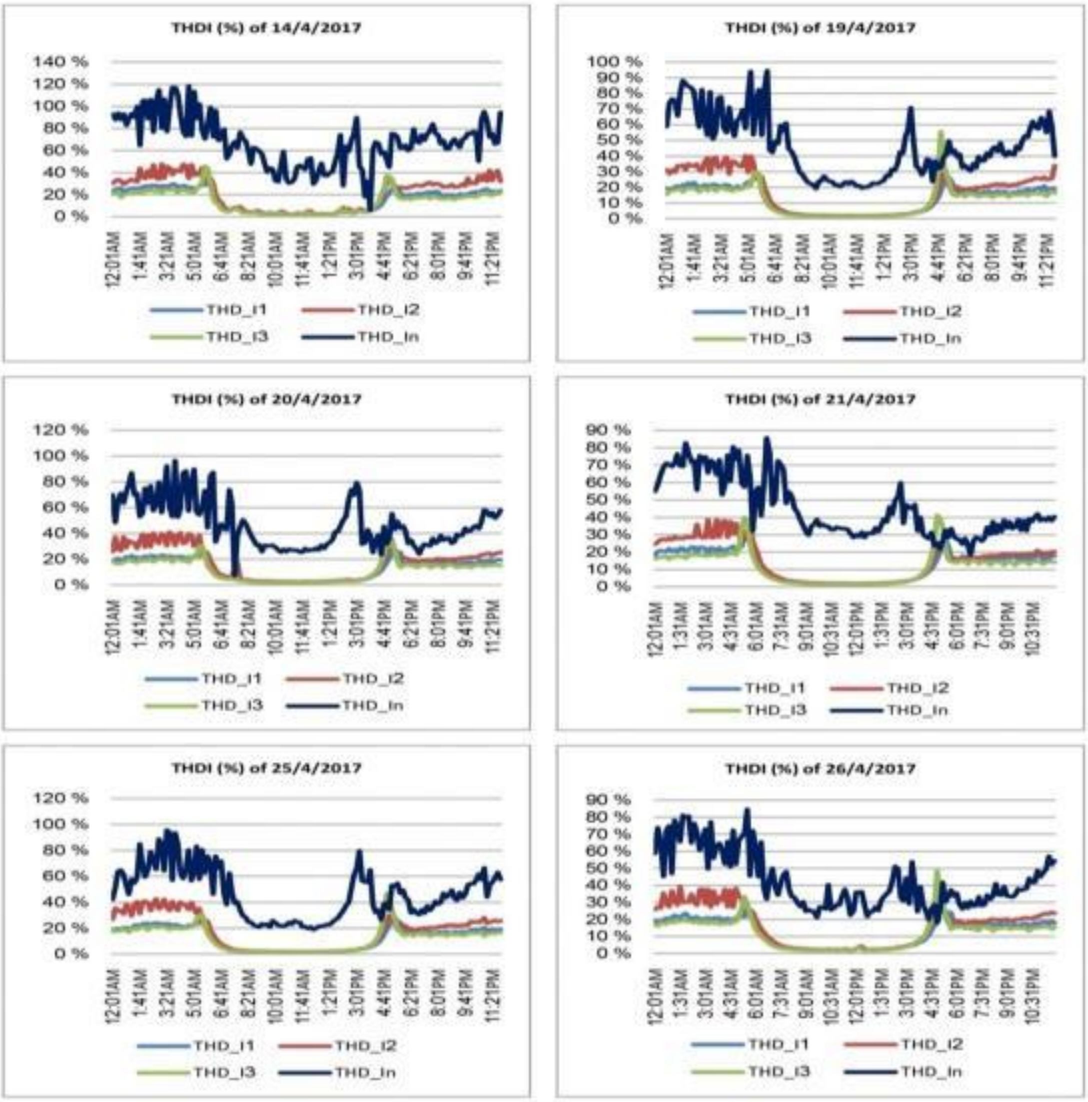

Fig. 5.24 THD (%) of phase and neutral currents during monitoring period “2” for the same days in which the system was down during monitoring period “1”

The THD_V values for these days varied between 0.6% to 1.8%, usually voltage distortion is not sensitive to varying solar irradiance. These values are close to those obtained during monitoring period “1” as previously described. THDV of the same disconnection days in monitoring period “1” are depicted in Fig. 5.25.

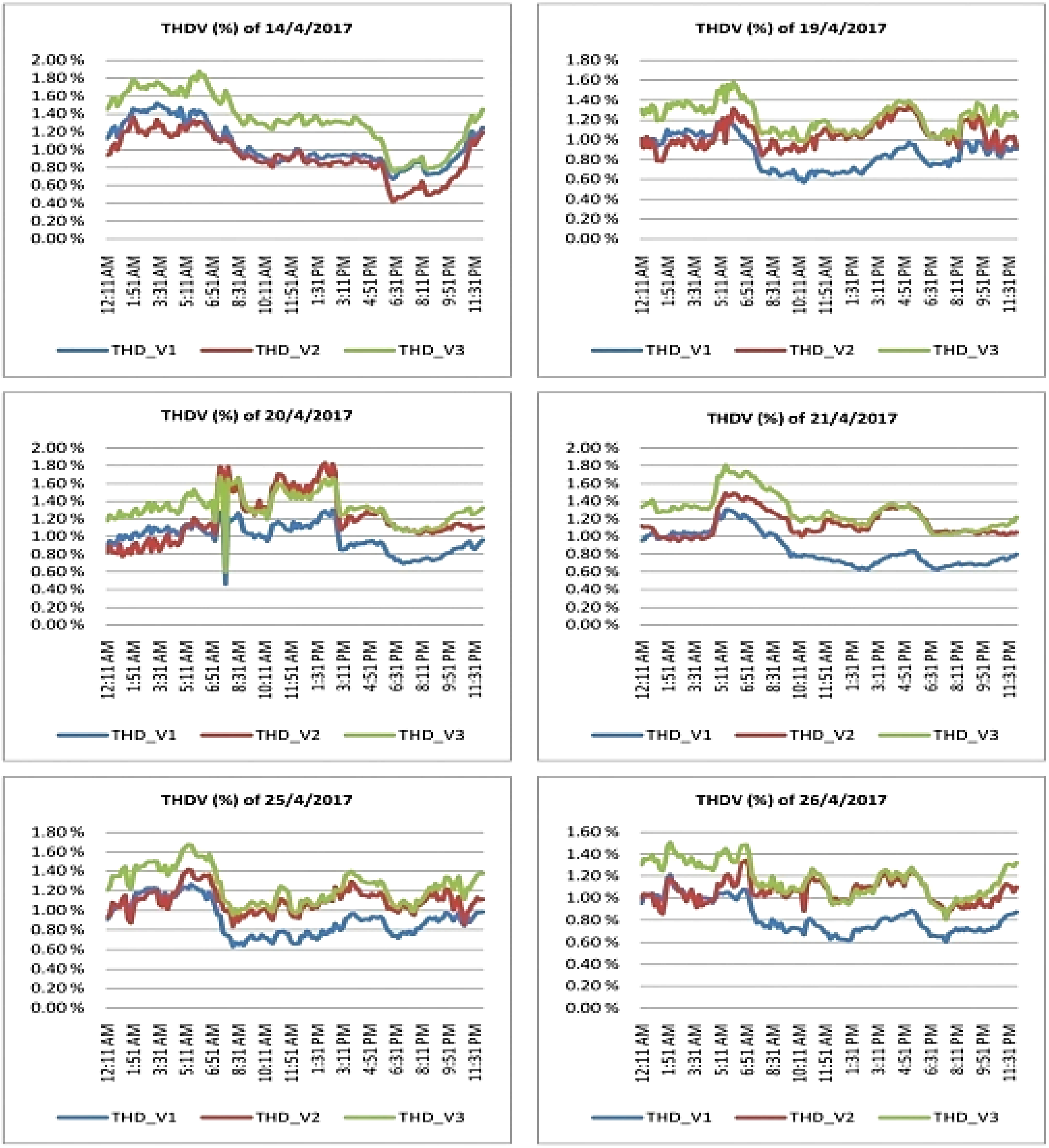

Fig. 5.25 THD (%) of phase voltages during monitoring period “2” for the same days in which the system was down during monitoring period “1”

The detailed results obtained for test system “1” during monitoring period “2” of each single day equivalent to disconnection day during monitoring period “1” are listed in Appendix “J”. And the general results obtained for whole days during monitoring period “2” can be found in Appendix “K”. In summary, the results obtained during monitoring periods confirmed that the behavior of PV system is affected system parameters such as harmonic distortion levels. These effects can be visualized for certain days during the two monitoring periods as in below Figures as per unit (PU) values.

In general, results show that the PV system is following the similar trend during two monitoring periods. It is to be noticed that during high solar radiation (max. PV output), the THD_I have low values, while TDD_I have high values which are complying the limits according to standards. However, during early morning and evening hours the THD_I emissions are increasing significantly range from 6% -42% during monitoring period “1” and from 7%-44% during monitoring period “2”. Whereas, TDD_I ranges from 0.35%-2.02% during monitoring period “1”, and from 0.3%-1.87% during monitoring period “2”. This may show a contradiction between the two concepts, but the reason is behind the definition of each term as discussed before; during low insolation level, the THD of current is increasing that may be due to fundamental current reduction in the PV inverters.

In either case, however, two levels of changes can be observed, the first was during the maximum radiation period during daylight hours, and the other during the period of the lower radiation, which is the minimum production times of the system or the period in which the system production is close to zero.In contrast, the THD_V is not sensitive to varying of PV production.

It is also observed that PV inverters are satisfying the standards in rated conditions. Voltage changes were also complying the limits stated in the standards.

5.3 Simulation Results of the Tests Systems

For the purpose of evaluating the impact of PV system on total system losses, the aforementioned test systems had been simulated with the aid of NEPLAN simulator. The total network losses were measured with and without the presence of these systems; in addition, harmonic emissions were analyzed to show its effect on total losses.

Table 5.1 shows the load flow results with existing PV systems and with the proposed "7.5 MW" PV system. Inspection of results listed in the table indicates that the total system losses are affected by existence of DG within the network.

It is known from the literature that the size and location of DG play important role in determining the effect of integrating these system within network. Therefore, it can be found from these results that location of these systems is positively affected system losses.

TABLE 5.1 Load flow analysis of Jericho system with existing and proposed new system

	without existing PV systems	**with current PV systems**	**with current PV systems and proposed new 7.5 MW PV system**
PLosses [kW]	2165.8	1834.5	1655.3
QLosses [kvar]	4080.9	3263.1	2929.4
PLoad [kW]	33063.6	33063.6	33063.6
QLoad [kvar]	1561.3	1561.3	1561.3
Pgenerated [kW]	35229.4	34898.1	34718.9
QGenerated [kvar]	5642.2	4824.4	4490.9
PImported [kW]	35229.4	32538.1	25948.9
QImported [kvar]	5642.2	5345.9	3710.9
Iimported [A]	0	0	0
PTR loss. [kW]	224.8	222.8	220.7
QTR loss. [kvar]	1962.7	1942.7	1936.8
PLine Losses [kW]	1941	1611.7	1434.6
QLine Losses [kvar]	2118.2	1320.4	992.8

In addition, if trying to go more specific to feeder level in which these systems are installed, the below results in Table 5.2 can be achieved.

TABLE 5.2 Load flow analysis of Jericho system with existing and proposed new system at feeder level

	without existing PV systems		**with current PV systems**		**with current PV systems and proposed new 7.5 MW PV system**	
	AL-Uja	**AL-Maghtas**	**AL-Uja**	**AL-Maghtas**	**AL-Uja**	**AL-Maghtas**
PLosses [kW]	264.1	410.3	264.1	351.5	86.2	351.5
QLosses [kvar]	30.6	384.7	30.6	254.5	-299.4	254.5
PLoad [kW]	8848.8	11932.8	8848.8	11932.8	8848.8	11932.8
QLoad [kvar]	402.5	581.2	402.5	581.2	402.5	581.2
Pgenerated [kW]	0	0	0	1710	6410	1710
QGenerated [kvar]	0	0	0	-127.4	1301.6	-127.4
PImported [kW]	11246	12343.6	11245.6	10575	4656.4	10575
QImported [kvar]	554.2	966.5	554.2	963.7	-1080.9	963.8
Iimported [A]	197	233.5	197	199	83.6	199
PTR loss. [kW]	49.3	76.6	49.3	75.5	47.7	75.5
QTR loss. [kvar]	214.2	814.8	214.2	803.6	209.6	803.6
PLine Losses [kW]	214.8	333.7	214.8	275.9	38.5	275.9
QLine Losses [kvar]	-183.7	-430.1	-183.7	-549.3	-509	-549.3

For the purpose of calculating energy losses produced at a certain period of time in the future; the load was forecasted for the next 5 years, and the forecasted daily load curve is entered to the simulator, the load curve represent a typical expected daily load curve during autumn of a year 2023. The reason behind choosing this period is due to fact that during sunny autumn and spring days in Jericho, the PV systems are operated at its full capacity, in addition, the proposed system is expected to be fully operated in the next coming years. To do analysis, a random period was chosen in November which extended from 20/11/2023 to 22/11/2023.

Performing calculations using time simulation analysis, the following results which listed in Table 5.3 are obtained with different scenarios with and without presence of PV systems.

TABLE 5.3 Time simulation analysis of Jericho system with existing and proposed new system

	without existing PV systems	with current PV systems	with current PV systems and proposed new 7.5 MW PV system
Load Energy [kWh]	1026107.7	1026107.7	1026107.7
Generated Energy [kWh]	1066393.8	1063835.8	1062462.9
Imported Energy [kWh]	1066393.8	1031645.4	942840.1
Energy PLosses [kWh]	40270	37710.2	36337.4
Energy QLosses [kvarh]	15303.6	9076.8	6433.1
Transformer Energy Losses [kWh]	4445.8	4450.7	4438.8
Maximum Load [kW]	23954.6	23954.6	23954.6
Minimum Load [kW]	18524.9	18524.9	18524.9
Maximum Generation [kW]	25017.9	25015.5	25013.5
Minimum Generation [kW]	19144.6	19110.7	19084.5
Pimported Maximum [kW]	25017.9	24991.9	24925.8
Qimported Maximum [kvar]	1063.1	1062.6	1045.8
Pimported Minimum [kW]	19144.6	18638.7	13920.7
Qimported Minimum [kvar]	-245	-244.1	-830.1
High Tension Losses [kWh]	40270	37710.2	36337.4
Maximum Losses [kW]	1062.9	1060.6	1058.6

As evident from Table 5.3, total energy losses reduced from 2.72% during the case representing no PV systems, compared to 2.49% in case in which all existing systems are included in analysis. In addition, it is expected that the new proposed system will reduce the total losses from 2.49% to 2.41%. The detailed results at feeder level are illustrated in Table 5.4.

TABLE 5.4 Time simulation analysis of Jericho system with existing and proposed new system at feeder level

	without existing PV systems		with current PV systems		with current PV systems and proposed new 7.5 MW PV system	
	AL-Uja	**AL-Maghtas**	**AL-Uja**	**AL-Maghtas**	**AL-Uja**	**AL-Maghtas**
Load Energy [kWh]	274616.8	370326.8	274616.8	370326.8	274616.8	370326.8
Generated Energy [kWh]	0	0	0	23324.4	87432.4	23324.4
Imported Energy [kWh]	345661.5	378060	345661.5	354336.8	256856.3	354336.8

	without existing PV systems		with current PV systems		with current PV systems and proposed new 7.5 MW PV system	
	AL-Uja	AL-Maghtas	AL-Uja	AL-Maghtas	AL-Uja	AL-Maghtas
Energy PLosses [kWh]	5208.8	7722.7	5208.8	7323.1	3843.1	7323.1
Energy QLosses [kvarh]	-14575.9	-22897.2	-14575.9	-23689.8	-17189.4	-23689.8
Transformer Energy Losses [kWh]	967.5	1519.3	967.5	1528	958.7	1528
Maximum Load [kW]	6411	8645.3	6411	8645.3	6411	8645.3
Minimum Load [kW]	4957.8	6685.7	4957.8	6685.7	4957.8	6685.7
Maximum Generation [kW]	0	0	0	1704.9	6390.8	1704.9
Minimum Generation [kW]	0	0	0	17.1	64.1	17.1
Pimported Maximum [kW]	8085.7	8849.2	8085.7	8831.7	8019.6	8831.7
Qimported Maximum [kvar]	-217.8	-289.8	-217.8	-289.5	-234.6	-289.5
Pimported Minimum [kW]	6225.7	6805.8	6225.7	6292.2	957.3	6292.2
Qimported Minimum [kvar]	-354.8	-595.8	-354.8	-595.2	-1722	-595.2
High Tension Losses [kWh]	5208.8	7722.7	5208.8	7323.1	3843.1	7323.1
Maximum Losses [kW]	100	100	100	100	100	100
Load Energy [kWh]	136.1	203.6	136.1	203.2	134.1	203.2

As detailed in Table 5.4 the existing as well as proposed system significantly contributed in reducing feeder losses in which these systems are connected. Going back to single line diagram displayed in Fig.3.6, it can be seen each PV system to which feeders is connected. The existing systems reduced AL-Maghtas feeder losses from 1.45% to 1.35%, while the proposed system will decrease the same feeder losses Al-Uja feeder losses from 1.32% to 1.04%.

The daily load curves for the selected test period in which the PV systems are expected to operate during next five years are shown in Fig. 5.26. As can be seen from the chart, when PV systems operate, the imported energy from BSP is reduced.

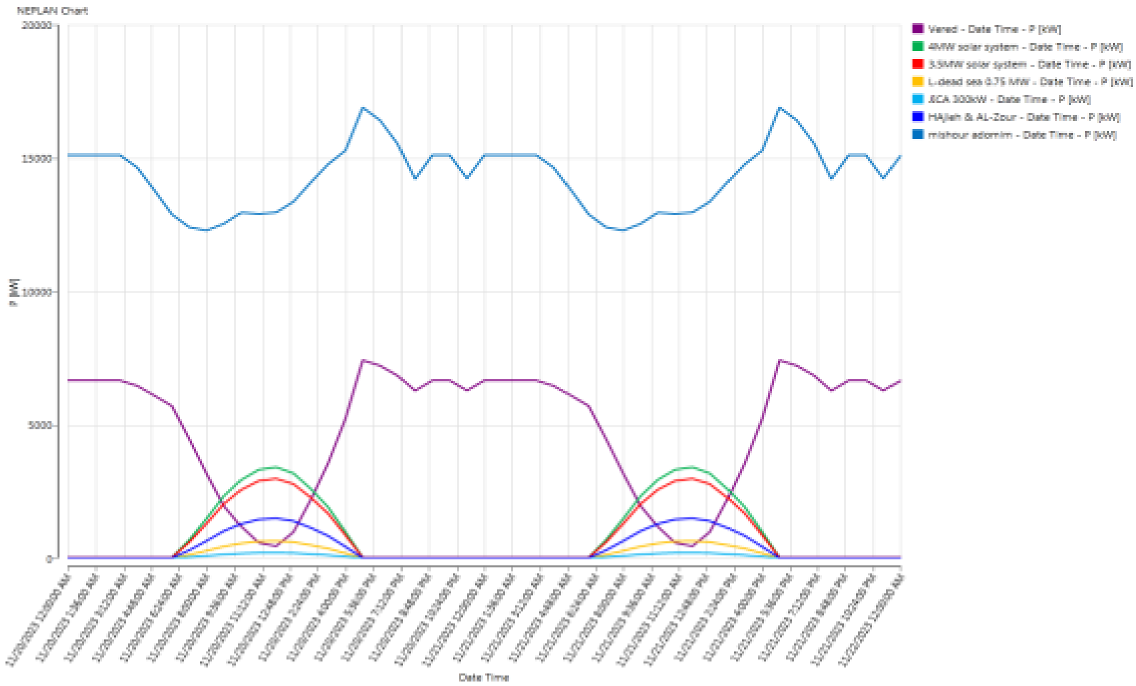

Fig. 5.26 Daily load curves of the test period during autumn 2023

Now, in order to show the effect of harmonic distortion on total system loss, as mentioned before, field measurements are classified into five periods of time using quasi-steady state assumption as presented in Table 4.3. For simulation purposes, the measurements of periods "2, 3, 4" which represent the on peak hours of the PV system will be taken as input values for the simulator based on the values obtained for measuring period "2" of test system. For the Proposed system (7.5 MW), the values of harmonic distortion are listed in appendix "L" [102].

The simulation results are given in Table 5.5

Table 5.5 Harmonic losses analysis results

	With 7.5 MW proposed system	with test system and without proposed one
Network total losses [kW]	1655.3	1834.5
Harmonic losses [kW]	46.535	0.105

From the above results, it can be observed that harmonics increased the total system losses by 2.8% when harmonic distortion of the proposed large scale system is presented in calculations, while for the test system “ 300 kW” the losses increased just by 105 W. Here, it is important to reiterate that harmonics increased total system losses, taking into account the system location and size as previously discussed in the literature. On the other hand, for more justifications for the results, the harmonic spectrum for each system is shown in the below Fig. 5.27, Fig. 5.28, and Fig. 5.29.

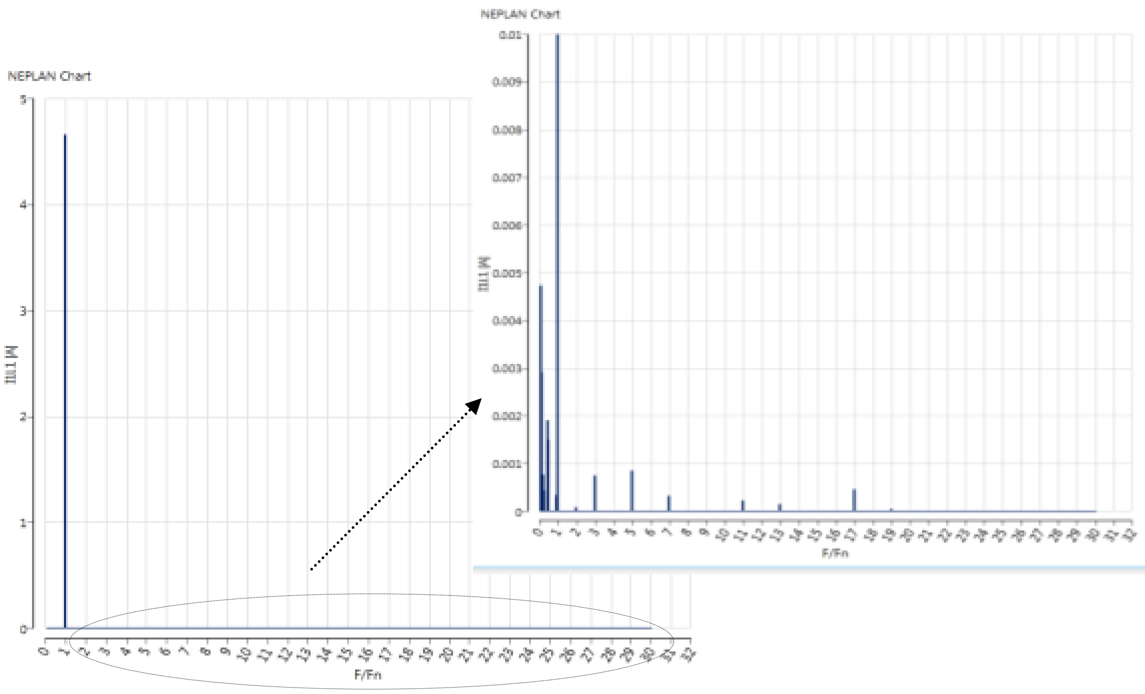

Fig. 5.27 Harmonic spectrum output of the test system

The results displayed in Fig. 5.27 shows that the fundamental current output of the PV system is around 4.6 A and the average TDDI is around 1.5%. These values are matched to the measured data illustrated in harmonic spectrum obtained during the two monitoring periods. Thus, the simulated resulted are consistent with the calculated one. For proposed system, the system as mentioned earlier was separated into two parts one of 4 MW capacity, and another one of 3.5 MW capacity. The harmonic spectrums for the both systems are shown in Fig. 5.28 and Fig. 5.29 respectively.

