جامعة بيرزيت
BIRZEIT UNIVERSITY

Faculty of Engineering and Technology

Joint Master in Electrical Engineering (JMEE)

Performance Analysis of Modern Power Systems in Presence of Demand Side Management

Submitted by:

Ahmad R. A. Alahmad

Supervisor:

Dr. Jaser Sa’ed

June, 2022

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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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Ahmad R. A. Alahmad

Approved By the Examining Committee:

Dr. Jaser Sa'ed

Dr. Mahran Quraan

Dr. Hakam Shehadeh

June, 2022

DECLARATION

I declare that this thesis entitled “Performance Analysis of Modern Power Systems in Presence of Demand Side Management” 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: ………………………………
Name: ………………………………….
Date: ……………………………………

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To my supervisor, Dr. Jaser Sa’ed, coordinators of the master program in electrical engineering, examining committee members, my dear friends, my father, mother, brothers and sisters, and my wife, Joud, Rasheed, and Jiyad, with sincere love and thanks.

Ahmad Alahmad

Jun 25, 2022

ABSTRACT

This thesis aimed to study and investigate the effect of implementing demand side management (DSM) techniques on the operation of active distribution networks. Firstly, the main DSM strategies will be studied. Then, the load shape has been changed by executing DSM strategies through a number of actions will be described. Moreover, the conservation voltage reduction (CVR) technique will be addressed and verified. After that, an adaptive CVR algorithm will be proposed in order to deal with voltage profile variation in the active distribution networks. Various possible integration scenarios between photovoltaic based distributed generator (PV-DG) and CVR schemes have been illustrated and the optimal integration of such schemes constraining the reduction of energy consumed by the user and utility are presented. The evaluation and the effectiveness of the proposed algorithm and schemes are verified on (static/dynamic) loads using IEEE 30-bus test systems with MATLAB and Open-DSS software.

المستخلص

الهدف من هذه الرسالة هو دراسة وبحث تأثير تنفيذ تقنيات إدارة جانب الطلب (DSM) على تشغيل شبكات التوزيع النشطة. حيث ستتم دراسة استراتيجيات DSM الرئيسية. بعد ذلك ، سيتم وصف التغييرات في شكل الحمل الناتجة عن تنفيذ استراتيجيات DSM المختلفة من خلال عدد من الإجراءات. علاوة على ذلك ، ستتم معالجة تقنية تقليل جهد الحفظ والتحقق منها. ثم سيتم اقتراح خوارزمية CVR متقدمة للتعامل مع التغيرات في ملف الجهد على شبكات التوزيع النشطة. سيتم توضيح سيناريوهات الدمج المحتملة بين المولد (PV-DG) ومخططات CVR , وسيتم تقديم الية الدمج الأمثل لمثل هذه المخططات التي تعمل على تقليل الطاقة التي يستهلكها المستخدم والشبكة. سيتم التحقق من فعالية الخوارزمية والخطط المقترحة على احمال (Dynamic/static) باستخدام شبكة نظام اختبار IEEE-30,و تقييمها باستخدام برنامج MATLAB وOpen-DSS .

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List of abbreviations

Abbreviation	**Full word**
CVR	Conservation Voltage Reduction
DSM	Demand Side Management
DG	Distributed Generation
PV	Photo Voltaic
RES	Renewable Energy Sources
ZIP	Impedance-Current-Power
LTC	Load Tap Changer
OLTC	On Load Tap Changer
DLC	Direct-Load-Control
ANSI	American National Standard Institute
EN	European National standard

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Chapter I: Introduction

1. Introduction

To satisfy the rise in power demand brought on by economic and industrial progress in many nations, more producing stations must be constructed along with adequate reserves for emergencies. So, utilities must meet a number of crucial goals. Their main goal is to reduce peak loads (level and smooth the load curve), as well as the dependency on expensive fuels to run plants during peak periods, in order to reduce the number of peaking power plants required to meet peak demands and reduce the associated emissions resulting from additional generating capacity. In addition to addressing environmental concerns, consumers also need a good, dependable power supply and are looking for ways to lower their energy costs. Customers can achieve some further savings if they allow the utilities to directly control their principal loads using various approaches, including conservation voltage reduction CVR as an action of demand side management DSM techniques.

By decreasing the voltage profile within acceptable bounds, conservation voltage reduction CVR aims to reduce load demand, losses, and/or energy consumption [1]. Most voltage-dependent loads have a positive correlation between voltage and power consumption in a range close to the nominal voltage, meaning that lowering the voltage also lowers the load demand. CVR takes advantage of this trait to lower load demand, improving system efficiency as a result.

The authors initially implemented CVR/DSM over a constant impedance load in the field test and focused on evaluating the outcomes just in such situation. This study will deal with both static and dynamic loads, using ZIP load modeling, which integrates constant (impedance, current, and power) loads.

1.1. Research problem

The daily rise of high-tech home appliances and the population increase, create a real challenge for the main utility to enhance the grid in order to meet those electricity needs. On the other hand, the traditional ways of dealing with these challenges (load disconnecting, grid reinforcement) could restrict that rise, or load the utility with unneeded cost for more grid reinforcement. Integrating PV-based DG to improve the grid and support demand also faces the challenge of variable output due to its reliance on weather conditions.

A proper adaptive algorithm that combines DSM techniques (primarily CVR) and PV-based DG will overcome all challenges by lowering consumed energy, energy losses, and end-user electricity bills. Improve the performance of the electrical grid as well.