As can be seen from the last two Figures, the harmonic spectrum for the proposed system is close to the input values listed in Appendix “C”.

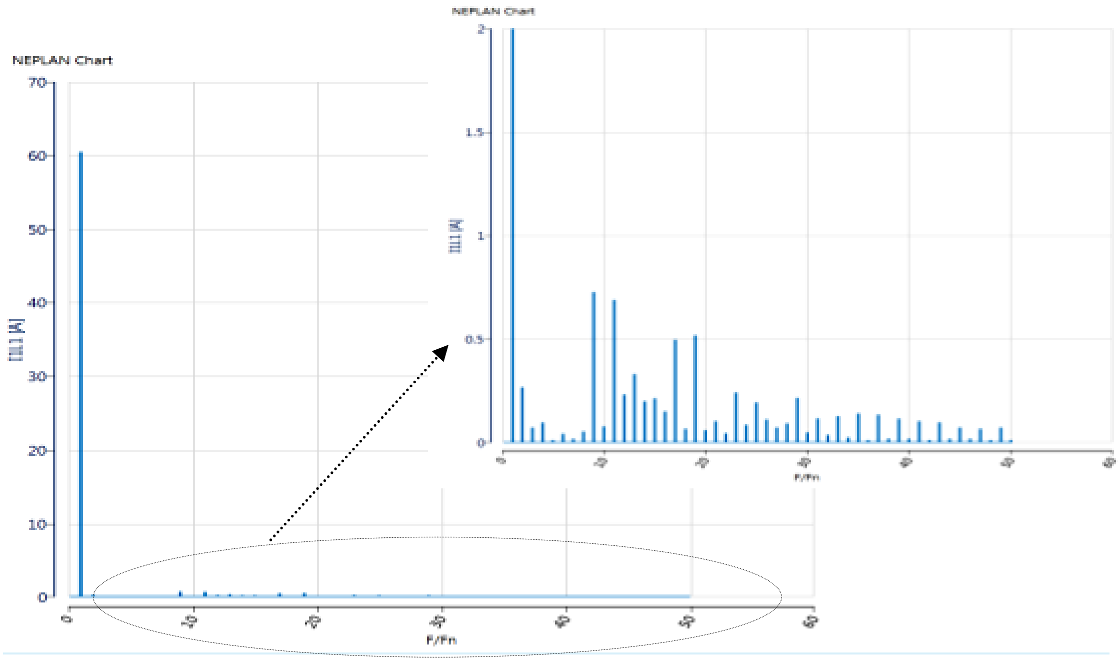

Fig. 5.28 Harmonic spectrum output of the proposed system- Part 1 (4 MW)

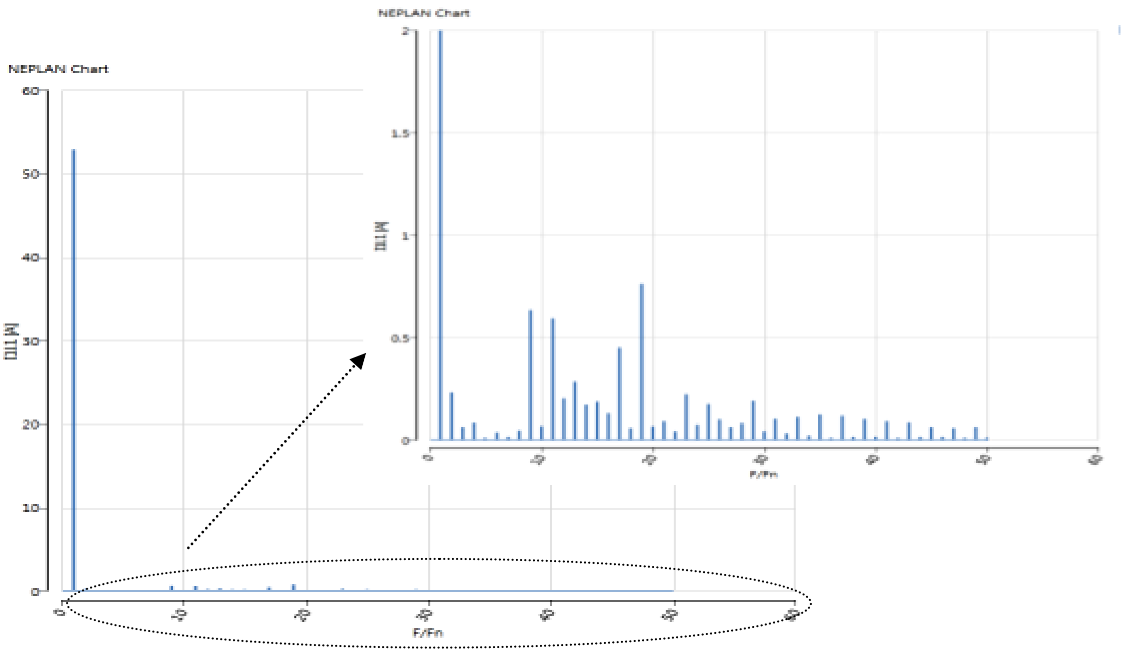

Fig. 5.29 Harmonic spectrum output of the proposed system- Part 2 (3.5 MW)

5.4 Result Summery

As previously discussed, the distortion level of distribution network is directly affected by the operation of PV systems. The below results represent the voltage, current, and distortion curves at PCC where the PV test system is connected. To interpret the results, PU curves were drawn for one selected day during monitoring period “1” in which the PV system was down. The results are given in Fig. 5.30.

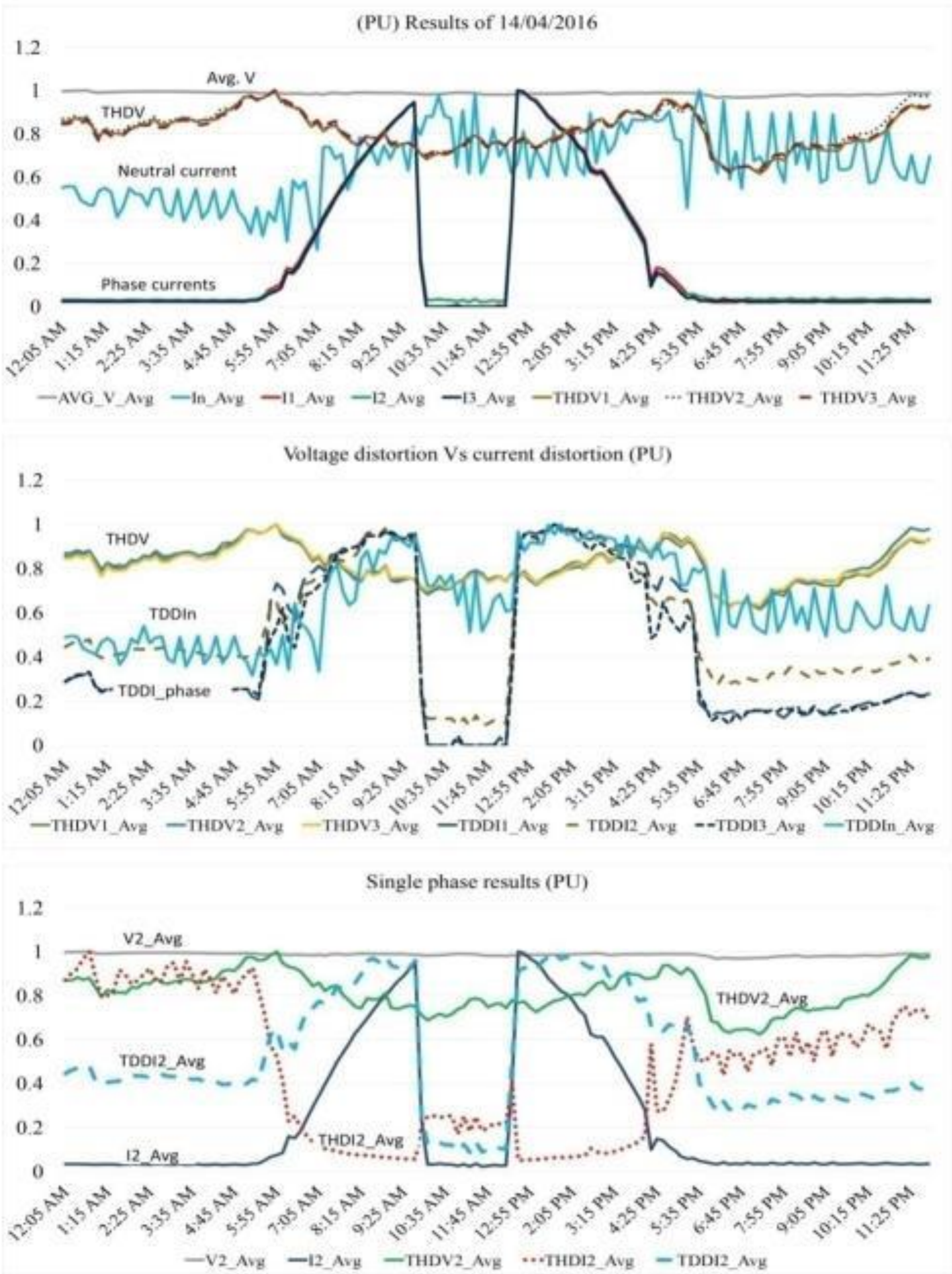

Fig. 5.30 PU results of Voltage, Current, THDV, TDDI for 14/04/2016

It is clear that PV system contributed in harmonic distortion levels, as it started to operate during on peak hours, TDD of phase and neutral currents increased, and THDV somehow decreased. A significant effect of PV systems on distortion levels was clearly noticeable.

Moreover, the simulation results for the test system as well as proposed one presented a direct impact of these distributed generators on total network losses. The results summarized in Fig. 5.31.

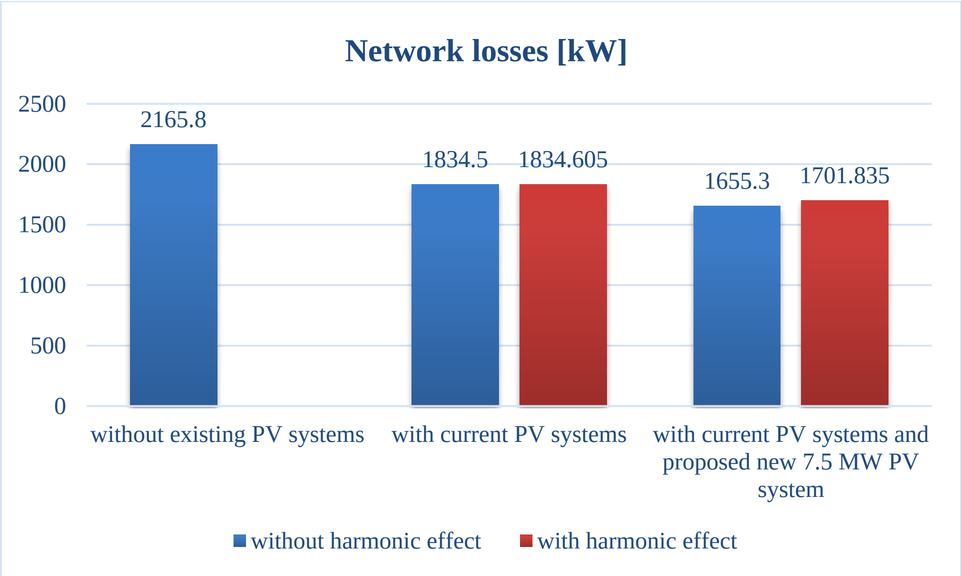

Fig. 5.31 Simulation Results for total network losses

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORKS

6.1 Conclusions

This thesis has analyzed the impact of integration of PV systems on distribution network harmonics as well as the associated impact of harmonics on total system losses. The study discussed two test systems; the first one is existing system of 300 kW installed capacity, and the second one is a proposed PV system with 7.5 MW installed capacity. A comprehensive measurement of existing PV system has been done at two different periods of time in order to monitor the behavior of such systems along various time intervals. The analysis show how the system affect the network parameters mainly harmonics emissions from PV inverters with varying solar irradiance. Measured results show that during high generations the PV system has higher TDDI values with respect to fundamental current. The distortion values are compliance with the standard. Nonetheless, the current harmonic injections from dispersed PV inverters can influence the distribution network severely and increase total system losses. To prove this, the test systems were modeled and simulated using NEPLAN simulator. Simulation results showed a significant impact of large scale systems compared to the small ones.

6.2 Recommendations for Future Work

Further works including investigation of various power quality impacts on distribution systems with different PV inverter technologies, as well as performance comparison between micro-inverter and string-inverter PV systems with regard to harmonic distortion levels could be suggested as an important area of research. More efforts have to be made regarding evaluating the distortion levels at different climate and operating conditions. Finally, while the electric vehicle market is still at a relatively early stage of development, it is poised to reshape industries and energy markets around the world in the near future. Thus, it is important to adapt to a new technology and investigate the impact of such technology on the electric system in terms of dynamic and steady state operation.

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LIST OF APPENDICES

Appendix A
Harmonic spectrum of phase and neutral currents of the test system during period "1" for randomly selected days (disconnection days are excluded)

2016	TDDI1 for 10,11,13,22,28-4-20116+2./5/2016														
	Sub-Period 1			Sub-Period 2			Sub-Period 3			Sub-Period 4			Sub-Period 5		
	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max
TDDI1_01	0.17627	0.0047	0.7374	3.2579	0.2475	8.7608	44.6	0.015	100	7.3413	0.005	17.153	0.642	1E-05	2.192
TDDI1_02	2.5E-05	3E-09	0.0001	7E-05	1E-06	0.0001	1E-04	8E-10	8E-04	6E-05	4E-07	0.0002	2E-05	8E-10	8E-05
TDDI1_03	0.00319	3E-07	0.0102	0.0088	0.0071	0.0103	0.009	0.001	0.012	0.0086	0.0006	0.0123	0.004	1E-06	0.012
TDDI1_04	1.7E-05	2E-07	4E-05	2E-05	9E-06	5E-05	3E-05	3E-09	9E-05	2E-05	8E-08	5E-05	2E-05	5E-07	4E-05
TDDI1_05	0.00184	0.0004	0.0072	0.0037	0.0004	0.0088	0.005	6E-05	0.012	0.0033	0.0006	0.0086	0.002	3E-06	0.007
TDDI1_06	4.4E-07	8E-10	2E-06	4E-07	8E-10	3E-06	1E-06	8E-10	6E-06	1E-06	8E-10	4E-06	9E-07	8E-10	7E-06
TDDI1_07	0.00102	8E-10	0.0055	0.0027	2E-06	0.0069	0.006	9E-06	0.023	0.0045	2E-07	0.0206	0.002	1E-07	0.008
TDDI1_08	7.6E-07	8E-10	3E-06	2E-06	1E-08	6E-06	6E-06	8E-10	3E-05	4E-06	1E-08	1E-05	1E-06	8E-10	1E-05
TDDI1_09	0.00024	9E-06	0.0006	0.0003	0.0002	0.0005	2E-04	3E-09	6E-04	0.0002	2E-06	0.0011	2E-04	5E-08	9E-04
TDDI1_10	7.1E-07	8E-10	4E-06	1E-06	1E-08	6E-06	2E-05	8E-10	5E-05	7E-06	7E-09	4E-05	4E-06	8E-10	5E-05
TDDI1_11	0.00038	4E-08	0.0018	0.001	5E-05	0.0019	6E-04	8E-10	0.002	0.0009	6E-05	0.0022	4E-04	3E-06	0.002
TDDI1_12	5.9E-08	8E-10	4E-07	4E-07	3E-09	3E-06	1E-06	8E-10	1E-05	1E-06	8E-10	1E-05	1E-06	8E-10	2E-05
TDDI1_13	0.00045	7E-06	0.0032	0.0017	2E-07	0.0044	0.002	1E-08	0.007	0.001	3E-06	0.0028	4E-04	7E-07	0.002
TDDI1_14	2E-06	8E-10	2E-05	2E-06	8E-10	9E-06	2E-06	8E-10	6E-06	3E-06	3E-09	1E-05	3E-06	8E-10	3E-05
TDDI1_15	4.3E-06	8E-10	2E-05	2E-05	8E-10	7E-05	4E-05	8E-10	2E-04	6E-05	4E-07	0.0002	3E-05	3E-09	2E-04
TDDI1_16	7.8E-06	8E-10	5E-05	2E-05	4E-08	9E-05	4E-05	8E-10	2E-04	2E-05	3E-08	8E-05	1E-05	8E-10	6E-05
TDDI1_17	0.00085	3E-09	0.0039	0.0023	3E-09	0.0072	0.003	8E-10	0.01	0.0042	3E-05	0.0108	0.001	8E-10	0.007
TDDI1_18	2.9E-07	8E-10	4E-06	4E-07	3E-09	2E-06	6E-07	8E-10	4E-06	3E-07	8E-10	1E-06	1E-07	8E-10	3E-07
TDDI1_19	7.3E-05	8E-10	0.0005	0.0003	4E-07	0.0015	4E-04	7E-09	0.001	0.0004	2E-07	0.0014	3E-04	8E-10	0.002
TDDI1_20	1.2E-05	8E-10	7E-05	3E-05	1E-05	5E-05	2E-05	4E-06	6E-05	3E-05	4E-07	6E-05	2E-05	8E-10	7E-05
TDDI1_21	1.2E-06	8E-10	8E-06	9E-07	8E-10	4E-06	3E-06	8E-10	2E-05	1E-06	8E-10	8E-06	2E-06	3E-09	1E-05
TDDI1_22	1.9E-06	8E-10	1E-05	5E-06	3E-09	2E-05	3E-06	8E-10	1E-05	5E-06	8E-10	2E-05	3E-06	8E-10	2E-05
TDDI1_23	6.7E-06	8E-10	3E-05	3E-05	8E-10	0.0001	5E-05	7E-09	2E-04	5E-05	9E-07	0.0001	2E-05	8E-10	7E-05
TDDI1_24	1.2E-08	8E-10	4E-08	2E-08	8E-10	1E-07	1E-07	8E-10	6E-07	3E-08	8E-10	1E-07	2E-08	8E-10	8E-08
TDDI1_25	2.3E-06	8E-10	9E-06	2E-06	3E-09	7E-06	1E-05	8E-10	3E-05	5E-06	8E-10	3E-05	1E-06	8E-10	4E-06
TDDI1_26	3.3E-08	8E-10	2E-07	9E-08	8E-10	3E-07	4E-07	8E-10	2E-06	2E-07	8E-10	1E-06	1E-07	8E-10	1E-06
TDDI1_27	4.2E-07	8E-10	1E-06	4E-07	8E-10	2E-06	7E-07	8E-10	5E-06	2E-07	8E-10	1E-06	6E-07	8E-10	3E-06
TDDI1_28	1E-07	8E-10	5E-07	5E-07	1E-08	1E-06	5E-07	8E-10	2E-06	5E-07	8E-10	1E-06	2E-07	8E-10	1E-06
TDDI1_29	1.1E-06	8E-10	7E-06	4E-06	1E-08	1E-05	4E-06	8E-10	1E-05	5E-06	8E-10	2E-05	4E-06	8E-10	2E-05
TDDI1_30	2.8E-09	8E-10	1E-08	3E-09	8E-10	1E-08	5E-09	8E-10	2E-08	2E-09	8E-10	7E-09	3E-09	8E-10	7E-09
TDDI1 [%]	0.73022	0.2933	1.7051	1.4405	1.2024	1.825	1.536	0.664	2.113	1.4801	0.4025	2.0313	0.758	0.21	1.701

2016	TDDI2 for 10,11,13,22,28-4-20116+2./5/2016														
	Sub-Period 1			Sub-Period 2			Sub-Period 3			Sub-Period 4			Sub-Period 5		
	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max
TDDI2_01	0.13707	0.0002	0.4252	2.5292	0.0294	7.3056	44.04	0.055	100	6.2149	0.0344	15.339	0.437	0.003	1.421
TDDI2_02	3E-05	8E-10	0.0002	0.0001	8E-10	0.0006	7E-04	1E-07	0.002	0.0001	7E-07	0.0008	3E-05	1E-08	2E-04
TDDI2_03	0.00858	0.0045	0.0131	0.0118	0.0097	0.0137	0.013	0.005	0.019	0.0114	0.0061	0.0179	0.007	0.003	0.016
TDDI2_04	1.8E-05	7E-09	6E-05	4E-05	1E-05	7E-05	7E-05	3E-08	2E-04	4E-05	2E-06	1E-04	2E-05	8E-10	6E-05
TDDI2_05	0.00046	4E-06	0.0029	0.0023	8E-06	0.0074	0.008	2E-07	0.015	0.0042	5E-06	0.0097	1E-03	2E-08	0.004
TDDI2_06	9.4E-07	8E-10	4E-06	1E-06	8E-10	5E-06	3E-06	8E-10	2E-05	3E-06	8E-10	2E-05	2E-06	8E-10	2E-05
TDDI2_07	0.00113	3E-06	0.0063	0.0027	7E-07	0.0095	0.007	3E-06	0.023	0.0052	0.0002	0.0209	0.001	8E-08	0.007
TDDI2_08	1.6E-06	8E-10	9E-06	6E-06	4E-07	1E-05	8E-06	8E-10	4E-05	7E-06	4E-08	3E-05	4E-06	8E-10	2E-05
TDDI2_09	0.00021	3E-09	0.0006	0.0002	4E-06	0.0007	9E-05	3E-09	5E-04	0.0001	8E-06	0.0006	1E-04	4E-07	5E-04
TDDI2_10	2.4E-06	8E-10	2E-05	1E-05	6E-07	3E-05	3E-05	7E-09	2E-04	3E-05	7E-07	0.0001	1E-05	8E-10	7E-05
TDDI2_11	0.00017	2E-08	0.0015	0.0007	3E-06	0.0019	4E-04	6E-08	0.002	0.0005	2E-06	0.001	3E-04	2E-08	0.001
TDDI2_12	4.8E-07	8E-10	2E-06	1E-06	8E-10	4E-06	2E-06	8E-10	1E-05	2E-06	8E-10	2E-05	9E-07	8E-10	4E-06
TDDI2_13	0.00083	4E-07	0.0071	0.0026	0.0001	0.0069	0.002	5E-07	0.008	0.0019	6E-08	0.0041	7E-04	8E-10	0.003
TDDI2_14	8.5E-07	8E-10	1E-05	9E-06	5E-08	4E-05	6E-06	8E-10	3E-05	1E-05	1E-08	5E-05	4E-06	8E-10	3E-05
TDDI2_15	3.8E-05	3E-09	0.0002	9E-05	8E-06	0.0002	6E-05	8E-10	3E-04	0.0001	9E-07	0.0003	8E-05	3E-09	4E-04
TDDI2_16	9.6E-06	3E-09	9E-05	2E-05	8E-10	0.0001	5E-05	5E-08	1E-04	4E-05	3E-09	0.0002	1E-05	8E-10	8E-05
TDDI2_17	0.00088	3E-07	0.005	0.0019	2E-06	0.0061	0.003	4E-06	0.008	0.0035	6E-05	0.0088	1E-03	1E-08	0.005
TDDI2_18	1.9E-06	8E-10	1E-05	1E-05	7E-09	3E-05	1E-06	8E-10	1E-05	3E-06	8E-10	2E-05	3E-06	8E-10	2E-05
TDDI2_19	7.4E-05	3E-09	0.0004	0.0004	9E-06	0.0014	7E-04	2E-07	0.002	0.0009	4E-07	0.0024	3E-04	8E-10	0.001
TDDI2_20	3.7E-06	8E-10	2E-05	6E-06	3E-08	3E-05	6E-06	8E-10	2E-05	4E-06	3E-09	1E-05	3E-06	8E-10	2E-05
TDDI2_21	2.1E-06	8E-10	2E-05	4E-06	7E-09	2E-05	1E-05	8E-10	7E-05	1E-05	5E-08	4E-05	8E-06	8E-10	4E-05
TDDI2_22	6.5E-07	8E-10	5E-06	2E-06	8E-10	6E-06	2E-06	8E-10	9E-06	1E-06	8E-10	5E-06	3E-07	8E-10	1E-06
TDDI2_23	1.3E-05	8E-10	8E-05	3E-05	8E-10	9E-05	4E-05	8E-10	1E-04	4E-05	1E-08	1E-04	1E-05	8E-10	5E-05
TDDI2_24	7.9E-08	8E-10	7E-07	3E-07	8E-10	2E-06	7E-07	8E-10	4E-06	6E-07	8E-10	4E-06	6E-07	8E-10	3E-06
TDDI2_25	1.3E-06	8E-10	7E-06	7E-06	4E-08	2E-05	1E-05	8E-10	5E-05	6E-06	8E-10	3E-05	2E-06	8E-10	7E-06
TDDI2_26	2.9E-08	8E-10	4E-07	4E-08	8E-10	2E-07	2E-07	8E-10	8E-07	8E-08	8E-10	3E-07	4E-08	8E-10	2E-07
TDDI2_27	4.5E-07	8E-10	9E-07	5E-07	3E-09	1E-06	6E-07	8E-10	2E-06	5E-07	2E-08	1E-06	5E-07	8E-10	2E-06
TDDI2_28	9.2E-08	8E-10	7E-07	5E-07	1E-07	1E-06	6E-07	8E-10	2E-06	5E-07	3E-09	1E-06	1E-07	8E-10	8E-07
TDDI2_29	7.9E-07	3E-09	3E-06	3E-06	3E-09	1E-05	4E-06	8E-10	1E-05	3E-06	3E-09	1E-05	3E-06	8E-10	2E-05
TDDI2_30	3.2E-09	8E-10	1E-08	1E-08	8E-10	1E-07	2E-08	8E-10	8E-08	7E-09	8E-10	3E-08	5E-09	8E-10	2E-08
TDDI2 [%]	1.04462	0.6825	1.8464	1.5161	1.2103	1.918	1.795	0.89	2.48	1.6311	0.8031	2.2676	0.98	0.58	1.711

2016	TDDI3 for 10,11,13,22,28-4-20116+2./5/2016														
	Sub-Period 1			Sub-Period 2			Sub-Period 3			Sub-Period 4			Sub-Period 5		
	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max
TDDI3_01	0.11811	0.0016	0.3958	2.7923	0.1434	7.7884	44.02	0.053	100	6.4067	8E-05	15.987	0.444	8E-05	1.491
TDDI3_02	8.1E-05	3E-05	0.0002	0.0001	3E-05	0.0003	8E-04	3E-06	0.002	1E-04	3E-07	0.0002	7E-05	3E-05	2E-04
TDDI3_03	0.00064	7E-09	0.0019	0.0006	6E-08	0.0014	4E-04	8E-10	0.002	0.0007	6E-05	0.0024	5E-04	1E-07	0.002
TDDI3_04	1.1E-05	7E-09	3E-05	1E-05	8E-08	3E-05	6E-05	3E-06	1E-04	2E-05	9E-06	3E-05	8E-06	6E-08	2E-05
TDDI3_05	0.00119	7E-09	0.0075	0.0023	3E-05	0.0078	0.005	3E-08	0.014	0.0026	2E-06	0.0091	0.001	9E-08	0.007
TDDI3_06	5.6E-06	8E-10	2E-05	4E-06	8E-08	1E-05	5E-06	8E-10	1E-05	4E-06	8E-10	1E-05	4E-06	8E-10	2E-05
TDDI3_07	0.00093	1E-08	0.0052	0.0027	5E-06	0.0068	0.006	3E-05	0.02	0.0043	4E-08	0.0191	0.001	8E-10	0.007
TDDI3_08	4.2E-06	8E-10	2E-05	2E-05	4E-06	4E-05	1E-05	8E-08	4E-05	1E-05	1E-07	2E-05	6E-06	8E-10	3E-05
TDDI3_09	0.00015	8E-06	0.0004	7E-05	2E-05	0.0001	4E-05	7E-09	1E-04	4E-05	3E-07	0.0001	8E-05	3E-09	4E-04
TDDI3_10	2E-06	7E-09	9E-06	2E-06	3E-09	9E-06	3E-05	3E-08	1E-04	2E-05	1E-07	0.0001	9E-06	8E-10	1E-04
TDDI3_11	0.0004	2E-05	0.0024	0.0016	0.0002	0.0027	8E-04	1E-08	0.003	0.0012	1E-05	0.0027	7E-04	2E-06	0.002
TDDI3_12	6.9E-07	8E-10	5E-06	4E-06	8E-10	2E-05	3E-06	8E-10	2E-05	2E-06	1E-08	6E-06	2E-06	8E-10	1E-05
TDDI3_13	0.00065	8E-10	0.0041	0.0018	3E-06	0.0052	0.002	7E-09	0.006	0.0013	5E-06	0.0031	5E-04	3E-09	0.002
TDDI3_14	3.6E-06	8E-10	3E-05	1E-05	3E-07	3E-05	1E-05	3E-09	4E-05	8E-06	7E-09	3E-05	7E-06	8E-10	5E-05
TDDI3_15	2.9E-05	9E-08	0.0001	2E-05	3E-08	9E-05	1E-04	7E-09	8E-04	0.0002	1E-06	0.0008	8E-05	1E-08	7E-04
TDDI3_16	2.8E-05	3E-09	0.0002	9E-05	3E-06	0.0002	7E-05	8E-10	2E-04	5E-05	1E-07	0.0001	4E-05	8E-10	1E-04
TDDI3_17	0.00084	8E-10	0.0048	0.0024	9E-05	0.0082	0.003	3E-08	0.01	0.0041	9E-05	0.0082	0.001	8E-10	0.008
TDDI3_18	1.6E-06	8E-10	8E-06	1E-05	2E-08	3E-05	4E-06	8E-10	2E-05	5E-06	3E-09	3E-05	6E-06	8E-10	3E-05
TDDI3_19	3.1E-05	8E-10	0.0002	0.0002	6E-08	0.001	3E-04	1E-08	0.001	0.0003	3E-06	0.0008	2E-04	8E-10	0.001
TDDI3_20	8.6E-06	8E-10	4E-05	2E-05	1E-05	4E-05	2E-05	7E-07	4E-05	2E-05	9E-07	5E-05	1E-05	8E-10	5E-05
TDDI3_21	4.3E-06	8E-10	5E-05	7E-06	3E-09	3E-05	2E-05	8E-10	1E-04	1E-05	2E-07	5E-05	1E-05	8E-10	9E-05
TDDI3_22	4.2E-07	8E-10	3E-06	5E-07	8E-10	3E-06	7E-07	8E-10	2E-06	1E-06	7E-09	5E-06	1E-06	8E-10	6E-06
TDDI3_23	6.9E-06	8E-10	4E-05	3E-05	1E-08	0.0001	3E-05	8E-10	1E-04	2E-05	7E-09	0.0001	8E-06	8E-10	7E-05
TDDI3_24	9.3E-08	8E-10	4E-07	5E-07	8E-10	2E-06	7E-07	8E-10	5E-06	5E-07	8E-10	2E-06	3E-07	8E-10	1E-06
TDDI3_25	9.9E-07	8E-10	4E-06	5E-06	2E-08	2E-05	8E-06	8E-10	3E-05	5E-06	3E-09	2E-05	4E-06	8E-10	2E-05
TDDI3_26	2.5E-08	8E-10	2E-07	8E-08	8E-10	5E-07	4E-07	8E-10	1E-06	7E-08	8E-10	3E-07	7E-08	8E-10	5E-07
TDDI3_27	3.7E-07	8E-10	1E-06	4E-07	8E-10	1E-06	1E-06	8E-10	4E-06	5E-07	3E-08	2E-06	9E-07	8E-10	7E-06
TDDI3_28	2.2E-08	8E-10	1E-07	7E-08	3E-09	3E-07	1E-07	8E-10	4E-07	1E-07	8E-10	7E-07	6E-08	8E-10	5E-07
TDDI3_29	1.7E-06	8E-10	1E-05	2E-06	1E-08	8E-06	8E-06	8E-10	3E-05	3E-06	6E-08	1E-05	2E-06	8E-10	8E-06
TDDI3_30	7.9E-09	8E-10	4E-08	2E-08	8E-10	1E-07	2E-08	8E-10	9E-08	7E-09	8E-10	3E-08	8E-09	8E-10	3E-08
TDDI3 [%]	0.5583	0.2069	1.4193	1.0419	0.7244	1.5332	1.254	0.485	1.893	1.1614	0.3015	1.6859	0.544	0.133	1.328

2016	TDDIn for 10,11,13,22,28-4-20116+2./5/2016														
	Sub-Period 1			Sub-Period 2			Sub-Period 3			Sub-Period 4			Sub-Period 5		
	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max
TDDIn_01	17.0083	3.5478	35.178	15.67	4.04	29.514	19.29	2.248	35.61	23.522	10.504	34.164	23.46	5.386	41.28
TDDIn_02	0.09533	0.0221	0.1984	0.1052	0.0385	0.1741	0.149	0.019	0.222	0.1551	0.0817	0.2016	0.124	0.03	0.203
TDDIn_03	0.16166	0.03	0.3491	0.1868	0.0575	0.3438	0.411	0.03	0.699	0.4359	0.118	0.6388	0.276	0.041	0.57
TDDIn_04	0.0009	0.0001	0.0016	0.0011	0.0004	0.0017	0.002	2E-04	0.003	0.0017	0.0008	0.0022	0.001	3E-04	0.002
TDDIn_05	0.05869	0.0117	0.1681	0.053	0.0162	0.1327	0.042	0.013	0.095	0.0476	0.0263	0.0913	0.058	0.013	0.145
TDDIn_06	0.00083	0.0003	0.0016	0.0009	0.0003	0.0013	0.001	2E-04	0.002	0.0011	0.0009	0.0019	0.001	3E-04	0.002
TDDIn_07	0.00729	0.0004	0.023	0.0065	0.0009	0.0213	0.007	6E-04	0.021	0.009	0.001	0.0254	0.007	8E-04	0.021
TDDIn_08	0.0003	3E-05	0.0008	0.0003	4E-05	0.0007	4E-04	4E-05	8E-04	0.0004	0.0001	0.0006	4E-04	4E-05	7E-04
TDDIn_09	0.00917	0.0021	0.0171	0.0095	0.0012	0.0173	0.012	0.002	0.026	0.0112	0.0067	0.0168	0.012	0.003	0.028
TDDIn_10	0.00027	5E-05	0.0006	0.0003	7E-05	0.0005	4E-04	7E-05	7E-04	0.0003	0.0002	0.0006	3E-04	7E-05	6E-04
TDDIn_11	0.00227	0.0002	0.0055	0.0021	0.0006	0.0043	0.002	6E-04	0.004	0.0022	0.0009	0.0035	0.002	5E-04	0.005
TDDIn_12	0.00013	1E-05	0.0005	0.0001	2E-05	0.0003	2E-04	1E-05	5E-04	0.0002	6E-05	0.0004	2E-04	2E-05	5E-04
TDDIn_13	0.00028	3E-05	0.0009	0.0004	9E-05	0.0014	7E-04	9E-05	0.002	0.0007	0.0001	0.0017	6E-04	3E-05	0.002
TDDIn_14	0.00014	3E-05	0.0004	0.0001	5E-05	0.0003	1E-04	3E-05	3E-04	0.0001	1E-04	0.0002	1E-04	3E-05	3E-04
TDDIn_15	0.00489	0.0012	0.0089	0.0061	0.0012	0.0109	0.007	0.001	0.012	0.0074	0.0035	0.0111	0.006	0.001	0.011
TDDIn_16	0.00019	3E-05	0.0005	0.0002	5E-05	0.0003	3E-04	3E-05	6E-04	0.0002	9E-05	0.0004	3E-04	5E-05	6E-04
TDDIn_17	0.00116	6E-05	0.0035	0.0013	0.0002	0.0031	0.001	2E-04	0.003	0.0018	0.0002	0.0031	0.001	1E-04	0.003
TDDIn_18	0.0001	2E-05	0.0003	0.0001	3E-05	0.0004	2E-04	2E-05	4E-04	0.0002	7E-05	0.0004	1E-04	3E-05	3E-04
TDDIn_19	0.00068	3E-05	0.0024	0.0008	5E-05	0.0027	0.001	5E-05	0.003	0.001	0.0001	0.0018	0.001	6E-05	0.003
TDDIn_20	0.0001	2E-05	0.0002	0.0001	2E-05	0.0003	1E-04	2E-05	3E-04	0.0001	7E-05	0.0004	1E-04	4E-05	3E-04
TDDIn_21	0.00167	0.0004	0.0033	0.002	0.0004	0.0037	0.002	3E-04	0.004	0.0026	0.0009	0.0041	0.002	1E-04	0.004
TDDIn_22	6.1E-05	1E-05	0.0002	6E-05	2E-05	0.0001	7E-05	1E-05	1E-04	7E-05	4E-05	0.0001	8E-05	2E-05	2E-04
TDDIn_23	0.00032	2E-05	0.001	0.0003	7E-05	0.0007	5E-04	6E-05	0.002	0.0003	7E-05	0.0011	5E-04	5E-05	0.003
TDDIn_24	3.4E-05	1E-05	7E-05	4E-05	1E-05	5E-05	6E-05	7E-06	1E-04	5E-05	3E-05	7E-05	5E-05	2E-05	1E-04
TDDIn_25	0.00034	2E-05	0.0012	0.0005	2E-05	0.0016	0.001	5E-05	0.005	0.0006	7E-05	0.0014	7E-04	2E-05	0.003
TDDIn_26	4.6E-05	1E-05	9E-05	5E-05	1E-05	0.0001	7E-05	1E-05	1E-04	6E-05	3E-05	9E-05	7E-05	2E-05	1E-04
TDDIn_27	0.00047	7E-05	0.0011	0.0007	0.0001	0.0014	1E-03	1E-04	0.003	0.0008	0.0003	0.0015	7E-04	1E-04	0.002
TDDIn_28	3.2E-05	7E-06	7E-05	3E-05	1E-05	5E-05	5E-05	7E-06	2E-04	5E-05	2E-05	7E-05	5E-05	1E-05	2E-04
TDDIn_29	0.00016	1E-05	0.0004	0.0001	3E-05	0.0004	4E-04	3E-05	0.003	0.0002	5E-05	0.0003	3E-04	3E-05	0.001
TDDIn_30	3.6E-05	7E-06	9E-05	4E-05	1E-05	7E-05	7E-05	7E-06	2E-04	6E-05	2E-05	9E-05	7E-05	1E-05	2E-04
TDDIn [%]	5.61733	2.819	7.7714	5.9784	3.5862	7.6506	7.693	2.616	9.673	8.1818	5.3116	9.2895	6.805	3.392	9.106

Appendix B

Results summery of the test system for randomly selected days during monitoring period "1"

2016	Sub-Period 1			Sub-Period 2			Sub-Period 3			Sub-Period 4			Sub-Period 5		
	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max
V1_Avg [V]	235.84	234.02	237.72	234.37	233.50	235.08	232.41	230.53	234.98	233.15	232.50	233.80	232.41	229.03	236.18
V2_Avg [V]	237.62	235.75	239.47	236.04	235.22	236.75	234.34	232.53	236.80	235.16	234.55	235.77	234.57	231.23	238.20
V3_Avg [V]	236.31	234.47	238.20	234.80	233.88	235.52	232.66	230.80	235.25	233.51	232.90	234.13	232.81	229.40	236.68
AVG_V_Avg [V]	236.59	234.74	238.46	235.07	234.20	235.78	233.14	231.29	235.67	233.94	233.32	234.57	233.26	229.89	237.02
In_Avg [A]	9.32	5.56	11.82	8.92	6.22	11.03	9.76	6.99	12.14	10.87	9.78	12.50	11.25	8.24	12.78
I1_Avg [A]	9.39	6.99	30.58	67.36	37.50	99.00	223.43	85.02	328.32	72.95	39.11	115.33	9.45	6.45	40.35
I2_Avg [A]	12.74	9.62	24.58	58.64	30.98	89.69	216.99	77.59	324.55	63.37	31.66	105.28	13.91	11.17	30.25
I3_Avg [A]	10.38	8.20	24.51	61.75	30.93	94.55	220.53	80.18	328.08	65.47	32.04	108.86	11.04	8.70	31.57
AVG_I_Avg [A]	10.84	8.88	26.56	62.58	33.13	94.41	220.32	81.02	326.94	67.26	34.31	109.82	11.47	9.27	34.06
THDV1_Avg [%]	1.60	1.44	1.85	1.56	1.45	1.65	1.22	1.05	1.50	1.35	1.29	1.43	1.27	1.00	1.64
THDV2_Avg [%]	1.41	1.27	1.63	1.40	1.32	1.48	1.10	0.92	1.35	1.19	1.15	1.25	1.11	0.88	1.44
THDV3_Avg [%]	1.48	1.31	1.71	1.47	1.37	1.56	1.18	1.00	1.42	1.28	1.21	1.35	1.18	0.93	1.54
THDI1_Avg [%]	22.99	17.09	30.69	10.05	6.20	16.79	3.77	1.92	10.71	9.94	6.00	14.79	20.38	13.84	32.15
THDI2_Avg [%]	31.42	23.28	38.26	12.08	7.50	19.74	4.49	2.28	12.90	12.50	7.36	18.71	24.07	17.70	35.74
THDI3_Avg [%]	18.11	13.65	33.76	9.14	5.31	16.61	3.36	1.71	9.97	9.42	5.46	14.96	15.05	9.95	38.59
THDIn_Avg [%]	12.96	8.68	20.83	15.24	12.07	19.30	24.14	12.52	35.11	21.12	15.50	26.40	13.97	10.73	25.50
TDDI1_Avg [%]	0.52%	0.36%	1.46%	1.47%	1.34%	1.60%	1.59%	1.25%	1.78%	1.47%	1.18%	1.67%	0.47%	0.27%	1.52%
TDDI2_Avg [%]	0.94%	0.78%	1.50%	1.55%	1.31%	1.75%	1.86%	1.43%	2.10%	1.58%	1.26%	1.85%	0.82%	0.63%	1.46%
TDDI3_Avg [%]	0.43%	0.29%	1.15%	1.08%	0.81%	1.26%	1.31%	0.87%	1.59%	1.12%	0.78%	1.39%	0.36%	0.18%	1.07%
TDDIn_Avg [%]	5.77%	3.78%	7.32%	6.09%	4.83%	7.05%	8.20%	5.80%	9.19%	8.10%	7.67%	8.61%	6.65%	5.38%	8.33%

Appendix C
Harmonic spectrum of phase and neutral currents of the test system for the days in which the system disconnected during monitoring period "1"

2016	TDDI1 for 14,19,20,21,25,26/4/2016														
	Sub-Period 1			Sub-Period 2			Sub-Period 3			Sub-Period 4			Sub-Period 5		
	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max
TDDI1_01	0.1931	0.0004	0.6055	3.8673	0.7131	7.9553	39.2156	4E-06	79.84	6.91276	0.0066	15.8843	0.57545	0.00665	2.29369
TDDI1_02	1E-05	8E-10	7E-05	6E-05	7E-06	0.0002	9.5E-05	8E-10	0.0004	3.5E-05	7E-09	0.00024	1E-05	7.8E-10	9.1E-05
TDDI1_03	0.0038	3E-06	0.0111	0.0093	0.0081	0.0109	0.0065	1E-08	0.0122	0.00731	3E-05	0.01118	0.00343	3.1E-07	0.01173
TDDI1_04	1E-05	1E-07	5E-05	2E-05	5E-06	5E-05	2.1E-05	8E-10	9E-05	8.1E-06	8E-10	2.5E-05	9.1E-06	2.2E-07	3.8E-05
TDDI1_05	0.0017	4E-05	0.0071	0.0022	0.0006	0.0063	0.00468	9E-08	0.0109	0.00363	2E-07	0.00786	0.00146	1.3E-07	0.0083
TDDI1_06	5E-07	8E-10	2E-06	3E-07	8E-10	2E-06	1.7E-06	8E-10	1E-05	7.9E-07	3E-09	4.4E-06	5.6E-07	7.8E-10	1.5E-06
TDDI1_07	0.0016	6E-07	0.0048	0.0029	2E-06	0.0077	0.00237	3E-09	0.0179	0.00187	5E-06	0.01217	0.00134	1.7E-07	0.00496
TDDI1_08	4E-07	8E-10	2E-06	3E-07	8E-10	1E-06	4.4E-06	8E-10	3E-05	1.1E-06	8E-10	3.7E-06	6.8E-07	7.8E-10	7E-06
TDDI1_09	0.0002	3E-07	0.0008	0.0002	4E-08	0.0005	0.00011	8E-10	0.0006	7.2E-05	3E-07	0.0006	9.3E-05	7.8E-10	0.00067
TDDI1_10	6E-07	8E-10	2E-06	2E-06	8E-10	1E-05	1.4E-05	8E-10	5E-05	6.4E-06	1E-08	3.1E-05	4.5E-06	7.8E-10	6.2E-05
TDDI1_11	0.0003	1E-08	0.0012	0.0005	6E-07	0.0017	0.00036	8E-10	0.0011	0.00057	2E-06	0.00282	0.0004	7.8E-10	0.0036
TDDI1_12	6E-08	8E-10	3E-07	7E-07	3E-09	2E-06	3.3E-06	8E-10	3E-05	4.6E-07	8E-10	5E-06	7.6E-07	7.8E-10	1.1E-05
TDDI1_13	0.0003	3E-06	0.0019	0.0016	8E-07	0.0058	0.00222	3E-09	0.0121	0.00093	1E-06	0.00575	0.00036	1.1E-06	0.00263
TDDI1_14	3E-06	8E-10	2E-05	2E-06	1E-08	8E-06	1.5E-06	8E-10	5E-06	9.4E-07	8E-10	2.6E-06	3.4E-07	7.8E-10	1.4E-06
TDDI1_15	1E-05	8E-10	6E-05	3E-05	5E-08	9E-05	4.1E-05	8E-10	0.0002	7.7E-05	2E-07	0.00015	2.1E-05	7.8E-10	9E-05
TDDI1_16	9E-06	8E-10	6E-05	2E-05	2E-08	8E-05	3E-05	8E-10	0.0001	6E-06	3E-09	1.8E-05	5E-06	7.8E-10	2.7E-05
TDDI1_17	0.0008	8E-10	0.003	0.0023	3E-06	0.0074	0.00257	8E-10	0.0071	0.00333	7E-07	0.00728	0.00116	1.2E-08	0.00479
TDDI1_18	3E-07	8E-10	2E-06	6E-07	2E-08	2E-06	6.9E-07	8E-10	3E-06	3.1E-07	8E-10	1.1E-06	1.6E-07	7.8E-10	9E-07
TDDI1_19	4E-05	8E-10	0.0002	0.0003	3E-07	0.0008	0.00033	8E-10	0.0013	0.00035	4E-08	0.00103	0.00023	7.8E-10	0.00113
TDDI1_20	1E-05	8E-10	7E-05	3E-05	1E-05	6E-05	2.1E-05	8E-10	5E-05	2.5E-05	8E-10	4.1E-05	1.4E-05	7.8E-10	5.5E-05
TDDI1_21	1E-06	8E-10	5E-06	2E-06	8E-10	1E-05	2.3E-06	8E-10	1E-05	9E-07	8E-10	3.6E-06	1.8E-06	7.8E-10	6.3E-06
TDDI1_22	3E-06	8E-10	1E-05	4E-06	8E-10	1E-05	3.4E-06	8E-10	1E-05	2.7E-06	8E-10	8.2E-06	2.4E-06	7.8E-10	1.1E-05
TDDI1_23	1E-05	7E-09	8E-05	4E-05	6E-08	0.0001	3.2E-05	8E-10	0.0001	3.6E-05	2E-08	0.00014	2.1E-05	3.1E-09	0.00017
TDDI1_24	2E-08	8E-10	1E-07	4E-08	8E-10	1E-07	1.5E-07	8E-10	5E-07	9.2E-08	8E-10	5.3E-07	2.9E-08	7.8E-10	2.2E-07
TDDI1_25	3E-06	8E-10	9E-06	4E-06	2E-08	1E-05	7E-06	8E-10	2E-05	6E-06	7E-09	1.9E-05	3E-06	7.8E-10	1.2E-05
TDDI1_26	2E-08	8E-10	2E-07	1E-07	8E-10	5E-07	1.5E-07	8E-10	7E-07	4.7E-08	8E-10	3.4E-07	2.2E-08	7.8E-10	1.5E-07
TDDI1_27	4E-07	8E-10	2E-06	8E-07	8E-10	5E-06	3.5E-07	8E-10	2E-06	3.8E-07	3E-09	1.6E-06	5E-07	7.8E-10	2.7E-06
TDDI1_28	1E-07	8E-10	1E-06	4E-07	3E-09	1E-06	3E-07	8E-10	1E-06	1.5E-07	8E-10	5.7E-07	4.5E-08	7.8E-10	1.7E-07
TDDI1_29	1E-06	8E-10	5E-06	4E-06	8E-10	1E-05	2.9E-06	8E-10	9E-06	4E-06	1E-08	1.3E-05	3.9E-06	3.1E-09	1.7E-05
TDDI1_30	4E-09	8E-10	1E-08	3E-09	8E-10	1E-08	3.9E-09	8E-10	1E-08	2.4E-09	8E-10	7E-09	3.3E-09	7.8E-10	1.2E-08
TDDI1 [%]	0.7721	0.2863	1.6128	1.3787	1.1905	1.7257	1.03002	0.0013	2.2056	1.23773	0.0648	1.98289	0.69208	0.06867	1.69965

2016	TDDI2 for 14,19,20,21,25,26/4/2016														
	Sub-Period 1			Sub-Period 2			Sub-Period 3			Sub-Period 4			Sub-Period 5		
	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max
TDDI2_01	0.1455	0.0116	0.4352	3.0601	0.377	6.7023	37.449	0.0342	79.655	5.90321	0.1145	14.2323	0.3962	0.00011	1.48243
TDDI2_02	3E-05	8E-10	0.0001	0.0001	8E-08	0.0004	0.0006	9E-07	0.0019	0.00013	7E-06	0.00037	2.3E-05	8E-08	8.4E-05
TDDI2_03	0.0091	0.0051	0.015	0.0122	0.0094	0.0146	0.008	3E-07	0.0204	0.0089	7E-07	0.01778	0.00585	0.00022	0.0165
TDDI2_04	2E-05	8E-10	6E-05	5E-05	3E-05	7E-05	6E-05	8E-10	0.0002	3.8E-05	2E-07	7.9E-05	1.9E-05	8E-10	5.8E-05
TDDI2_05	0.0002	8E-10	0.0019	0.0033	8E-07	0.0093	0.0072	1E-05	0.0181	0.00565	3E-05	0.01298	0.00106	2.3E-06	0.00517
TDDI2_06	7E-07	8E-10	6E-06	5E-07	8E-10	4E-06	3E-06	8E-10	2E-05	1.7E-06	8E-10	7.8E-06	1.6E-06	8E-10	2.2E-05
TDDI2_07	0.0005	5E-07	0.0038	0.0013	8E-07	0.01	0.0035	6E-08	0.0193	0.00181	4E-06	0.0137	0.00074	9.2E-07	0.0055
TDDI2_08	1E-06	8E-10	8E-06	9E-06	1E-07	2E-05	7E-06	8E-10	2E-05	5.6E-06	1E-08	1.7E-05	3.4E-06	8E-10	2E-05
TDDI2_09	0.0003	8E-06	0.0008	0.0002	9E-06	0.0005	9E-05	8E-10	0.0004	0.00012	5E-06	0.00042	9.9E-05	1.3E-08	0.00037
TDDI2_10	2E-06	8E-10	1E-05	1E-05	2E-06	3E-05	4E-05	4E-08	0.0002	2.5E-05	2E-08	6E-05	8.5E-06	8E-10	9.5E-05
TDDI2_11	6E-05	8E-10	0.0003	0.0005	2E-07	0.002	0.0003	3E-09	0.0008	0.00024	9E-07	0.00071	0.00032	1.3E-08	0.00261
TDDI2_12	4E-07	8E-10	2E-06	9E-07	8E-10	3E-06	3E-06	8E-10	3E-05	1.8E-06	3E-09	1.7E-05	2E-06	8E-10	2.3E-05
TDDI2_13	0.0008	3E-09	0.0067	0.0027	0.0001	0.0074	0.003	8E-10	0.0163	0.00187	1E-06	0.01142	0.00072	8E-10	0.00517
TDDI2_14	2E-06	8E-10	1E-05	1E-05	3E-08	5E-05	8E-06	8E-10	4E-05	7.7E-06	4E-08	2.1E-05	2.7E-06	8E-10	1.2E-05
TDDI2_15	6E-05	8E-10	0.0003	0.0001	2E-06	0.0005	7E-05	8E-10	0.0004	0.0001	8E-10	0.00039	9.6E-05	8E-10	0.00042
TDDI2_16	2E-05	8E-10	0.0002	9E-05	3E-06	0.0003	9E-05	8E-10	0.0003	6.7E-05	8E-10	0.00013	2.4E-05	8E-10	0.00012
TDDI2_17	0.0006	5E-07	0.0024	0.0022	2E-05	0.0073	0.0022	2E-08	0.0071	0.0026	9E-07	0.00653	0.00088	3.2E-09	0.00378
TDDI2_18	2E-06	8E-10	9E-06	7E-06	2E-07	2E-05	2E-06	8E-10	2E-05	3.6E-06	7E-09	2.3E-05	3.6E-06	8E-10	2.7E-05
TDDI2_19	8E-05	8E-10	0.0004	0.0003	5E-06	0.001	0.0006	3E-07	0.0024	0.0008	9E-07	0.00264	0.0002	8E-10	0.00083
TDDI2_20	5E-06	8E-10	3E-05	6E-06	3E-09	2E-05	5E-06	8E-10	1E-05	3.7E-06	8E-10	1.1E-05	2.2E-06	8E-10	1.2E-05
TDDI2_21	5E-06	8E-10	2E-05	9E-06	4E-08	4E-05	2E-05	3E-09	7E-05	1.6E-05	5E-08	6E-05	1.3E-05	8E-10	8.3E-05
TDDI2_22	1E-06	8E-10	8E-06	1E-06	8E-10	5E-06	2E-06	8E-10	6E-06	1.2E-06	8E-10	5E-06	3.5E-07	8E-10	2.1E-06
TDDI2_23	2E-05	8E-10	9E-05	2E-05	1E-08	7E-05	3E-05	7E-09	0.0001	2.6E-05	2E-07	8.7E-05	1.8E-05	8E-10	0.00011
TDDI2_24	2E-07	8E-10	1E-06	3E-07	8E-10	3E-06	2E-07	8E-10	1E-06	1.2E-07	8E-10	5.4E-07	1E-07	8E-10	5.4E-07
TDDI2_25	1E-06	8E-10	5E-06	7E-06	6E-08	2E-05	9E-06	8E-10	3E-05	5.9E-06	3E-09	2.4E-05	1.8E-06	8E-10	7.5E-06
TDDI2_26	5E-08	8E-10	4E-07	2E-07	8E-10	1E-06	2E-07	8E-10	9E-07	4.8E-08	8E-10	2.9E-07	2.6E-08	8E-10	9.6E-08
TDDI2_27	3E-07	8E-10	1E-06	3E-07	8E-10	1E-06	6E-07	8E-10	2E-06	3.8E-07	1E-08	1.1E-06	5.7E-07	8E-10	2E-06
TDDI2_28	7E-08	8E-10	4E-07	5E-07	1E-08	1E-06	3E-07	8E-10	1E-06	2.5E-07	8E-10	6.7E-07	8.1E-08	8E-10	4.2E-07
TDDI2_29	8E-07	3E-09	3E-06	3E-06	3E-08	1E-05	4E-06	8E-10	1E-05	2.8E-06	5E-08	9.5E-06	2.6E-06	7.2E-09	1E-05
TDDI2_30	3E-09	8E-10	1E-08	1E-08	8E-10	6E-08	3E-08	8E-10	1E-07	4.9E-09	8E-10	1.3E-08	7.3E-09	8E-10	2.9E-08
TDDI2 [%]	1.038	0.7233	1.6564	1.5129	1.1539	1.8968	1.2256	0.1408	2.5551	1.37017	0.1043	2.28235	0.86141	0.22595	1.70527

2016	TDDI3 for 14,19,20,21,25,26/4/2016														
	Sub-Period 1			Sub-Period 2			Sub-Period 3			Sub-Period 4			Sub-Period 5		
	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max
TDDI3_01	0.1229	6E-05	0.3716	3.3215	0.4239	7.046	38.599	0.0007	79.475	6.15546	0.0001	15.0658	0.42519	0.00039	1.735
TDDI3_02	9E-05	3E-05	0.0003	0.0001	3E-06	0.0003	0.0007	3E-07	0.0022	7.7E-05	1E-07	0.00052	6.8E-05	7.4E-06	0.00018
TDDI3_03	0.0011	3E-07	0.0029	0.0009	0.0003	0.0021	0.0004	2E-07	0.0021	0.00046	3E-07	0.00175	0.00037	3.1E-09	0.002
TDDI3_04	8E-06	7E-09	2E-05	2E-05	5E-06	3E-05	5E-05	8E-08	0.0001	1.6E-05	2E-08	3.3E-05	9.1E-06	1.1E-07	2.7E-05
TDDI3_05	0.0009	1E-08	0.0043	0.0027	6E-06	0.0072	0.0051	8E-08	0.0162	0.00424	5E-08	0.0109	0.00095	1.7E-07	0.00391
TDDI3_06	4E-06	8E-10	2E-05	3E-06	7E-09	9E-06	5E-06	8E-10	2E-05	2.9E-06	3E-09	1E-05	3.1E-06	3.1E-09	1.2E-05
TDDI3_07	0.0009	9E-07	0.0031	0.0026	0.0002	0.0078	0.0039	2E-07	0.0178	0.00175	5E-08	0.01202	0.00085	3.1E-09	0.00445
TDDI3_08	6E-06	2E-07	3E-05	2E-05	8E-06	4E-05	9E-06	8E-10	3E-05	8.7E-06	8E-10	1.9E-05	4.2E-06	7.7E-10	1.4E-05
TDDI3_09	0.0002	4E-05	0.0006	0.0001	2E-05	0.0005	3E-05	3E-09	0.0001	1.1E-05	7E-09	6.4E-05	4.9E-05	7.7E-10	0.0003
TDDI3_10	2E-06	8E-10	1E-05	2E-06	8E-10	7E-06	2E-05	8E-10	0.0002	1.1E-05	3E-09	8.7E-05	9.9E-06	7.7E-10	0.00012
TDDI3_11	0.0002	5E-07	0.001	0.0012	0.0001	0.0026	0.0004	8E-10	0.0015	0.00066	2E-08	0.00163	0.00056	2E-06	0.0036
TDDI3_12	9E-07	8E-10	4E-06	2E-06	3E-09	1E-05	2E-06	8E-10	6E-06	9.2E-07	8E-10	7.1E-06	3.2E-06	7.7E-10	1.5E-05
TDDI3_13	0.0007	3E-09	0.0036	0.0019	7E-05	0.004	0.0026	8E-10	0.0129	0.00103	7E-09	0.00549	0.00065	7.7E-10	0.00371
TDDI3_14	3E-06	8E-10	2E-05	8E-06	4E-08	3E-05	8E-06	8E-10	3E-05	5.9E-06	7E-09	1.8E-05	5.3E-06	7.7E-10	3.9E-05
TDDI3_15	4E-05	8E-10	0.0003	7E-05	2E-08	0.0005	0.0001	8E-10	0.0008	0.00021	3E-09	0.00083	6.3E-05	7.7E-08	0.00046
TDDI3_16	4E-05	8E-10	0.0002	0.0001	2E-05	0.0003	8E-05	8E-10	0.0002	5.8E-05	3E-09	0.00012	4.1E-05	7.7E-10	0.00016
TDDI3_17	0.0005	8E-10	0.0018	0.0017	2E-05	0.0047	0.0021	8E-10	0.0084	0.00303	8E-10	0.00769	0.00087	7.7E-10	0.00361
TDDI3_18	4E-06	8E-10	2E-05	1E-05	5E-08	4E-05	3E-06	8E-10	1E-05	2.9E-06	7E-09	1.4E-05	7.5E-06	7.7E-10	3.7E-05
TDDI3_19	7E-05	8E-10	0.0003	0.0001	3E-07	0.0004	0.0002	3E-09	0.0006	0.00013	8E-10	0.00059	8.2E-05	3.1E-09	0.00037
TDDI3_20	7E-06	3E-09	4E-05	2E-05	2E-06	3E-05	1E-05	8E-10	3E-05	1.3E-05	8E-10	4.5E-05	1E-05	7.7E-10	4.5E-05
TDDI3_21	1E-05	8E-10	6E-05	3E-05	7E-07	9E-05	2E-05	8E-10	7E-05	2.7E-05	8E-10	7.6E-05	2.4E-05	7.7E-08	0.00011
TDDI3_22	6E-07	8E-10	3E-06	7E-07	8E-10	4E-06	4E-07	8E-10	2E-06	2.8E-07	8E-10	1.9E-06	7.3E-07	7.7E-10	3.9E-06
TDDI3_23	1E-05	8E-10	6E-05	2E-05	3E-09	6E-05	2E-05	8E-10	0.0001	2.3E-05	4E-08	1E-04	2.1E-05	3.1E-09	0.0001
TDDI3_24	2E-07	8E-10	1E-06	4E-07	8E-10	1E-06	2E-07	8E-10	1E-06	1.8E-07	8E-10	6.5E-07	6.6E-08	7.7E-10	2.8E-07
TDDI3_25	1E-06	8E-10	6E-06	6E-06	8E-10	2E-05	1E-05	8E-10	4E-05	4E-06	8E-10	2.2E-05	4.2E-06	7.7E-10	1.8E-05
TDDI3_26	3E-08	8E-10	2E-07	4E-08	8E-10	2E-07	2E-07	8E-10	7E-07	5.1E-08	8E-10	2.5E-07	4.6E-08	7.7E-10	2.8E-07
TDDI3_27	4E-07	8E-10	9E-07	3E-07	3E-09	1E-06	1E-06	8E-10	6E-06	3.1E-07	8E-10	8.9E-07	1.1E-06	7.7E-10	5.3E-06
TDDI3_28	4E-08	8E-10	2E-07	7E-08	8E-10	3E-07	1E-07	8E-10	7E-07	6E-08	8E-10	2.5E-07	5.7E-08	7.7E-10	2.8E-07
TDDI3_29	2E-06	8E-10	1E-05	3E-06	8E-10	8E-06	8E-06	8E-10	2E-05	1.2E-06	8E-10	5.7E-06	1.8E-06	7.7E-10	7.6E-06
TDDI3_30	7E-09	8E-10	2E-08	2E-08	8E-10	6E-08	3E-08	8E-10	1E-07	7E-09	8E-10	2.8E-08	6.8E-09	7.7E-10	2.8E-08
TDDI3 [%]	0.594	0.2431	1.12	1.0419	0.7035	1.37	0.9444	0.0212	1.9786	0.98787	0.0078	1.66231	0.48247	0.10872	1.2802

2016	TDDIn for 14,19,20,21,25,26/4/2016														
	Sub-Period 1			Sub-Period 2			Sub-Period 3			Sub-Period 4			Sub-Period 5		
	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max
TDDIn_01	19.006	2.9849	38.085	18.856	2.5107	36.261	31.555	1.8836	100	29.5345	18.195	52.9525	31.9117	7.91733	73.2587
TDDIn_02	0.1016	0.0181	0.1814	0.119	0.0242	0.2008	0.1309	0.0222	0.2144	0.13976	0.0854	0.18842	0.12363	0.04849	0.1768
TDDIn_03	0.2095	0.0259	0.4064	0.2474	0.038	0.4412	0.5027	0.0369	1.0164	0.54187	0.2229	0.82121	0.34102	0.06694	0.63812
TDDIn_04	0.0008	0.0002	0.0015	0.0009	0.0003	0.0014	0.0015	0.0002	0.0034	0.00151	0.0009	0.00193	0.00133	0.00047	0.00197
TDDIn_05	0.0233	0.0004	0.0511	0.0269	0.0092	0.0841	0.0367	0.0024	0.1112	0.03139	0.008	0.10233	0.03793	0.00871	0.14246
TDDIn_06	0.001	0.0002	0.0017	0.001	0.0002	0.0017	0.0014	0.0002	0.0023	0.0016	0.001	0.00214	0.00137	0.0004	0.00197
TDDIn_07	0.0022	0.0003	0.0066	0.0027	0.0004	0.0086	0.0034	0.0003	0.0168	0.00248	0.0004	0.00949	0.00274	0.00022	0.01115
TDDIn_08	0.0004	2E-05	0.0008	0.0004	2E-05	0.0008	0.0005	2E-05	0.0008	0.00043	0.0002	0.00062	0.00039	8.2E-05	0.00064
TDDIn_09	0.0123	0.0023	0.0254	0.0129	0.0019	0.0253	0.0179	0.0016	0.0325	0.01702	0.0068	0.03091	0.01526	0.00276	0.03451
TDDIn_10	0.0003	4E-05	0.0006	0.0003	5E-05	0.0005	0.0003	5E-05	0.0006	0.00035	0.0002	0.00056	0.00028	0.00012	0.00058
TDDIn_11	0.0009	3E-05	0.0019	0.0008	0.0002	0.0017	0.0011	0.0003	0.0042	0.001	0.0004	0.00301	0.00183	0.0004	0.0088
TDDIn_12	0.0002	1E-05	0.0004	0.0002	1E-05	0.0003	0.0002	1E-05	0.0005	0.00029	8E-05	0.00049	0.00032	2.5E-05	0.0006
TDDIn_13	0.0003	5E-05	0.0013	0.0005	9E-05	0.0021	0.0015	7E-05	0.0061	0.00129	0.0002	0.00347	0.00115	4.6E-05	0.00665
TDDIn_14	0.0002	2E-05	0.0004	0.0001	2E-05	0.0003	0.0002	2E-05	0.0003	0.00014	9E-05	0.00027	0.00016	5.9E-05	0.0003
TDDIn_15	0.0051	0.0011	0.0097	0.0063	0.0011	0.0103	0.0074	0.0012	0.0115	0.00781	0.0055	0.01067	0.00628	0.00253	0.0161
TDDIn_16	0.0002	3E-05	0.0005	0.0002	2E-05	0.0004	0.0003	3E-05	0.0005	0.00029	0.0001	0.00043	0.00033	8.2E-05	0.00069
TDDIn_17	0.0006	1E-04	0.0015	0.0009	0.0002	0.0021	0.0011	0.0002	0.0035	0.00148	0.0001	0.00316	0.00109	0.00011	0.0042
TDDIn_18	0.0001	2E-05	0.0003	0.0002	2E-05	0.0004	0.0002	2E-05	0.0005	0.00022	9E-05	0.00043	0.00019	4.6E-05	0.00042
TDDIn_19	0.001	3E-05	0.0027	0.0012	2E-05	0.0031	0.0015	0.0001	0.003	0.00134	0.0003	0.00239	0.00182	7.4E-05	0.01115
TDDIn_20	0.0001	2E-05	0.0003	0.0001	2E-05	0.0003	0.0001	1E-05	0.0002	0.00014	6E-05	0.00025	0.00021	4.6E-05	0.00098
TDDIn_21	0.0019	0.0003	0.0036	0.0025	0.0003	0.0047	0.002	0.0001	0.0046	0.00212	0.0003	0.00352	0.00188	0.00013	0.00456
TDDIn_22	7E-05	1E-05	0.0001	7E-05	1E-05	0.0001	1E-04	7E-06	0.0002	0.00011	6E-05	0.00017	0.0001	3E-05	0.00025
TDDIn_23	0.0001	4E-05	0.0004	0.0001	5E-05	0.0004	0.0012	8E-05	0.0041	0.00069	0.0001	0.00352	0.00103	5.3E-05	0.00462
TDDIn_24	4E-05	1E-05	6E-05	4E-05	7E-06	7E-05	7E-05	7E-06	0.0001	5.8E-05	5E-05	9.1E-05	5.7E-05	2.5E-05	0.00014
TDDIn_25	0.0006	2E-05	0.0013	0.0009	3E-05	0.0019	0.0016	3E-05	0.0038	0.0011	0.0002	0.00253	0.00101	3.5E-05	0.00231
TDDIn_26	5E-05	1E-05	1E-04	5E-05	1E-05	0.0001	7E-05	7E-06	1E-04	7.2E-05	5E-05	9.9E-05	7.5E-05	2.5E-05	0.00014
TDDIn_27	0.0005	1E-04	0.0011	0.0008	0.0001	0.0016	0.0009	0.0002	0.0016	0.00082	0.0003	0.00141	0.00069	0.00018	0.00181
TDDIn_28	3E-05	7E-06	5E-05	3E-05	7E-06	5E-05	8E-05	5E-06	0.0002	7.5E-05	5E-05	0.00016	8.2E-05	2.1E-05	0.0003
TDDIn_29	7E-05	2E-05	0.0003	7E-05	2E-05	0.0003	0.0003	4E-05	0.0009	0.00023	5E-05	0.00076	0.00027	3E-05	0.00098
TDDIn_30	4E-05	1E-05	7E-05	4E-05	7E-06	7E-05	8E-05	7E-06	0.0002	8.5E-05	4E-05	0.0002	8E-05	2.1E-05	0.00018
TDDIn [%]	5.7546	2.6496	8.0374	6.3317	2.8789	8.423	8.1823	2.8102	11.084	8.63994	7.1232	10.1913	7.10616	4.15264	9.18207

Appendix D
Phase loading during disconnection times

14/04/2016				
	I1	I2	I3	In
9:55 AM	64.88	72.18	68.11	9.63
10:05 AM	0	9.643	0	10.66
10:15 AM	0	9.616	0	10.64
10:25 AM	0	10.77	0	11.82
10:35 AM	0	9.645	0	10.66
10:45 AM	1.221	9.696	0	10.55
10:55 AM	1.086	7.651	2.395	7.83
11:05 AM	0	9.985	0	10.98
11:15 AM	0	6.771	0	7.46
11:25 AM	0	10.88	0	11.89
11:35 AM	0	6.768	0	7.46
11:45 AM	0	7.585	0	8.36
11:55 AM	0	9.06	0	9.96
12:05 PM	2.337	7.945	0	8.41
12:15 PM	0	8.178	0	9.08
12:25 PM	128	129.1	128.1	7.50

19/04/2016				
	I1	I2	I3	In
1:05 PM	120.6	122.7	117.5	8.712
1:15 PM	12.08	15.05	0	13.86
1:25 PM	11.68	15.56	0	14.16
1:35 PM	11.74	15.72	0	14.25
1:45 PM	11.6	14.63	0	13.45
1:55 PM	11.78	15.36	0	14.02
2:05 PM	9.861	15.75	0.971	14.56
2:15 PM	3.029	17.85	5.944	16.9
2:25 PM	0	23.14	6.137	22.5
2:35 PM	2.398	23.03	4.418	22.25
2:45 PM	0.904	16.18	6.533	15.76
2:55 PM	0	18.41	5.569	18.46
3:05 PM	4.91	19	7.381	17.33
3:15 PM	129.6	124	127.2	12.33

21/04/2016				
	I1	I2	I3	In
10:15 AM	304.9	300.6	304.1	11.17
10:25 AM	57.46	68.9	65.63	13.89
10:35 AM	0	15.35	10.64	14.65
10:45 AM	2.924	15.31	7.591	13.27
10:55 AM	0	14.61	7.49	14.40
11:05 AM	1.49	15.19	7.407	14.00
11:15 AM	1.43	15.43	4.715	15.29
11:25 AM	0	14.66	6.902	14.65
11:35 AM	0.435	15.15	4.284	15.36
11:45 AM	2.567	15.57	6.285	13.85
11:55 AM	0	14.7	5.361	14.87
12:05 PM	0.912	15.28	4.344	15.42
12:15 PM	2.06	15.86	6.455	14.46
12:25 PM	0	14.96	5.254	15.12
12:35 PM	0	15.34	4.416	15.62
12:45 PM	2.948	15.62	6.551	14.77
12:55 PM	93.34	98.29	96.11	14.78

25/04/2016				
	I1	I2	I3	In
11:45 AM	227.4	227.2	227.9	10.71
11:55 AM	0	15.09	11.03	14.52
12:05 PM	0	15.66	11.16	15.02
12:15 PM	0	15.18	11.12	14.62
12:25 PM	2.983	14.78	11.15	12.29
12:35 PM	0	15.57	11.11	14.94
12:45 PM	0	15.2	11.12	14.64
12:55 PM	0	14.68	5.483	14.9
1:05 PM	3.064	15.57	6.819	14.88
1:15 PM	0	15.35	7.742	15.26
1:25 PM	0	14.68	4.816	14.93
1:35 PM	0	15.48	7.43	15.53
1:45 PM	2.961	15.22	7.031	13.49
1:55 PM	0.077	14.62	5.063	14.85
2:05 PM	0	15.36	5.952	15.31
2:15 PM	0	15.11	6.129	15.08
2:25 PM	3.142	14.82	9.864	14.45
2:35 PM	204.4	198.4	202.7	14.28

20/04/2016				
	I1	I2	I3	In
3:05 PM	95.21	95.59	91.53	8.938
3:15 PM	11.86	15.53	0	14.17
3:25 PM	11.69	15.88	0	14.39
3:35 PM	11.84	15.1	0	13.84
3:45 PM	11.63	12.25	0.39	13.14
3:55 PM	11.29	14.95	2.899	12.64
4:05 PM	3.052	15.53	7.544	14.42
4:15 PM	0	15.57	6.936	15.39
4:25 PM	0	16.25	5.101	16.57
4:35 PM	3.053	15.31	7.749	13.16
4:45 PM	0	15.15	6.059	15.19
4:55 PM	3.749	16.11	6.568	15.15
5:05 PM	15.34	16.76	13.93	13.02

26/04/2016				
	I1	I2	I3	In
1:25 PM	196.3	197.4	196	10.4
1:35 PM	0.488	14.73	11.23	13.92
1:45 PM	0	15.25	11.07	14.66
1:55 PM	2.951	15.54	11.03	12.89
2:05 PM	0	14.61	11.1	14.14
2:15 PM	0	15.07	11.09	14.51
2:25 PM	0	15.35	10.99	14.74
2:35 PM	1.8	17.67	10.83	15.49
2:45 PM	1.145	22.37	10.8	19.73
2:55 PM	0	22.5	10.86	20.54
3:05 PM	0	18.98	8.023	18.3
3:15 PM	3.564	20.2	12.85	18.53
3:25 PM	139.9	130.3	134.3	12.96

Appendix E
Results summery of the test system for disconnection days during monitoring period "1"

2016	Sub-Period 1			Sub-Period 2			Sub-Period 3			Sub-Period 4			Sub-Period 5		
	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max
V1_Avg [V]	236.58	234.57	237.65	235.08	233.82	236.17	230.60	227.70	234.17	231.04	230.60	231.50	230.55	227.48	233.92
V2_Avg [V]	238.84	237.02	239.98	237.30	236.05	238.30	232.87	229.97	236.32	233.43	233.00	233.88	233.14	230.15	236.48
V3_Avg [V]	237.18	235.15	238.30	235.64	234.38	236.67	230.96	228.22	234.67	231.61	231.15	232.08	231.04	228.00	234.55
AVG_V_Avg [V]	237.53	235.58	238.64	236.01	234.75	237.04	231.48	228.64	235.05	232.03	231.58	232.49	231.58	228.55	234.98
In_Avg [A]	9.39	5.98	12.26	9.93	7.63	11.88	11.46	8.26	16.75	12.71	11.81	13.81	12.63	9.34	15.39
I1_Avg [A]	9.63	6.99	33.83	76.19	44.76	112.33	211.45	2.45	312.00	70.47	38.49	102.64	9.48	6.14	36.33
I2_Avg [A]	13.07	9.93	25.97	66.68	35.74	102.84	186.30	13.39	307.60	62.76	31.48	94.79	14.84	11.93	27.18
I3_Avg [A]	10.52	8.26	26.18	70.62	38.27	107.95	202.66	18.67	311.10	64.09	31.82	96.44	11.99	9.06	28.82
AVG_I_Avg [A]	11.07	9.14	28.66	71.16	39.61	107.71	187.02	6.79	310.11	65.64	34.24	97.60	12.09	9.26	30.64
THDV1_Avg [%]	1.35	1.14	1.53	1.23	1.06	1.40	0.81	0.64	1.04	0.85	0.80	0.91	0.99	0.78	1.29
THDV2_Avg [%]	0.82	0.69	0.88	0.77	0.72	0.82	0.74	0.62	0.92	0.79	0.74	0.85	0.77	0.63	0.91
THDV3_Avg [%]	1.18	0.93	1.33	1.08	0.95	1.24	0.85	0.67	1.05	0.80	0.75	0.88	0.87	0.66	1.15
THDI1_Avg [%]	24.91	15.33	30.21	7.73	5.05	11.47	2.91	0.78	9.47	7.35	4.57	12.11	19.03	11.35	29.58
THDI2_Avg [%]	32.99	20.26	39.93	10.16	6.42	15.42	4.48	2.32	11.57	9.32	5.86	15.48	20.56	13.00	30.70
THDI3_Avg [%]	19.58	14.05	28.32	6.94	4.50	10.44	3.13	1.65	8.44	6.92	3.81	12.18	13.05	8.75	31.83
THDIn_Avg [%]	12.66	9.65	20.30	15.72	12.16	21.94	22.13	10.62	35.85	19.50	15.48	23.67	13.65	10.06	23.90
TDDI1_Avg [%]	0.54%	0.33%	1.61%	1.66%	1.54%	1.79%	1.57%	1.20%	1.77%	1.56%	1.47%	1.62%	0.42%	0.20%	1.47%
TDDI2_Avg [%]	1.03%	0.88%	1.51%	1.69%	1.53%	1.87%	1.73%	1.30%	1.95%	1.53%	1.36%	1.69%	0.79%	0.35%	1.30%
TDDI3_Avg [%]	0.52%	0.36%	1.33%	1.41%	1.25%	1.52%	1.29%	0.85%	1.50%	1.34%	1.22%	1.44%	0.44%	0.31%	1.23%
TDDIn_Avg [%]	26.91%	17.74%	33.42%	18.81%	14.54%	25.18%	20.40%	9.39%	26.21%	12.83%	8.30%	16.45%	19.18%	13.36%	25.34%

Appendix F
Results obtained of the test system during whole monitoring period "1"

2016	Sub-Period 1			Sub-Period 2			Sub-Period 3			Sub-Period 4			Sub-Period 5		
	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max
V1_Avg [V]	236.26	234.12	238.23	235.26	234.21	236.15	232.92	230.90	235.40	232.22	230.21	233.79	231.91	221.48	235.65
V2_Avg [V]	238.43	236.33	240.31	237.26	236.23	238.15	235.07	233.13	237.43	234.44	232.44	236.00	234.27	223.84	237.87
V3_Avg [V]	236.81	234.67	238.80	235.71	234.63	236.63	233.17	231.23	235.70	232.59	230.60	234.11	232.32	221.88	236.16
AVG_V_Avg [V]	237.17	235.04	239.11	236.08	235.03	236.97	233.72	231.76	236.17	233.08	231.09	234.63	232.83	222.40	236.55
In_Avg [A]	9.31	5.27	12.03	9.19	6.74	11.31	9.87	7.20	12.17	11.04	9.63	12.54	11.47	7.85	13.17
I1_Avg [A]	9.68	6.97	32.01	65.75	39.74	95.72	220.13	86.61	317.99	76.21	45.02	111.77	9.74	6.14	40.57
I2_Avg [A]	12.97	9.69	25.40	57.03	32.14	87.02	213.54	77.82	314.07	65.92	35.61	101.78	14.19	10.84	30.26
I3_Avg [A]	10.66	8.29	25.51	60.05	33.21	91.20	217.03	80.56	317.13	68.58	37.16	105.08	11.37	8.55	31.81
AVG_I_Avg [A]	11.11	8.99	27.61	60.94	35.03	91.29	216.90	81.73	316.38	70.24	39.28	106.21	11.77	9.05	34.21
THDV1_Avg [%]	1.37	1.23	1.61	1.35	1.24	1.46	1.05	0.88	1.30	1.18	1.12	1.24	1.16	0.91	1.47
THDV2_Avg [%]	0.97	0.86	1.17	0.99	0.92	1.05	0.80	0.64	1.03	0.91	0.87	0.95	0.88	0.69	1.15
THDV3_Avg [%]	1.17	1.04	1.42	1.20	1.10	1.29	1.01	0.81	1.27	1.07	1.01	1.13	1.03	0.78	1.36
THDI1_Avg [%]	24.00	16.84	30.84	10.23	6.94	15.11	3.56	1.83	9.20	8.66	5.65	12.55	19.99	12.87	31.77
THDI2_Avg [%]	32.32	22.29	42.44	12.98	8.55	19.10	4.43	2.30	11.62	11.26	7.04	16.82	23.23	16.39	34.06
THDI3_Avg [%]	18.87	13.99	32.21	9.57	6.24	14.93	3.37	1.73	9.19	8.15	5.29	12.03	14.38	9.40	34.82
THDIn_Avg [%]	12.93	8.95	19.59	15.18	12.04	19.41	23.98	12.93	35.49	20.48	15.31	25.65	14.07	10.30	23.34
TDDI1_Avg [%]	0.56%	0.34%	1.47%	1.44%	1.32%	1.55%	1.50%	1.29%	1.67%	1.41%	1.23%	1.54%	0.45%	0.26%	1.41%
TDDI2_Avg [%]	0.98%	0.80%	1.47%	1.57%	1.39%	1.72%	1.81%	1.49%	2.02%	1.51%	1.29%	1.69%	0.79%	0.61%	1.35%
TDDI3_Avg [%]	0.46%	0.31%	1.08%	1.10%	0.92%	1.24%	1.30%	0.91%	1.54%	1.08%	0.84%	1.28%	0.35%	0.19%	0.96%
TDDIn_Avg [%]	5.74%	3.77%	7.16%	6.22%	4.99%	7.24%	8.22%	6.04%	9.30%	7.83%	7.12%	8.39%	6.47%	4.93%	8.13%

Appendix G
Harmonic spectrum of phase and neutral currents of the test system for randomly selected days during monitoring period "2"

2017	TDDI1 for 10,11,13,22,28/4/2017+2/5/2017														
	Sub-Period 1			Sub-Period 2			Sub-Period 3			Sub-Period 4			Sub-Period 5		
	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max
TDDI1_01	0.2089	0.00053	1.0489	3.7751	0.2766	10.966	45.194	0.0153	94.818	6.4011	1.383	16.341	0.366	0.0011	1.40202
TDDI1_02	2E-05	3.2E-08	0.0002	0.0002	9E-08	0.0006	0.0008	2E-08	0.0019	0.0002	3E-06	0.0004	3E-05	9E-10	0.00017
TDDI1_03	0.0051	2.2E-08	0.018	0.0109	0.0004	0.015	0.009	5E-05	0.015	0.0127	0.0089	0.016	0.0049	4E-07	0.01556
TDDI1_04	1E-05	2.9E-07	4E-05	3E-05	1E-05	6E-05	9E-05	1E-06	0.0002	3E-05	3E-06	6E-05	1E-05	9E-10	3.2E-05
TDDI1_05	0.0009	8.9E-10	0.0037	0.0038	0.0004	0.0099	0.0074	7E-07	0.0166	0.0049	0.0011	0.0115	0.0009	2E-07	0.00402
TDDI1_06	3E-07	8.9E-10	1E-06	5E-07	8E-09	3E-06	1E-06	9E-10	6E-06	1E-06	9E-08	3E-06	7E-07	9E-10	6.4E-06
TDDI1_07	0.0019	3.6E-07	0.0089	0.004	3E-05	0.0089	0.0019	2E-05	0.0065	0.0017	6E-05	0.0047	0.0017	2E-08	0.00599
TDDI1_08	7E-07	8.9E-10	7E-06	3E-06	9E-10	9E-06	7E-06	9E-10	4E-05	3E-06	4E-09	1E-05	1E-06	9E-10	7.7E-06
TDDI1_09	0.0001	2.7E-05	0.0003	0.0002	7E-05	0.0003	0.0001	4E-09	0.0004	0.0002	5E-05	0.0003	9E-05	8E-09	0.0002
TDDI1_10	1E-06	8.9E-10	5E-06	3E-06	3E-08	1E-05	2E-05	8E-09	4E-05	5E-06	4E-08	1E-05	2E-06	9E-10	1E-05
TDDI1_11	0.0002	5.6E-06	0.0011	0.001	0.0001	0.0029	0.0009	2E-08	0.0034	0.0021	0.0009	0.005	0.0005	1E-06	0.00263
TDDI1_12	1E-07	8.9E-10	1E-06	3E-07	4E-09	8E-07	4E-07	9E-10	2E-06	2E-07	9E-10	5E-07	2E-07	9E-10	7E-07
TDDI1_13	0.0002	8.9E-10	0.0011	0.0009	6E-06	0.0029	0.001	1E-07	0.0039	0.0013	1E-06	0.0031	0.0002	9E-10	0.00102
TDDI1_14	3E-07	8.9E-10	3E-06	2E-06	9E-10	1E-05	7E-07	9E-10	5E-06	1E-06	6E-08	3E-06	1E-06	9E-10	8.2E-06
TDDI1_15	4E-05	1.9E-06	0.0002	0.0001	6E-07	0.0003	0.0001	4E-09	0.0004	0.0002	9E-10	0.0004	4E-05	8E-09	0.00015
TDDI1_16	5E-06	8.9E-10	4E-05	6E-06	8E-09	2E-05	6E-06	9E-10	3E-05	2E-06	1E-08	1E-05	4E-06	9E-10	3.5E-05
TDDI1_17	0.0004	8.9E-10	0.0028	0.0016	2E-06	0.0063	0.0014	2E-07	0.006	0.0014	8E-06	0.0042	0.0005	8E-09	0.00279
TDDI1_18	1E-06	8.9E-10	1E-05	8E-07	9E-10	6E-06	5E-07	9E-10	3E-06	8E-07	8E-09	4E-06	4E-07	9E-10	3.1E-06
TDDI1_19	5E-05	8E-09	0.0004	0.0002	7E-08	0.0006	0.0002	9E-10	0.0005	0.0002	5E-06	0.0006	6E-05	8E-09	0.00034
TDDI1_20	2E-06	8.9E-10	2E-05	3E-06	8E-09	1E-05	4E-06	9E-10	3E-05	6E-06	9E-10	3E-05	2E-06	9E-10	2.5E-05
TDDI1_21	8E-06	3.6E-09	4E-05	6E-06	1E-08	3E-05	1E-05	9E-10	4E-05	5E-06	9E-10	2E-05	5E-06	9E-10	3.3E-05
TDDI1_22	7E-08	8.9E-10	3E-07	2E-07	9E-10	1E-06	3E-07	9E-10	2E-06	1E-07	9E-10	6E-07	8E-08	9E-10	6E-07
TDDI1_23	8E-06	8.9E-10	5E-05	3E-05	8E-09	1E-04	5E-05	9E-10	0.0002	1E-05	4E-09	6E-05	5E-06	9E-10	3.2E-05
TDDI1_24	2E-07	8.9E-10	1E-06	2E-07	9E-10	1E-06	4E-07	9E-10	2E-06	2E-07	9E-10	9E-07	3E-07	9E-10	2E-06
TDDI1_25	2E-06	3.6E-09	1E-05	6E-06	9E-10	2E-05	1E-05	9E-10	8E-05	5E-06	7E-08	2E-05	4E-06	9E-10	1.4E-05
TDDI1_26	7E-08	8.9E-10	4E-07	2E-07	9E-10	8E-07	3E-07	9E-10	2E-06	3E-07	9E-10	1E-06	1E-07	9E-10	7E-07
TDDI1_27	8E-07	3.6E-09	4E-06	1E-06	9E-10	3E-06	2E-06	9E-10	7E-06	1E-06	1E-08	4E-06	9E-07	9E-10	3.5E-06
TDDI1_28	1E-08	8.9E-10	6E-08	4E-08	9E-10	2E-07	8E-08	9E-10	3E-07	1E-08	9E-10	4E-08	2E-08	9E-10	7.2E-08
TDDI1_29	6E-07	8.9E-10	3E-06	2E-06	4E-09	9E-06	9E-06	9E-10	3E-05	2E-06	4E-09	7E-06	1E-06	9E-10	6.4E-06
TDDI1_30	2E-09	8.9E-10	8E-09	3E-09	9E-10	8E-09	4E-09	9E-10	1E-08	4E-09	9E-10	2E-08	4E-09	9E-10	1.4E-08
TDDI1_32	3E-08	8.9E-10	1E-07	3E-08	9E-10	2E-07	8E-08	9E-10	4E-07	4E-08	9E-10	2E-07	3E-08	9E-10	1.5E-07
TDDI1_34	4E-09	8.9E-10	1E-08	9E-09	9E-10	2E-08	3E-08	9E-10	2E-07	5E-09	9E-10	1E-08	5E-09	9E-10	2.2E-08
TDDI1_36	6E-09	8.9E-10	3E-08	3E-09	9E-10	8E-09	3E-09	9E-10	1E-08	2E-09	9E-10	8E-09	4E-09	9E-10	2.2E-08
TDDI1_38	4E-09	8.9E-10	1E-08	2E-09	9E-10	8E-09	2E-08	9E-10	2E-07	6E-09	9E-10	1E-08	4E-09	9E-10	1.4E-08
TDDI1 [%]	0.7502	0.21307	1.6884	1.5051	0.9865	1.9663	1.4207	0.2018	1.924	1.5595	1.2604	1.8917	0.6996	0.1489	1.72885

2017	TDDI2 for 10,11,13,22,28/4/2017+2/5/2017														
	Sub-Period 1			Sub-Period 2			Sub-Period 3			Sub-Period 4			Sub-Period 5		
	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max
TDDI2_01	0.1822	0.00247	0.6983	2.7139	0.0301	8.8388	43.578	0.0175	88.753	3.2458	0.0608	9.0073	0.1924	0.0024	0.55321
TDDI2_02	2E-05	9.2E-10	9E-05	5E-05	9E-08	0.0001	0.0003	2E-08	0.0014	5E-05	5E-08	0.0001	3E-05	1E-08	9.5E-05
TDDI2_03	0.0102	0.00545	0.0157	0.0132	0.0108	0.0168	0.0116	0.0059	0.022	0.0087	0.0039	0.0138	0.006	2E-06	0.01183
TDDI2_04	2E-05	1.8E-06	5E-05	4E-05	1E-05	6E-05	6E-05	4E-06	0.0001	3E-05	1E-05	5E-05	1E-05	3E-06	3.3E-05
TDDI2_05	0.0007	8.3E-09	0.0033	0.0029	1E-05	0.0063	0.0079	5E-05	0.0242	0.0028	0.0001	0.0115	0.0008	4E-09	0.00603
TDDI2_06	6E-07	8.3E-09	2E-06	6E-07	3E-08	2E-06	3E-06	9E-10	1E-05	2E-06	9E-10	5E-06	7E-07	9E-10	3.1E-06
TDDI2_07	0.0011	3.7E-07	0.0057	0.0021	0.0001	0.0057	0.0033	3E-05	0.007	0.002	2E-05	0.0047	0.0007	7E-08	0.00513
TDDI2_08	2E-06	9.2E-10	2E-05	7E-06	4E-09	2E-05	6E-06	9E-10	2E-05	4E-06	8E-09	1E-05	2E-06	9E-10	1.3E-05
TDDI2_09	0.0001	2.3E-05	0.0002	7E-05	9E-08	0.0002	3E-05	4E-09	0.0001	3E-05	1E-07	7E-05	5E-05	8E-09	0.00015
TDDI2_10	1E-06	9.2E-10	7E-06	7E-06	5E-08	3E-05	2E-05	9E-10	6E-05	1E-05	2E-08	4E-05	3E-06	9E-10	1.5E-05
TDDI2_11	0.0002	9.2E-10	0.0006	0.0006	8E-07	0.0015	0.0007	4E-09	0.0034	0.0017	7E-05	0.0067	0.0003	9E-10	0.00212
TDDI2_12	2E-07	9.2E-10	2E-06	3E-07	9E-10	1E-06	4E-07	9E-10	2E-06	8E-07	4E-09	3E-06	5E-07	9E-10	2.9E-06
TDDI2_13	0.0002	9.2E-10	0.0013	0.0009	0.0001	0.0025	0.001	6E-08	0.0034	0.0012	2E-06	0.0047	0.0004	9E-10	0.00141
TDDI2_14	9E-07	9.2E-10	8E-06	4E-06	8E-09	3E-05	7E-06	9E-10	2E-05	7E-06	1E-08	2E-05	2E-06	9E-10	8.8E-06
TDDI2_15	9E-06	9.2E-10	4E-05	4E-05	5E-08	0.0002	6E-05	3E-08	0.0002	8E-05	9E-10	0.0003	1E-05	9E-10	4.1E-05
TDDI2_16	3E-06	9.2E-10	2E-05	3E-06	1E-07	1E-05	1E-05	9E-10	7E-05	2E-06	8E-09	8E-06	7E-07	9E-10	2.7E-06
TDDI2_17	0.0003	9.2E-10	0.0023	0.0017	4E-07	0.007	0.0016	6E-08	0.007	0.001	2E-05	0.0039	0.0005	9E-10	0.00222
TDDI2_18	1E-07	9.2E-10	7E-07	2E-07	9E-10	9E-07	8E-07	9E-10	3E-06	2E-07	9E-10	1E-06	3E-07	9E-10	1E-06
TDDI2_19	6E-05	9.2E-10	0.0005	0.0002	3E-07	0.0006	0.0001	4E-09	0.0004	0.0002	3E-07	0.0007	1E-04	9E-10	0.00052
TDDI2_20	1E-06	9.2E-10	1E-05	2E-06	4E-09	1E-05	6E-06	9E-10	2E-05	2E-06	9E-10	1E-05	2E-06	9E-10	1.4E-05
TDDI2_21	7E-06	9.2E-10	3E-05	5E-06	9E-10	2E-05	8E-06	9E-10	3E-05	3E-06	4E-09	1E-05	6E-06	9E-10	3.6E-05
TDDI2_22	8E-07	9.2E-10	6E-06	1E-06	8E-09	4E-06	9E-07	9E-10	4E-06	8E-07	9E-10	4E-06	8E-07	9E-10	5.2E-06
TDDI2_23	2E-05	3.3E-08	0.0001	5E-05	3E-08	0.0002	9E-05	9E-10	0.0004	2E-05	4E-09	0.0001	9E-06	9E-10	4.8E-05
TDDI2_24	4E-08	9.2E-10	3E-07	3E-08	9E-10	2E-07	2E-07	9E-10	8E-07	4E-08	9E-10	1E-07	3E-08	9E-10	2.1E-07
TDDI2_25	4E-06	3.7E-09	2E-05	1E-05	8E-07	5E-05	3E-05	9E-10	0.0001	8E-06	2E-08	4E-05	5E-06	9E-10	3.2E-05
TDDI2_26	4E-08	9.2E-10	2E-07	4E-08	9E-10	2E-07	3E-07	9E-10	1E-06	8E-08	9E-10	3E-07	3E-08	9E-10	1.3E-07
TDDI2_27	7E-07	9.2E-10	1E-06	6E-07	4E-09	3E-06	1E-06	9E-10	5E-06	6E-07	9E-10	2E-06	1E-06	9E-10	2.7E-06
TDDI2_28	2E-08	9.2E-10	1E-07	8E-08	9E-10	4E-07	7E-08	9E-10	3E-07	1E-07	9E-10	8E-07	7E-08	9E-10	7.2E-07
TDDI2_29	3E-06	9.2E-10	1E-05	4E-06	2E-08	1E-05	1E-05	4E-09	4E-05	5E-06	8E-09	2E-05	4E-06	9E-10	1.8E-05
TDDI2_30	5E-09	9.2E-10	2E-08	4E-09	9E-10	1E-08	2E-08	9E-10	7E-08	2E-08	9E-10	1E-07	1E-08	9E-10	5.9E-08
TDDI2_32	3E-08	9.2E-10	2E-07	1E-07	9E-10	3E-07	2E-07	9E-10	7E-07	2E-07	9E-10	7E-07	8E-08	9E-10	5.3E-07
TDDI2_34	5E-09	9.2E-10	3E-08	2E-08	9E-10	1E-07	5E-08	9E-10	4E-07	1E-08	9E-10	6E-08	9E-09	9E-10	4.5E-08
TDDI2_36	7E-09	9.2E-10	2E-08	5E-09	9E-10	1E-08	4E-09	9E-10	1E-08	3E-09	9E-10	8E-09	6E-09	9E-10	1.5E-08
TDDI2_38	3E-09	9.2E-10	8E-09	5E-09	9E-10	2E-08	2E-08	9E-10	9E-08	1E-08	9E-10	3E-08	5E-09	9E-10	1.5E-08
TDDI2 [%]	1.0914	0.7431	1.6087	1.4723	1.2042	1.7928	1.5339	0.901	2.4099	1.2841	0.6642	1.9582	0.8182	0.1052	1.54335

2017	TDDI3 for 10,11,13,22,28/4/2017+2/5/2017														
	Sub-Period 1			Sub-Period 2			Sub-Period 3			Sub-Period 4			Sub-Period 5		
	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max
TDDI3_01	0.1315	0.00011	0.7129	3.068	0.0415	9.7119	45.008	0.0091	100	3.2787	0.0018	9.7302	0.1488	4E-06	0.62517
TDDI3_02	7E-05	1.5E-06	0.0003	0.0002	3E-05	0.0004	0.0004	3E-08	0.0016	0.0001	3E-07	0.0004	5E-05	2E-06	0.00025
TDDI3_03	0.0006	7.7E-09	0.002	0.0004	4E-05	0.0009	0.0004	1E-08	0.0027	0.0001	2E-08	0.0004	0.0002	9E-10	0.00132
TDDI3_04	5E-06	7.7E-09	2E-05	8E-06	6E-07	2E-05	1E-05	9E-10	4E-05	5E-06	2E-07	1E-05	3E-06	9E-10	1.1E-05
TDDI3_05	0.0015	5.9E-05	0.0042	0.002	8E-05	0.0047	0.0062	4E-06	0.0148	0.0028	0.0002	0.0092	0.0012	1E-05	0.00448
TDDI3_06	2E-06	3.4E-09	5E-06	2E-06	3E-09	7E-06	4E-06	9E-10	2E-05	4E-06	9E-10	2E-05	2E-06	9E-10	6.8E-06
TDDI3_07	0.005	7.5E-05	0.0232	0.0099	0.0008	0.0192	0.0056	4E-06	0.0148	0.0094	0.0005	0.0223	0.0038	7E-05	0.0171
TDDI3_08	1E-06	7.7E-09	1E-05	6E-06	9E-10	2E-05	1E-05	3E-09	5E-05	7E-06	9E-10	2E-05	3E-06	9E-10	1.7E-05
TDDI3_09	7E-05	7.7E-09	0.0002	4E-05	9E-08	0.0001	4E-05	9E-10	0.0002	3E-05	8E-09	0.0001	4E-05	1E-08	0.00016
TDDI3_10	4E-06	8.6E-10	2E-05	4E-06	3E-09	2E-05	2E-05	3E-09	4E-05	3E-06	3E-09	2E-05	3E-06	9E-10	1.7E-05
TDDI3_11	0.0002	3.1E-08	0.0007	0.0009	0.0002	0.0017	0.0009	7E-08	0.0047	0.0023	4E-05	0.0066	0.0004	9E-10	0.00255
TDDI3_12	2E-06	8.6E-10	1E-05	2E-06	9E-10	7E-06	3E-06	9E-10	1E-05	4E-06	6E-08	1E-05	3E-06	9E-10	1.1E-05
TDDI3_13	0.0003	8.6E-10	0.0022	0.001	0.0001	0.0027	0.0013	2E-07	0.004	0.001	2E-08	0.0032	0.0005	9E-10	0.00177
TDDI3_14	1E-06	8.6E-10	8E-06	4E-06	3E-09	2E-05	7E-06	9E-10	5E-05	6E-06	3E-09	3E-05	3E-06	9E-10	1.8E-05
TDDI3_15	8E-06	3.4E-09	4E-05	2E-05	2E-07	1E-04	6E-05	3E-09	0.0003	0.0001	2E-07	0.0004	2E-05	9E-10	0.0001
TDDI3_16	3E-06	3.4E-09	4E-05	2E-06	9E-10	1E-05	5E-06	9E-10	3E-05	2E-06	3E-09	6E-06	2E-06	9E-10	1.4E-05
TDDI3_17	0.0003	8.6E-10	0.0014	0.001	3E-06	0.0037	0.0008	1E-08	0.0038	0.0008	4E-06	0.0036	0.0004	9E-10	0.00219
TDDI3_18	1E-06	8.6E-10	1E-05	2E-06	1E-08	8E-06	2E-06	9E-10	8E-06	2E-06	3E-09	6E-06	9E-07	9E-10	7.1E-06
TDDI3_19	0.0001	3.4E-09	0.0008	0.0003	5E-06	0.001	0.0002	8E-09	0.0006	0.0002	8E-07	0.0009	0.0001	9E-10	0.00068
TDDI3_20	1E-06	8.6E-10	8E-06	2E-06	9E-10	8E-06	2E-06	9E-10	9E-06	1E-06	9E-10	7E-06	1E-06	9E-10	8.8E-06
TDDI3_21	3E-06	8.6E-10	1E-05	9E-06	2E-07	2E-05	8E-06	9E-10	3E-05	8E-06	9E-10	3E-05	4E-06	3E-09	2.3E-05
TDDI3_22	1E-06	8.6E-10	9E-06	2E-06	9E-10	6E-06	1E-06	9E-10	6E-06	1E-06	8E-09	7E-06	1E-06	9E-10	7.1E-06
TDDI3_23	2E-05	8.6E-10	9E-05	4E-05	3E-07	0.0001	7E-05	3E-08	0.0003	3E-05	9E-10	1E-04	2E-05	8E-09	9.2E-05
TDDI3_24	5E-07	8.6E-10	4E-06	1E-06	3E-09	4E-06	3E-07	9E-10	2E-06	6E-07	9E-10	4E-06	3E-07	9E-10	2.1E-06
TDDI3_25	2E-06	8.6E-10	9E-06	6E-06	2E-08	3E-05	4E-05	3E-09	0.0002	8E-06	8E-09	4E-05	1E-05	9E-10	3.9E-05
TDDI3_26	6E-08	8.6E-10	2E-07	6E-08	9E-10	2E-07	2E-07	9E-10	9E-07	2E-07	9E-10	9E-07	2E-07	9E-10	1.2E-06
TDDI3_27	1E-06	1.4E-08	6E-06	3E-06	1E-08	7E-06	2E-06	9E-10	7E-06	2E-06	8E-09	6E-06	2E-06	9E-10	7.1E-06
TDDI3_28	5E-08	8.6E-10	3E-07	2E-07	9E-10	6E-07	2E-07	9E-10	1E-06	6E-08	9E-10	2E-07	8E-08	9E-10	5.8E-07
TDDI3_29	2E-06	8.6E-10	1E-05	4E-06	2E-08	1E-05	4E-06	9E-10	2E-05	3E-06	1E-08	8E-06	3E-06	9E-10	8.9E-06
TDDI3_30	9E-09	8.6E-10	4E-08	1E-08	9E-10	4E-08	2E-08	9E-10	7E-08	1E-08	9E-10	3E-08	1E-08	9E-10	4.2E-08
TDDI3_32	1E-08	8.6E-10	7E-08	4E-08	9E-10	1E-07	1E-07	9E-10	6E-07	8E-09	9E-10	4E-08	1E-08	9E-10	5.5E-08
TDDI3_34	1E-08	8.6E-10	6E-08	4E-08	9E-10	1E-07	8E-08	9E-10	4E-07	3E-08	9E-10	1E-07	7E-08	9E-10	2.8E-07
TDDI3_36	3E-08	8.6E-10	7E-08	7E-09	9E-10	2E-08	1E-08	9E-10	3E-08	6E-09	9E-10	2E-08	1E-08	9E-10	5.5E-08
TDDI3_38	7E-09	8.6E-10	4E-08	6E-09	9E-10	2E-08	2E-08	9E-10	1E-07	1E-08	9E-10	1E-07	2E-08	9E-10	8.6E-08
TDDI3 [%]	0.7495	0.31305	1.6941	1.2432	0.9911	1.5329	1.1692	0.3635	1.77	1.2381	0.4719	1.9779	0.6464	0.2529	1.52819

2017	TDDIn for 10,11,13,22,28/4/2017+2/5/2017														
	Sub-Period 1			Sub-Period 2			Sub-Period 3			Sub-Period 4			Sub-Period 5		
	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max
TDDIn_01	14.462	2.59875	25.568	10.166	4.1357	17.704	40.47	0.4402	93.752	14.633	0.6482	34.039	19.228	3.2514	35.5443
TDDIn_02	0.0629	0.01778	0.1044	0.0643	0.0211	0.1004	0.0793	0.0015	0.1505	0.068	0.0054	0.1128	0.069	0.0136	0.11668
TDDIn_03	7.0325	1.45222	15.702	4.707	1.1705	10.51	4.1182	0.1242	15.722	2.0197	0.082	5.7661	4.3768	0.1815	11.328
TDDIn_04	0.0038	0.00052	0.0071	0.003	0.0009	0.0052	0.0033	8E-05	0.0093	0.0035	0.0002	0.0065	0.0047	0.0005	0.00757
TDDIn_05	0.0527	0.00746	0.1141	0.0579	0.0097	0.1269	0.057	0.0012	0.154	0.034	0.004	0.0688	0.0477	0.0049	0.13144
TDDIn_06	0.0015	0.00039	0.0032	0.0011	0.0004	0.0022	0.0008	1E-05	0.0026	0.0009	3E-05	0.0018	0.0011	0.0003	0.00298
TDDIn_07	0.0144	0.00245	0.0466	0.0132	0.0042	0.0353	0.0157	0.0006	0.0458	0.0241	0.0022	0.0795	0.0124	0.0011	0.04688
TDDIn_08	0.0008	6.8E-05	0.0028	0.0005	0.0001	0.0014	0.0005	4E-06	0.0023	0.0003	3E-05	0.0005	0.0004	9E-05	0.00113
TDDIn_09	0.3368	0.06006	0.8854	0.191	0.0363	0.5221	0.164	0.005	0.8842	0.1236	0.0014	0.3684	0.1829	0.0018	0.55278
TDDIn_10	0.0002	3.3E-05	0.0006	0.0002	4E-05	0.0003	0.0003	2E-06	0.0008	0.0002	1E-05	0.0003	0.0002	6E-05	0.00039
TDDIn_11	0.0098	0.00264	0.0242	0.0131	0.0045	0.0221	0.0105	0.0004	0.0248	0.0233	0.0029	0.0477	0.0134	0.0029	0.03344
TDDIn_12	0.0001	2.6E-05	0.0004	0.0001	3E-05	0.0002	0.0001	2E-06	0.0002	0.0001	2E-05	0.0003	0.0002	5E-05	0.00032
TDDIn_13	0.0011	0.00018	0.0028	0.0024	0.0002	0.0076	0.0029	6E-05	0.0112	0.0113	0.0008	0.0307	0.0027	0.0002	0.01098
TDDIn_14	0.0001	4E-05	0.0003	0.0002	4E-05	0.0003	0.0002	4E-06	0.0004	0.0002	2E-05	0.0004	0.0002	4E-05	0.00061
TDDIn_15	0.0064	0.00075	0.0204	0.003	0.0002	0.0082	0.0032	8E-05	0.0173	0.0022	9E-05	0.0075	0.0038	0.0002	0.01138
TDDIn_16	0.0002	4E-05	0.0004	0.0002	8E-05	0.0003	0.0002	2E-06	0.0005	0.0003	3E-05	0.0007	0.0003	7E-05	0.00068
TDDIn_17	0.0026	0.0001	0.0053	0.003	0.0002	0.0114	0.0034	6E-06	0.0094	0.0071	0.0009	0.025	0.0046	0.0004	0.01951
TDDIn_18	0.0001	3.3E-05	0.0002	0.0001	4E-05	0.0002	0.0002	2E-06	0.0003	0.0002	3E-05	0.0004	0.0002	4E-05	0.00025
TDDIn_19	0.0004	6.8E-05	0.0012	0.0006	0.0001	0.0025	0.0007	3E-05	0.0025	0.0024	0.0004	0.0051	0.0019	5E-05	0.00883
TDDIn_20	0.0001	2.6E-05	0.0002	1E-04	3E-05	0.0002	0.0001	4E-07	0.0002	0.0001	1E-05	0.0002	0.0001	3E-05	0.00034
TDDIn_21	0.0008	0.00015	0.0017	0.0006	6E-05	0.0015	0.0007	2E-05	0.002	0.001	2E-05	0.0033	0.0011	0.0002	0.00215
TDDIn_22	7E-05	2E-05	0.0001	7E-05	3E-05	0.0001	8E-05	4E-07	0.0001	8E-05	1E-05	0.0001	1E-04	3E-05	0.00018
TDDIn_23	0.0009	0.00015	0.0015	0.0008	0.0003	0.0014	0.0008	1E-05	0.0018	0.0007	6E-05	0.0018	0.0009	0.0003	0.0015
TDDIn_24	7E-05	1.5E-05	0.0001	6E-05	3E-05	9E-05	7E-05	4E-07	0.0001	7E-05	6E-06	0.0001	7E-05	2E-05	0.0001
TDDIn_25	0.0002	6.8E-05	0.0004	0.0002	7E-05	0.0005	0.0005	4E-06	0.0033	0.0008	6E-05	0.0025	0.001	5E-05	0.00395
TDDIn_26	7E-05	1.5E-05	0.0001	5E-05	2E-05	8E-05	6E-05	4E-07	0.0001	5E-05	6E-06	9E-05	7E-05	2E-05	0.00013
TDDIn_27	0.0002	2.6E-05	0.0005	0.0002	4E-05	0.0005	0.0006	4E-06	0.0027	0.0005	3E-05	0.0019	0.001	0.0001	0.00356
TDDIn_28	7E-05	1.5E-05	0.0001	5E-05	2E-05	9E-05	6E-05	4E-07	0.0001	6E-05	1E-05	0.0001	8E-05	1E-05	0.00016
TDDIn_29	0.0003	7.9E-05	0.0004	0.0004	2E-05	0.0007	0.0002	1E-05	0.0007	0.0003	7E-05	0.0005	0.0003	1E-05	0.00049
TDDIn_30	5E-05	1.5E-05	7E-05	6E-05	4E-06	0.0001	5E-05	1E-05	0.0001	7E-05	1E-05	0.0001	5E-05	2E-06	0.0001
TDDIn_32	7E-05	2.6E-05	0.0001	8E-05	4E-06	0.0002	7E-05	1E-05	0.0001	1E-04	2E-05	0.0002	7E-05	2E-06	0.00015
TDDIn_34	5E-05	2E-05	7E-05	6E-05	4E-06	0.0001	5E-05	6E-06	8E-05	7E-05	1E-05	0.0001	6E-05	2E-06	9.1E-05
TDDIn_36	5E-05	1.5E-05	7E-05	5E-05	4E-06	9E-05	4E-05	6E-06	8E-05	6E-05	1E-05	0.0001	5E-05	2E-06	9.1E-05
TDDIn_38	6E-05	2E-05	9E-05	6E-05	4E-06	0.0001	5E-05	6E-06	0.0001	8E-05	2E-05	0.0001	7E-05	2E-06	0.00012
TDDI1n [%]	21.788	11.3516	33.53	18.779	8.4164	41.067	13.908	3.2344	25.378	20.099	4.6734	34.674	26.189	6.0305	42.6281

Appendix H
Results summery of the test system for randomly selected days during monitoring period "2"

2017	Sub-Period 1			Sub-Period 2			Sub-Period 3			Sub-Period 4			Sub-Period 5		
	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max
V1_Avg [V]	235.09	232.82	236.78	233.83	232.62	234.80	230.30	227.80	234.10	230.86	230.12	231.53	230.08	226.68	233.98
V2_Avg [V]	233.83	231.48	235.62	232.48	231.28	233.42	228.97	226.43	232.72	229.31	228.53	229.97	228.57	225.18	232.60
V3_Avg [V]	234.98	232.82	236.68	233.56	232.40	234.52	230.15	227.70	233.72	230.71	229.93	231.40	230.14	226.93	233.90
AVG_V_Avg [V]	234.63	232.37	236.36	233.29	232.10	234.23	229.80	227.31	233.51	230.29	229.53	230.97	229.60	226.27	233.49
In_Avg [A]	8.10	6.45	8.80	6.78	5.57	7.65	10.30	4.61	14.88	6.55	4.82	7.95	7.95	6.20	9.34
I1_Avg [A]	8.63	6.38	24.91	55.02	31.26	75.01	211.63	67.91	309.25	62.11	37.22	84.66	9.68	7.15	31.37
I2_Avg [A]	12.99	10.81	20.98	46.52	24.57	66.19	204.35	60.46	303.43	49.58	26.44	71.44	13.42	11.69	20.42
I3_Avg [A]	9.44	8.17	19.04	50.61	25.56	72.25	213.95	64.71	315.33	54.30	29.28	77.78	9.08	7.73	21.49
AVG_I_Avg [A]	10.35	8.77	21.53	50.72	27.16	71.15	209.98	64.36	309.33	55.33	31.39	77.94	10.72	9.00	24.02
THDV1_Avg [%]	1.08	0.90	1.24	0.99	0.88	1.07	0.75	0.61	0.98	0.85	0.78	0.92	0.79	0.60	1.06
THDV2_Avg [%]	1.18	0.97	1.36	1.15	1.05	1.21	0.95	0.78	1.25	1.08	1.00	1.16	0.94	0.69	1.29
THDV3_Avg [%]	1.44	1.25	1.65	1.40	1.25	1.51	1.09	0.92	1.34	1.19	1.11	1.26	1.06	0.79	1.42
THDI1_Avg [%]	22.00	18.40	28.85	13.69	10.01	20.58	3.69	1.83	11.67	11.29	8.20	15.42	17.80	13.49	28.80
THDI2_Avg [%]	29.20	23.51	37.98	16.59	12.40	24.09	4.31	2.04	13.87	14.30	8.82	20.97	23.37	18.72	31.87
THDI3_Avg [%]	19.65	15.80	39.85	15.85	9.80	26.07	3.59	1.54	15.65	13.47	8.09	21.06	18.11	13.19	46.89
THDIn_Avg [%]	67.00	49.62	90.03	61.61	47.97	78.33	38.98	19.46	79.41	35.46	27.94	45.85	48.04	29.11	72.33
TDDI1_Avg [%]	0.49%	0.30%	1.36%	1.49%	1.36%	1.59%	1.45%	1.11%	1.67%	1.44%	1.20%	1.56%	0.44%	0.19%	1.45%
TDDI2_Avg [%]	1.00%	0.87%	1.41%	1.47%	1.37%	1.58%	1.59%	1.25%	1.92%	1.45%	1.20%	1.61%	0.80%	0.52%	1.31%
TDDI3_Avg [%]	0.50%	0.37%	1.37%	1.26%	1.13%	1.34%	1.15%	0.84%	1.46%	1.27%	1.04%	1.40%	0.44%	0.30%	1.20%
TDDIn_Avg [%]	26.58%	20.19%	32.21%	21.50%	17.59%	26.27%	19.40%	9.42%	27.12%	13.98%	11.91%	15.83%	19.77%	13.48%	27.05%

Appendix I
Harmonic spectrum of phase and neutral currents during period "2" of each single day equivalent to disconnection day during monitoring period "1"

2017	TDDI1 for 14,19,20,21,25,26/4/2017														
	Sub-Period 1			Sub-Period 2			Sub-Period 3			Sub-Period 4			Sub-Period 5		
	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max
TDDI1_01	0.00408	0.00019	0.0161	5.1899	0.72392	11.5868	9.44101	0.13334	15.2967	7.5704	1.7799	16.3407	0.19018	4.5E-05	1.2303
TDDI1_02	5.8E-07	8.9E-10	2.8E-06	0.0003	1.3E-05	0.00057	0.00017	3.2E-08	0.00038	0.0002	2.6E-06	0.00038	4.1E-06	8.9E-10	2.5E-05
TDDI1_03	0.00028	5.1E-07	0.0014	0.0121	0.00115	0.0146	0.00612	4E-06	0.00897	0.0131	0.0106	0.01599	0.00187	1.3E-07	0.01298
TDDI1_04	7.8E-06	2.9E-07	1.2E-05	4E-05	2.1E-05	5E-05	2.5E-05	6E-07	4.7E-05	3E-05	1.2E-05	6E-05	7E-06	2.2E-08	2.2E-05
TDDI1_05	0.00024	2.5E-06	0.00029	0.0054	0.00287	0.01188	0.00555	5.2E-05	0.00825	0.0061	0.00178	0.01145	0.00053	9.5E-05	0.0023
TDDI1_06	5.3E-09	8.9E-10	1.4E-08	4E-07	3.6E-09	1.6E-06	3.6E-09	8.9E-10	1.4E-08	6E-07	5.7E-08	1.5E-06	1.6E-07	8.9E-10	7.5E-07
TDDI1_07	3.4E-06	5.7E-08	1.4E-05	0.0023	9.6E-06	0.00479	0.00049	6.6E-06	0.00115	0.0017	2.9E-05	0.00349	0.00062	2.2E-08	0.00432
TDDI1_08	2.9E-08	8.9E-10	1.5E-07	1E-06	3.6E-09	5.4E-06	8.1E-07	8.9E-10	4.7E-06	3E-06	3.6E-09	6.9E-06	1.7E-07	8.9E-10	1.2E-06
TDDI1_09	7.3E-05	5.3E-05	0.00013	0.0001	2.6E-07	0.00027	3.6E-05	7.2E-08	0.00015	0.0002	6.9E-05	0.00025	6.1E-05	1.3E-07	0.00023
TDDI1_10	9.2E-08	8.9E-10	2.3E-07	3E-06	8E-09	6.6E-06	2.9E-06	3.6E-09	7.9E-06	4E-06	1.4E-08	1.3E-05	5.2E-07	3.6E-09	3.3E-06
TDDI1_11	7.4E-06	8.9E-10	1.1E-05	0.0016	0.00046	0.00291	9.1E-06	8E-09	3.8E-05	0.0017	0.00058	0.00326	0.00013	5.6E-07	0.00083
TDDI1_12	3E-09	8.9E-10	8E-09	6E-07	8E-09	2.2E-06	1.8E-09	8.9E-10	3.6E-09	5E-07	8.9E-10	2.1E-06	4.1E-08	8.9E-10	2.6E-07
TDDI1_13	1.5E-06	1.3E-07	3.8E-06	0.0011	1.9E-06	0.00266	2.2E-06	1.5E-07	7.2E-06	0.0012	7.9E-06	0.00255	0.0001	1.4E-08	0.00071
TDDI1_14	1.6E-08	3.6E-09	4.4E-08	1E-06	8.9E-10	6E-06	2.5E-09	8.9E-10	8E-09	8E-07	8.9E-10	2.4E-06	2.9E-07	8.9E-10	2.1E-06
TDDI1_15	6.8E-06	5.6E-06	7.5E-06	0.0001	7.2E-08	0.00037	6.8E-06	8.9E-10	2.4E-05	0.0002	3.2E-08	0.00042	1.7E-06	3.6E-09	8.9E-06
TDDI1_16	3.2E-08	3.6E-09	7.2E-08	8E-06	3.6E-09	3.4E-05	9.9E-09	8.9E-10	3.2E-08	2E-06	3.6E-09	6.6E-06	2.9E-06	8.9E-10	2E-05
TDDI1_17	9.7E-08	8.9E-10	2.6E-07	0.0024	1.5E-05	0.00996	6.8E-07	3.6E-09	3.8E-06	0.0014	7E-06	0.00302	0.00016	8.9E-10	0.00112
TDDI1_18	8.9E-10	8.9E-10	8.9E-10	9E-07	8.9E-10	5.3E-06	6.1E-09	8.9E-10	3.2E-08	2E-06	1.4E-08	1E-05	3.9E-07	8.9E-10	2.7E-06
TDDI1_19	3.1E-07	8.9E-10	1.7E-06	0.0001	3.6E-09	0.00043	1.6E-06	1.4E-08	5.6E-06	0.0002	8.5E-06	0.00055	3E-05	8.9E-10	0.0002
TDDI1_20	8.9E-10	8.9E-10	8.9E-10	1E-05	1.4E-08	2.8E-05	2.9E-08	8.9E-10	8.9E-08	2E-06	3.6E-09	9.3E-06	4.3E-07	8.9E-10	3E-06
TDDI1_21	3.9E-07	8.9E-10	1.2E-06	8E-06	1.4E-08	3E-05	1.2E-06	8.9E-10	6.4E-06	1E-05	3.6E-09	3E-05	5E-06	3.6E-09	3.3E-05
TDDI1_22	8.9E-10	8.9E-10	8.9E-10	4E-07	8.9E-10	1.2E-06	3.1E-09	8.9E-10	1.4E-08	2E-07	8.9E-10	9.7E-07	6.2E-08	8.9E-10	4.3E-07
TDDI1_23	8E-09	8.9E-10	2.2E-08	4E-05	3.2E-08	0.00018	6.5E-08	8.9E-10	1.5E-07	1E-05	5.1E-07	4.2E-05	5.2E-06	8.9E-10	3.6E-05
TDDI1_24	8.9E-10	8.9E-10	8.9E-10	6E-07	8.9E-10	1.6E-06	7.4E-08	8.9E-10	4.3E-07	3E-07	8.9E-10	1.1E-06	1.7E-07	8.9E-10	1.2E-06
TDDI1_25	1.1E-07	3.6E-09	2E-07	5E-06	3.6E-09	2E-05	8.5E-09	8.9E-10	2.2E-08	5E-06	8.9E-10	1.6E-05	4.6E-06	8E-09	3.1E-05
TDDI1_26	8.9E-10	8.9E-10	8.9E-10	3E-07	8.9E-10	1.6E-06	1.8E-09	8.9E-10	3.6E-09	3E-07	8.9E-10	1.1E-06	6.8E-08	8.9E-10	4.7E-07
TDDI1_27	7.5E-08	3.6E-09	1.7E-07	1E-06	3.6E-09	3.2E-06	2.8E-08	8.9E-10	8.9E-08	5E-07	8.9E-10	1.7E-06	1.3E-07	8.9E-10	7.5E-07
TDDI1_28	2.5E-09	8.9E-10	8E-09	9E-08	8.9E-10	3.2E-07	8.9E-10	8.9E-10	8.9E-10	6E-08	8.9E-10	3.6E-07	9.3E-09	8.9E-10	5.7E-08
TDDI1_29	2.5E-09	8.9E-10	8E-09	2E-06	3.6E-09	8.4E-06	2.7E-08	8.9E-10	1.3E-07	2E-06	2.2E-08	6.7E-06	4.8E-07	8.9E-10	3.3E-06
TDDI1_30	8.9E-10	8.9E-10	8.9E-10	3E-09	8.9E-10	1.4E-08	8.9E-10	8.9E-10	8.9E-10	5E-09	8.9E-10	1.4E-08	2.8E-09	8.9E-10	1.4E-08
TDDI1_32	5.3E-09	8.9E-10	8E-09	3E-08	8.9E-10	1.7E-07	1.3E-09	8.9E-10	3.6E-09	4E-08	8.9E-10	1.7E-07	1.1E-08	8.9E-10	7.2E-08
TDDI1_34	8.9E-10	8.9E-10	8.9E-10	1E-08	8.9E-10	3.2E-08	8.9E-10	8.9E-10	8.9E-10	7E-09	8.9E-10	3.2E-08	3.9E-09	8.9E-10	2.2E-08
TDDI1_36	8.9E-10	8.9E-10	8.9E-10	4E-09	8.9E-10	8E-09	8.9E-10	8.9E-10	8.9E-10	2E-09	8.9E-10	3.6E-09	1.3E-09	8.9E-10	3.6E-09
TDDI1_38	8.9E-10	8.9E-10	8.9E-10	1E-09	8.9E-10	3.6E-09	8.9E-10	8.9E-10	8.9E-10	3E-09	8.9E-10	1.4E-08	2.8E-09	8.9E-10	1.4E-08
TDDI1 [%]	0.32992	0.26931	0.45169	1.6399	1.28992	1.88643	1.19908	0.10139	1.56785	1.5842	1.34829	1.87307	0.37505	0.1813	1.45136

2017	TDDI2 for 14,19,20,21,25,26/4/2017														
	Sub-Period 1			Sub-Period 2			Sub-Period 3			Sub-Period 4			Sub-Period 5		
	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max
TDDI2_01	0.24477	0.02355	0.71669	4.5299	0.43934	10.2719	47.4917	0.12672	94.3808	4.7609	0.47668	13.617	0.19954	0.002589	0.57278
TDDI2_02	2.7E-05	9.2E-10	9.7E-05	7E-05	1.3E-07	0.00027	0.00037	1.5E-08	0.00172	7E-05	9.2E-10	0.00018	2.7E-05	9.19E-10	9E-05
TDDI2_03	0.0107	0.00623	0.01851	0.0142	0.01219	0.01787	0.01204	0.00066	0.01872	0.0104	0.00795	0.01448	0.00602	6.7E-07	0.01314
TDDI2_04	2.4E-05	1.3E-07	6.3E-05	5E-05	8.1E-06	9.2E-05	6.5E-05	5.3E-07	0.00013	5E-05	2.3E-05	7.1E-05	1.7E-05	1.55E-06	4.9E-05
TDDI2_05	0.0013	1.5E-08	0.00434	0.0069	0.00218	0.01901	0.01204	9.1E-05	0.03216	0.0069	0.00145	0.01719	0.00124	3.68E-09	0.00576
TDDI2_06	6.2E-07	9.2E-10	1.4E-06	7E-07	3.7E-09	3.8E-06	3.3E-06	9.2E-10	9.6E-06	3E-06	4.4E-07	5.7E-06	8.2E-07	9.19E-10	4E-06
TDDI2_07	0.00088	8.3E-09	0.00609	0.0017	6.8E-06	0.00546	0.00275	3.7E-09	0.00706	0.0022	6.9E-05	0.00958	0.00058	7.45E-08	0.00599
TDDI2_08	5.1E-06	9.2E-10	2.2E-05	1E-05	3.3E-07	2.4E-05	5.4E-06	9.2E-10	1.6E-05	9E-06	8.3E-09	2.1E-05	4.4E-06	9.19E-10	1.8E-05
TDDI2_09	0.00013	3.9E-05	0.00037	7E-05	9.2E-08	0.00019	3.2E-05	9.2E-10	0.00015	4E-05	4.8E-06	0.00016	4.2E-05	1.78E-06	0.00017
TDDI2_10	1.4E-06	9.2E-10	7.4E-06	7E-06	9.2E-10	2.4E-05	1.8E-05	3.7E-09	4.8E-05	2E-05	5.3E-07	4.1E-05	3E-06	9.19E-10	1.1E-05
TDDI2_11	0.00014	3.3E-08	0.00061	0.0016	0.00013	0.00366	0.0005	3.7E-09	0.00369	0.0015	0.00021	0.00467	0.00042	2.12E-06	0.00375
TDDI2_12	5E-08	9.2E-10	2.4E-07	7E-07	9.2E-10	2.7E-06	3.3E-07	9.2E-10	1.7E-06	8E-07	9.2E-10	2.6E-06	4.9E-07	9.19E-10	3E-06
TDDI2_13	0.00025	9.2E-10	0.00081	0.0012	1.8E-05	0.00248	0.00099	8.3E-09	0.00363	0.0014	0.0003	0.00341	0.00046	1.11E-07	0.00198
TDDI2_14	2.5E-06	9.2E-10	1.4E-05	1E-05	1.3E-07	4.7E-05	1.2E-05	3.7E-09	4.1E-05	1E-05	1.1E-07	4.5E-05	2.1E-06	9.19E-10	1.1E-05
TDDI2_15	1.3E-05	9.2E-10	9.2E-05	1E-05	9.2E-08	4.5E-05	5.7E-05	3.7E-09	0.00035	0.0001	9.2E-10	0.00038	2E-05	9.19E-10	0.00011
TDDI2_16	8.7E-07	9.2E-10	5.2E-06	7E-06	9.2E-10	2.3E-05	1.3E-05	9.2E-10	7.6E-05	6E-06	3.3E-07	2E-05	1.6E-06	3.68E-09	1.3E-05
TDDI2_17	0.00111	1.5E-08	0.0092	0.0031	1.7E-06	0.01226	0.00232	2.3E-08	0.01472	0.0015	6.7E-07	0.0033	0.00046	3.68E-09	0.00229
TDDI2_18	1.2E-07	9.2E-10	3E-07	7E-08	9.2E-10	2.1E-07	3.3E-07	9.2E-10	1.3E-06	1E-07	9.2E-10	3.3E-07	1.5E-07	9.19E-10	6.7E-07
TDDI2_19	3.3E-05	9.2E-10	0.00023	0.0001	1.5E-08	0.00069	0.00012	8.3E-09	0.00034	0.0002	8.3E-09	0.00047	7.5E-05	3.68E-09	0.00029
TDDI2_20	3.5E-06	8.3E-09	1.7E-05	7E-06	4.5E-08	2.9E-05	9E-06	9.2E-10	2.9E-05	2E-06	9.2E-10	1.4E-05	9E-07	9.19E-10	5.6E-06
TDDI2_21	6.2E-06	9.2E-10	3.3E-05	5E-06	3.7E-09	1.7E-05	6E-06	9.2E-10	1.8E-05	4E-06	9.2E-10	2.8E-05	7.1E-06	9.19E-10	4.6E-05
TDDI2_22	1E-06	9.2E-10	4.4E-06	1E-06	9.2E-10	3.9E-06	1.2E-06	9.2E-10	3.9E-06	2E-06	9.2E-10	5.7E-06	1.8E-06	9.19E-10	7.4E-06
TDDI2_23	1.4E-05	9.2E-10	5.9E-05	6E-05	7.2E-07	0.00026	4.9E-05	9.2E-10	0.00016	2E-05	9.2E-10	5.4E-05	1.1E-05	9.19E-10	5.2E-05
TDDI2_24	3.9E-08	9.2E-10	2.7E-07	1E-07	9.2E-10	4.9E-07	1.9E-07	9.2E-10	9.4E-07	7E-08	9.2E-10	3E-07	4.5E-08	9.19E-10	3.3E-07
TDDI2_25	7.9E-06	9.2E-10	4.5E-05	1E-05	5.9E-08	6.5E-05	2.7E-05	9.2E-10	9.8E-05	8E-06	8.3E-09	3.8E-05	6E-06	9.19E-10	5E-05
TDDI2_26	5E-08	9.2E-10	3E-07	1E-07	9.2E-10	3.7E-07	1.4E-07	9.2E-10	5.3E-07	5E-08	9.2E-10	2.1E-07	4.1E-08	9.19E-10	2.1E-07
TDDI2_27	6.4E-07	9.2E-10	1.5E-06	3E-07	9.2E-10	1.5E-06	1.6E-06	9.2E-10	5.9E-06	9E-07	8.3E-09	5E-06	1.1E-06	9.19E-10	4.3E-06
TDDI2_28	2E-08	9.2E-10	1.8E-07	7E-08	9.2E-10	3.3E-07	9.4E-08	9.2E-10	4.9E-07	7E-08	9.2E-10	3E-07	2.1E-08	9.19E-10	9.2E-08
TDDI2_29	2E-06	8.3E-09	9.8E-06	4E-06	1.5E-08	1.2E-05	1.3E-05	9.2E-10	3.4E-05	7E-06	9.2E-10	2.1E-05	4.4E-06	9.19E-10	2E-05
TDDI2_30	5.8E-09	9.2E-10	1.5E-08	6E-09	9.2E-10	2.3E-08	9.8E-09	9.2E-10	3.3E-08	1E-08	9.2E-10	4.5E-08	8.2E-09	9.19E-10	4.5E-08
TDDI2_32	3.5E-08	9.2E-10	2.1E-07	4E-08	9.2E-10	2.1E-07	1.1E-07	9.2E-10	3.3E-07	5E-08	9.2E-10	2.4E-07	3.9E-08	9.19E-10	3.3E-07
TDDI2_34	1.4E-08	9.2E-10	7.4E-08	4E-08	9.2E-10	1.3E-07	3.8E-08	9.2E-10	1.3E-07	2E-08	9.2E-10	7.4E-08	1.1E-08	9.19E-10	5.9E-08
TDDI2_36	6.4E-09	9.2E-10	2.3E-08	6E-09	9.2E-10	1.5E-08	6.9E-09	9.2E-10	3.3E-08	8E-09	9.2E-10	3.3E-08	7.4E-09	9.19E-10	3.3E-08
TDDI2_38	3.3E-09	9.2E-10	1.5E-08	3E-09	9.2E-10	1.5E-08	1.6E-08	9.2E-10	1.6E-07	2E-09	9.2E-10	8.3E-09	3.6E-09	9.19E-10	1.5E-08
TDDI2 [%]	1.14526	0.79719	1.78198	1.6967	1.34301	2.14708	1.66156	0.28317	2.38317	1.5243	1.09991	2.17623	0.81045	0.106257	1.71542

2017	TDDI3 for 14,19,20,21,25,26/4/2017														
	Sub-Period 1			Sub-Period 2			Sub-Period 3			Sub-Period 4			Sub-Period 5		
	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max
TDDI3_01	0.21675	4E-06	0.71586	5.0348	0.40958	10.9942	48.2636	0.12542	94.5644	4.4708	0.60951	10.4755	0.18627	0.000243	0.71586
TDDI3_02	0.00012	7.6E-06	0.00043	0.0003	4.4E-05	0.0005	0.00044	8.6E-10	0.00158	3E-05	1E-07	9.2E-05	4.8E-05	5.5E-06	0.00025
TDDI3_03	0.00069	0.00017	0.0019	0.0005	0.00016	0.00126	0.0003	8.6E-10	0.00149	3E-05	1.4E-06	8.7E-05	0.00018	8.59E-10	0.00101
TDDI3_04	7.2E-06	3.4E-09	2.3E-05	1E-05	5.5E-08	2.3E-05	1.4E-05	8.6E-10	4.5E-05	1E-05	1.1E-06	2.1E-05	5.3E-06	8.59E-10	2.4E-05
TDDI3_05	0.00145	5.4E-06	0.00499	0.0051	5.5E-08	0.01199	0.0079	2.4E-05	0.01984	0.0049	0.00292	0.00819	0.00159	9.19E-05	0.00387
TDDI3_06	2.5E-06	8.6E-10	7.6E-06	2E-06	8.6E-10	7.1E-06	5.6E-06	8.6E-10	2.5E-05	3E-06	8.6E-10	1.1E-05	1.9E-06	8.59E-10	5.2E-06
TDDI3_07	0.00462	7.7E-05	0.02387	0.0081	7.3E-05	0.02295	0.00528	3.1E-08	0.01279	0.0065	0.00308	0.00804	0.0036	6.83E-05	0.01943
TDDI3_08	3.1E-06	8.6E-10	1.2E-05	7E-06	1.8E-06	1.1E-05	1.3E-05	3.4E-09	2.7E-05	9E-06	5.6E-06	1.3E-05	4.2E-06	7.74E-09	1.3E-05
TDDI3_09	7.9E-05	7.7E-09	0.00024	5E-05	4.5E-07	0.00018	4.7E-05	1.4E-08	0.0002	7E-06	8.6E-10	3E-05	3.1E-05	7.74E-09	0.00015
TDDI3_10	2.5E-06	8.6E-10	1.1E-05	2E-06	8.6E-10	8.8E-06	1.8E-05	8.6E-10	4E-05	7E-06	1.2E-06	1.8E-05	3.8E-06	8.59E-10	1.5E-05
TDDI3_11	0.00025	1.4E-08	0.0012	0.0022	0.00107	0.0037	0.00055	8.6E-10	0.00347	0.0014	0.00046	0.00231	0.00054	8.59E-10	0.00336
TDDI3_12	2.1E-06	8.6E-10	8.1E-06	2E-06	7.7E-09	6.8E-06	2.3E-06	8.6E-10	9.5E-06	8E-06	9.4E-07	1.5E-05	2.5E-06	8.59E-10	9.3E-06
TDDI3_13	0.00038	8.6E-10	0.00125	0.0013	4.6E-05	0.00244	0.00132	2.1E-08	0.00413	0.0012	3.9E-05	0.00222	0.00048	8.59E-10	0.00194
TDDI3_14	1.2E-06	3.4E-09	8.6E-06	8E-07	1.4E-08	2.5E-06	4.3E-06	8.6E-10	2.1E-05	3E-06	4.2E-08	1.1E-05	3.5E-06	8.59E-10	1.7E-05
TDDI3_15	8.9E-06	8.6E-10	4.7E-05	3E-05	3.1E-07	8.3E-05	5.2E-05	3.4E-09	0.00017	6E-05	3.1E-07	0.00018	2.7E-05	8.59E-10	0.00015
TDDI3_16	3.4E-06	7.7E-09	2.9E-05	4E-06	3.4E-09	1.3E-05	6.6E-06	8.6E-10	3.1E-05	3E-06	8.6E-10	9.8E-06	1.9E-06	8.59E-10	8.9E-06
TDDI3_17	0.00077	8.6E-10	0.00568	0.0011	1.4E-06	0.00387	0.00131	1.4E-08	0.00747	0.0012	0.00012	0.00275	0.00032	8.59E-10	0.0014
TDDI3_18	2E-06	8.6E-10	1.5E-05	1E-06	7.7E-09	5.5E-06	2.6E-06	8.6E-10	8.6E-06	2E-06	7.7E-09	6.2E-06	1.1E-06	8.59E-10	5E-06
TDDI3_19	4.8E-05	3.4E-09	0.00029	0.0002	7E-08	0.00108	0.00019	3.4E-09	0.00059	0.0002	9.4E-07	0.00067	0.00012	8.59E-10	0.00053
TDDI3_20	3.1E-06	8.6E-10	1.7E-05	5E-06	8.6E-10	1.7E-05	2.4E-06	8.6E-10	8.9E-06	3E-06	2.1E-08	1E-05	1.1E-06	8.59E-10	7E-06
TDDI3_21	4.3E-06	8.6E-10	1.8E-05	5E-06	8.6E-08	2.5E-05	2.9E-06	8.6E-10	1.1E-05	3E-06	8.6E-10	7.3E-06	1.3E-06	8.59E-10	9.5E-06
TDDI3_22	1.9E-06	8.6E-10	7.4E-06	2E-06	2.1E-08	7E-06	2.2E-06	8.6E-10	6.8E-06	4E-06	1.7E-06	1E-05	2.5E-06	8.59E-10	1.1E-05
TDDI3_23	1.5E-05	8.6E-10	7.7E-05	5E-05	2.1E-08	0.00015	6.5E-05	1.4E-08	0.00017	2E-05	7E-08	4.2E-05	1.3E-05	7.74E-09	7.5E-05
TDDI3_24	8E-07	8.6E-10	3.3E-06	2E-06	8.6E-10	4.2E-06	5.2E-07	8.6E-10	2.9E-06	3E-06	1.7E-07	5.2E-06	8.5E-07	8.59E-10	4.3E-06
TDDI3_25	3.7E-06	8.6E-10	3.3E-05	1E-05	3.4E-09	5.3E-05	3.8E-05	8.6E-10	0.00013	1E-05	8.6E-10	3.9E-05	9.5E-06	8.59E-10	5.2E-05
TDDI3_26	8.7E-08	8.6E-10	5.4E-07	2E-07	8.6E-10	6.3E-07	2.8E-07	8.6E-10	1.2E-06	4E-07	8.6E-10	1.2E-06	2.2E-07	8.59E-10	1.1E-06
TDDI3_27	1.6E-06	8.6E-10	4.2E-06	2E-06	3.1E-07	5.1E-06	1.6E-06	8.6E-10	5.4E-06	2E-06	5.5E-08	4E-06	1.4E-06	8.59E-10	3.9E-06
TDDI3_28	4.9E-08	8.6E-10	3.8E-07	9E-08	8.6E-10	3.8E-07	2.7E-07	8.6E-10	9.4E-07	7E-08	3.4E-09	3.8E-07	8.8E-08	8.59E-10	3.4E-07
TDDI3_29	1E-06	8.6E-10	6.4E-06	5E-06	8.6E-10	1.2E-05	2.2E-06	8.6E-10	8.8E-06	2E-06	3.4E-09	5.6E-06	2.6E-06	8.59E-10	8.1E-06
TDDI3_30	4.8E-09	8.6E-10	2.1E-08	2E-08	8.6E-10	8.6E-08	3.5E-08	8.6E-10	1.5E-07	2E-08	8.6E-10	7E-08	1.6E-08	8.59E-10	5.5E-08
TDDI3_32	2.6E-08	8.6E-10	8.6E-08	3E-08	8.6E-10	8.6E-08	9.2E-08	8.6E-10	5.4E-07	1E-08	8.6E-10	5.5E-08	1.4E-08	8.59E-10	7E-08
TDDI3_34	2E-08	8.6E-10	1E-07	5E-08	8.6E-10	1.5E-07	5.5E-08	8.6E-10	3.8E-07	4E-08	8.6E-10	1.2E-07	9.9E-08	8.59E-10	3.1E-07
TDDI3_36	3.6E-08	8.6E-10	8.6E-08	8E-09	8.6E-10	3.1E-08	1.6E-08	8.6E-10	7E-08	2E-09	8.6E-10	7.7E-09	1.8E-08	8.59E-10	5.5E-08
TDDI3_38	4E-09	8.6E-10	1.4E-08	2E-09	8.6E-10	7.7E-09	1.6E-08	8.6E-10	7E-08	2E-09	8.6E-10	3.4E-09	8.7E-09	8.59E-10	3.1E-08
TDDI3 [%]	0.7506	0.29395	1.72032	1.3752	1.01121	1.82851	1.21642	0.107	1.82069	1.2508	1.10913	1.43633	0.66045	0.2846	1.62258

2017	TDDIn for 14,19,20,21,25,26/4/2017														
	Sub-Period 1			Sub-Period 2			Sub-Period 3			Sub-Period 4			Sub-Period 5		
	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max
TDDIn_01	11.0273	2.14181	18.2804	6.6223	2.67504	11.9562	43.0078	0.08943	93.3831	12.311	0.02982	26.5013	21.4289	6.056287	39.9103
TDDIn_02	0.05952	0.0144	0.10775	0.0494	0.02151	0.09522	0.09165	0.0014	0.15	0.0746	0.00049	0.12507	0.06982	0.019689	0.12239
TDDIn_03	6.92153	1.1843	17.0268	3.8186	1.26438	7.85779	3.82485	0.04232	9.30734	1.568	0.02341	4.96653	3.84035	0.869926	11.8118
TDDIn_04	0.00466	0.00109	0.01098	0.003	0.00082	0.00768	0.00392	6.8E-05	0.0079	0.0034	1.5E-05	0.00671	0.00431	0.001356	0.00859
TDDIn_05	0.05029	0.01006	0.09998	0.0609	0.02189	0.14658	0.0745	0.00071	0.15099	0.0367	7.9E-05	0.06226	0.06643	0.003562	0.12687
TDDIn_06	0.00188	0.00029	0.00372	0.0011	0.00034	0.00239	0.0012	1.5E-05	0.00334	0.0011	3.6E-06	0.00215	0.00138	0.000339	0.00284
TDDIn_07	0.0141	0.00239	0.04743	0.0126	0.00312	0.04206	0.01447	4.9E-05	0.04025	0.0116	0.0002	0.04524	0.00944	0.000439	0.03975
TDDIn_08	0.00117	9.1E-05	0.00387	0.0007	9.1E-05	0.00233	0.0009	3.6E-06	0.00264	0.0007	4E-07	0.00181	0.0008	0.000103	0.00258
TDDIn_09	0.34227	0.05167	0.98608	0.1583	0.04206	0.39033	0.13215	0.00122	0.38087	0.08	0.0014	0.30372	0.15473	0.022263	0.57567
TDDIn_10	0.0002	4E-05	0.00047	0.0001	3.3E-05	0.00027	0.00028	1.6E-06	0.00064	0.0002	4E-07	0.00036	0.00023	6.81E-05	0.00041
TDDIn_11	0.00917	0.00155	0.01846	0.0137	0.00419	0.0258	0.00961	0.00012	0.02341	0.0201	7.9E-05	0.03824	0.01221	0.00239	0.03367
TDDIn_12	0.00012	2E-05	0.00029	8E-05	2.6E-05	0.00015	0.00011	4E-07	0.00025	9E-05	4E-07	0.00015	0.00012	4.88E-05	0.00027
TDDIn_13	0.00089	0.00018	0.00186	0.0024	0.00029	0.00561	0.00183	1E-05	0.0064	0.011	4.9E-05	0.03344	0.00282	0.000161	0.00907
TDDIn_14	0.00013	4.9E-05	0.00032	0.0001	3.3E-05	0.00021	0.00016	1.6E-06	0.00029	0.0001	4E-07	0.00032	0.00024	5.8E-05	0.00058
TDDIn_15	0.00619	0.00068	0.02041	0.002	0.00049	0.0064	0.00267	2.6E-05	0.00735	0.0012	3.6E-06	0.00298	0.00316	0.000232	0.01249
TDDIn_16	0.00021	3.3E-05	0.00039	0.0002	5.8E-05	0.00032	0.00024	1.6E-06	0.00049	0.0002	4E-07	0.00044	0.00027	9.07E-05	0.00047
TDDIn_17	0.0024	0.00041	0.00702	0.0027	0.00012	0.0135	0.00444	4E-05	0.01596	0.0106	0.0001	0.0258	0.00425	0.000363	0.01235
TDDIn_18	0.00013	3.3E-05	0.00021	0.0001	4E-05	0.00021	0.00015	1.6E-06	0.00025	0.0002	4E-07	0.00029	0.00016	6.81E-05	0.00027
TDDIn_19	0.00024	7.9E-05	0.00061	0.0004	7.9E-05	0.00122	0.00067	1.5E-05	0.00203	0.0026	4E-05	0.0063	0.00197	5.8E-05	0.00848
TDDIn_20	9.3E-05	2.6E-05	0.00016	8E-05	2.6E-05	0.0002	0.00011	4E-07	0.0002	0.0001	4E-07	0.00027	0.00012	4.03E-05	0.00021
TDDIn_21	0.00067	5.8E-05	0.0014	0.0006	0.0001	0.00136	0.00104	1E-05	0.00233	0.0007	3.6E-06	0.00198	0.00103	0.000294	0.00186
TDDIn_22	6.3E-05	1.5E-05	0.0001	5E-05	2E-05	9.1E-05	8.6E-05	4E-07	0.00021	9E-05	4E-07	0.00015	9.5E-05	3.27E-05	0.00016
TDDIn_23	0.00074	0.00012	0.0014	0.0006	0.00021	0.00122	0.00084	3.6E-06	0.00181	0.0005	1.6E-06	0.00085	0.001	0.000252	0.00176
TDDIn_24	5.7E-05	1E-05	9.1E-05	6E-05	2E-05	0.00012	6.7E-05	4E-07	0.00013	7E-05	4E-07	0.00015	7.6E-05	3.27E-05	0.00012
TDDIn_25	0.00015	4.9E-05	0.00034	0.0001	3.3E-05	0.00032	0.00107	1.6E-06	0.00387	0.0006	1.6E-06	0.00319	0.00118	6.81E-05	0.00488
TDDIn_26	6.3E-05	1E-05	0.00012	4E-05	1.5E-05	7.9E-05	6.2E-05	4E-07	0.00012	6E-05	6.4E-06	0.00012	7.5E-05	3.27E-05	0.00012
TDDIn_27	0.00023	2.6E-05	0.00047	0.0001	4E-05	0.00036	0.00107	3.6E-06	0.00327	0.0005	4E-07	0.00203	0.00121	0.000103	0.00298
TDDIn_28	8.5E-05	1E-05	0.00018	4E-05	1.5E-05	7.9E-05	6.1E-05	4E-07	0.00012	6E-05	6.4E-06	0.00012	8.4E-05	3.27E-05	0.00015
TDDIn_29	0.00017	5.8E-05	0.00034	0.0003	1.6E-06	0.00058	0.00022	4E-07	0.00039	0.0003	6.8E-05	0.00047	0.0003	6.81E-05	0.00047
TDDIn_30	3.9E-05	1.5E-05	7.9E-05	6E-05	4E-07	0.0001	5.1E-05	6.4E-06	9.1E-05	7E-05	2.6E-05	0.00012	5.1E-05	1.01E-05	7.9E-05
TDDIn_32	5.1E-05	2E-05	9.1E-05	8E-05	4E-07	0.00016	6.8E-05	6.4E-06	0.00015	9E-05	2.6E-05	0.00016	6.9E-05	1.45E-05	0.0001
TDDIn_34	3.8E-05	1.5E-05	6.8E-05	6E-05	4E-07	0.0001	4.6E-05	6.4E-06	7.9E-05	7E-05	2.6E-05	9.1E-05	5.4E-05	1.01E-05	0.0001
TDDIn_36	3.7E-05	1E-05	6.8E-05	5E-05	4E-07	9.1E-05	4.4E-05	6.4E-06	6.8E-05	6E-05	2.6E-05	9.1E-05	5.2E-05	1.01E-05	7.9E-05
TDDIn_38	4.4E-05	1.5E-05	9.1E-05	7E-05	4E-07	0.00012	5.1E-05	6.4E-06	7.9E-05	8E-05	3.3E-05	0.00013	6.6E-05	1.01E-05	0.00012
TDDI1n [%]	19.6001	11.7399	29.0463	18.668	2.14536	31.4858	12.5261	1.60902	23.5485	19.292	9.91325	35.4243	24.8318	11.2854	40.2393

Appendix J
Results obtained of the test system during monitoring period “2” of each single day equivalent to disconnection day during monitoring period "1

	Sub-Period 1			Sub-Period 2			Sub-Period 3			Sub-Period 4			Sub-Period 5		
	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max
V1_Avg [V]	236.24	234.18	237.57	234.76	233.93	235.50	230.60	200.60	234.68	231.77	231.35	232.20	230.16	226.62	233.75
V2_Avg [V]	235.02	232.90	236.38	233.39	232.52	234.15	229.28	199.46	233.37	230.48	230.05	230.88	228.87	225.30	232.55
V3_Avg [V]	236.05	234.12	237.33	234.42	233.62	235.18	230.38	200.54	234.32	231.71	231.32	232.07	230.36	226.93	233.88
AVG_V_Avg [V]	235.77	233.73	237.09	234.19	233.36	234.94	230.09	200.22	234.12	231.32	230.91	231.71	229.79	226.28	233.39
In_Avg [A]	7.25	5.42	8.51	5.84	4.87	6.83	10.89	3.74	15.00	5.91	2.90	7.93	8.17	6.26	9.85
I1_Avg [A]	9.15	6.58	31.70	70.67	39.24	105.75	232.87	95.66	307.00	79.21	47.32	112.73	9.01	5.86	36.26
I2_Avg [A]	12.15	9.55	24.91	62.11	31.14	97.03	225.78	87.47	301.18	63.97	31.75	98.50	13.48	11.64	22.05
I3_Avg [A]	9.57	7.90	25.04	67.22	34.00	104.17	236.26	94.17	312.67	69.86	36.11	106.06	9.22	7.73	23.97
AVG_I_Avg [A]	10.29	8.15	27.19	66.67	34.79	102.31	231.64	92.58	306.95	71.01	38.39	105.76	10.57	8.68	27.41
THDV1_Avg [%]	1.12	0.96	1.28	1.11	1.01	1.19	0.84	0.63	1.07	0.88	0.85	0.91	0.81	0.67	0.98
THDV2_Avg [%]	1.07	0.86	1.33	1.25	1.13	1.37	1.12	0.84	1.36	1.18	1.13	1.22	1.01	0.83	1.28
THDV3_Avg [%]	1.43	1.26	1.66	1.51	1.38	1.60	1.23	0.97	1.50	1.31	1.27	1.35	1.13	0.94	1.37
THDI1_Avg [%]	22.35	17.34	28.95	9.56	5.75	15.41	2.69	1.80	5.95	7.57	4.98	11.33	18.35	13.97	27.68
THDI2_Avg [%]	33.32	21.31	41.51	11.05	6.56	18.37	3.13	2.01	8.08	9.40	5.87	15.32	22.67	18.76	31.50
THDI3_Avg [%]	20.46	15.82	34.92	9.17	5.04	15.86	2.36	1.54	5.39	8.12	4.98	13.21	17.55	13.68	44.03
THDIn_Avg [%]	72.32	46.61	95.28	57.26	39.94	84.09	36.95	18.87	74.29	35.91	21.18	48.72	45.05	27.72	64.51
TDDI1_Avg [%]	0.54%	0.33%	1.61%	1.66%	1.54%	1.79%	1.57%	1.20%	1.77%	1.56%	1.47%	1.62%	0.42%	0.20%	1.47%
TDDI2_Avg [%]	1.03%	0.88%	1.51%	1.69%	1.53%	1.87%	1.73%	1.30%	1.95%	1.53%	1.36%	1.69%	0.79%	0.35%	1.30%
TDDI3_Avg [%]	0.52%	0.36%	1.33%	1.41%	1.25%	1.52%	1.29%	0.85%	1.50%	1.34%	1.22%	1.44%	0.44%	0.31%	1.23%
TDDIn_Avg [%]	26.91%	17.74%	33.42%	18.81%	14.54%	25.18%	20.40%	9.39%	26.21%	12.83%	8.30%	16.45%	19.18%	13.36%	25.34%

Appendix K
Results obtained of the test system during whole monitoring period "2"

2017	Sub-Period 1			Sub-Period 2			Sub-Period 3			Sub-Period 4			Sub-Period 5		
	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max	Avg.	Min.	Max
V1_Avg [V]	234.95	224.73	236.82	234.06	233.02	234.91	229.10	212.99	233.70	230.77	230.24	231.28	229.88	226.41	233.76
V2_Avg [V]	233.72	223.48	235.65	232.69	231.64	233.56	227.85	211.78	232.39	229.37	228.82	229.88	228.52	225.00	232.52
V3_Avg [V]	234.80	224.68	236.65	233.74	232.72	234.57	228.96	212.95	233.37	230.73	230.19	231.23	230.06	226.69	233.84
AVG_V_Avg [V]	234.49	224.30	236.37	233.50	232.46	234.34	228.64	212.58	233.15	230.29	229.75	230.80	229.49	226.04	233.37
In_Avg [A]	7.61	5.71	8.55	6.27	5.22	7.16	10.41	3.69	14.83	6.27	4.13	8.04	8.02	6.24	9.52
I1_Avg [A]	9.21	6.37	30.93	66.59	38.38	97.97	220.55	88.84	304.71	70.28	43.03	96.13	9.25	6.11	35.51
I2_Avg [A]	12.71	10.01	24.55	57.55	30.05	88.76	213.46	79.98	299.23	56.52	29.69	82.77	13.44	11.46	23.03
I3_Avg [A]	9.68	7.79	24.92	62.84	32.77	95.99	223.46	85.78	310.81	61.41	32.76	89.26	9.25	7.71	24.26
AVG_I_Avg [A]	10.54	8.23	26.73	62.33	33.74	94.24	219.16	84.91	304.90	62.74	35.31	89.33	10.65	8.67	27.37
THDV1_Avg [%]	1.06	0.88	1.24	1.03	0.94	1.12	0.78	0.61	0.98	0.88	0.83	0.93	0.82	0.66	1.02
THDV2_Avg [%]	1.11	0.90	1.36	1.20	1.09	1.29	1.03	0.80	1.30	1.19	1.12	1.27	1.03	0.83	1.34
THDV3_Avg [%]	1.41	1.21	1.64	1.43	1.31	1.53	1.15	0.93	1.40	1.28	1.22	1.33	1.13	0.90	1.41
THDI1_Avg [%]	21.53	16.10	28.70	10.27	6.53	15.82	3.22	1.75	8.70	9.58	6.99	13.53	18.14	13.51	27.92
THDI2_Avg [%]	30.47	21.26	38.19	12.15	7.65	19.06	3.80	1.96	11.33	11.69	7.63	18.28	22.80	18.23	31.83
THDI3_Avg [%]	19.68	15.06	36.72	10.44	5.92	17.45	3.21	1.49	11.21	11.69	7.45	18.35	17.62	13.26	43.72
THDIn_Avg [%]	67.99	45.18	90.79	57.92	38.84	79.22	37.44	19.98	76.12	33.23	23.08	45.37	45.04	28.62	67.41
TDDI1_Avg [%]	0.51%	0.30%	1.53%	1.59%	1.48%	1.68%	1.48%	1.19%	1.67%	1.50%	1.33%	1.51%	0.43%	0.18%	1.42%
TDDI2_Avg [%]	0.99%	0.82%	1.46%	1.61%	1.47%	1.73%	1.63%	1.29%	1.87%	1.47%	1.24%	1.54%	0.77%	0.36%	1.27%
TDDI3_Avg [%]	0.51%	0.34%	1.34%	1.33%	1.13%	1.44%	1.22%	0.88%	1.44%	1.29%	1.07%	1.35%	0.44%	0.29%	1.19%
TDDIn_Avg [%]	25.65%	17.51%	31.98%	19.48%	14.26%	25.03%	19.27%	9.43%	25.03%	12.53%	9.02%	14.48%	18.91%	12.78%	24.86%

Appendix L
Harmonic Distortion Levels for the Proposed 7.5 MW PV System

Harmonic order (f/fn)	In (%)	Harmonic order (f/fn)	In (%)
1	100	**26**	0.18
2	0.44	**27**	0.12
3	0.12	**28**	0.15
4	0.16	**29**	0.35
5	0.02	**30**	0.08
6	0.07	**31**	0.19
7	0.03	**32**	0.06
8	0.09	**33**	0.21
9	1.19	**34**	0.04
10	0.13	**35**	0.23
11	1.16	**36**	0.02
12	0.38	**37**	0.22
13	0.56	**38**	0.03
14	0.34	**39**	0.19
15	0.35	**40**	0.03
16	0.26	**41**	0.17
17	0.88	**42**	0.02
18	0.11	**43**	0.16
19	0.44	**44**	0.03
20	0.08	**45**	0.12
21	0.17	**46**	0.03
22	0.07	**47**	0.11
23	0.38	**48**	0.02
24	0.14	**49**	0.12
25	0.31	**50**	0.02