1.2. Important and expected impact

This research provides an adaptive algorithm that creates an interactive operation between the demand side management and the utility, in order to improve the use of PV-based DG as a backup energy supply, as well as to adopt CVR to minimize energy use and conserve it. DSM and RES have beneficial impacts on the utility, the customer and the environment. On the side of the utility: decreasing the energy losses, increasing the reliability, and enhancing the system security. On the side of end-user: reducing the user bills, having a secure and reliable electrical service. Finally, reducing the gas emission on the side of the environment.

1.3. Research methodology

The methodology will be as follows:

- Collecting data, reading and analyzing research in the field of this study to write a broad background and literature review.
- Building the required algorithms and making simulation tests using Open-DSS and MATLAB.
- Testing the effectiveness of the algorithms on the IEEE-30 bus test system.
- Suggesting and investigating some scenarios for the work (with and without DSM, with and without DG).
- Evaluating and discussing the results and writing the recommendations.

1.4. Main contributions

The main contributions of this thesis can be summarized as:

- Proposed an adaptive CVR-algorithm that provide an optimized voltage reduction of the network at specific time.
- Implemented dynamic load modeling as residential, commercial, and industrial by using ZIP load modeling.
- Applied the proposed CVR-algorithm for dynamic load distribution network in order to insure the maximized consumed energy reduction. Moreover the adaptiveness of the proposed algorithm has been verified.
- Evaluated the CVR factors for dynamic load distribution network in the presence of the proposed CVR-algorithm.

Chapter II: Literature review

2. Literature review

The daily increase in the population and the increasing desire to use advanced home appliances to promote luxury as a new culture in modern societies create challenges for the main utility in meeting the requirements of these devices. These challenges and others can be addressed with smart grid technology by improving the efficiency and reliability of the electrical system [2]. Smart grid enhances the solutions for the increasing demands by integrating renewable energy sources based on distribution generation, this integration aims to support and improve the electrical system [3]. PV units are a familiar example of a clean-energy source that reduces the emissions caused by the traditional fuel electrical sources [4]. The dependency of PV sources on the weather circumstances creates a problem of instability in penetration levels of energy. Figure2-1 explains the DSM techniques which they are the solution for compensating for that insecurity by reshaping load demand in a way that improves DG integration [5]. On the other hand, DSM has the advantage of reducing the cost of energy while using the CVR. Many regulations should exist for the implementation of DSM and CVR techniques to reduce many of their limitations, the characteristics of grid components, and the various types of DG [6].

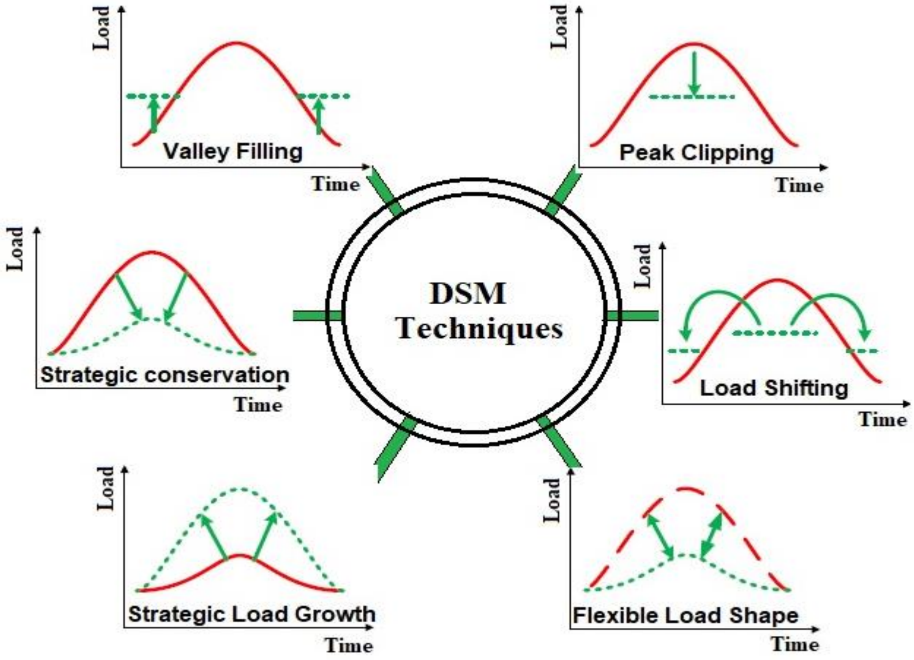

Figure 2-1: Demand side management techniques [7].

Recently, the authors have been interested in designing some algorithms for implementing the CVR/DSM techniques, dealing with many scenarios with and without integrating DG through the electrical grid [7].

The concept of CVR aims to reduce the voltage of the feeder to an acceptable value for the end user appliances, corresponding to the national standards, There are many regulations that control the CVR implementation [8]. The acceptable value according to the relevant voltage standards was plus/minus five percent [9] to plus/minus ten percent [10]. As a result of that reduction, the end-user far away from the substation will receive an unacceptable voltage value, so the networks should include regulators or capacitor banks in order to compensate for the voltage drop [11].

The concept of conservation voltage reduction (CVR) started to appear in the first half of the 1970s as a result of the increasing interest in energy conservation at that time [12], the anthers of [1] researcher of this paper discussed the impact of the voltage reduction on the active and reactive power and energy conservation. He found that the impact of the voltage reduction varies according to the type of the load, while others proved experimentally that the energy saved as a result of using the voltage-reduction was significant, in the impact of CVR was discussed using different types of loads (residential, commercial, industrial) to achieve the results of increasing the efficiency of the electricity system. Also they provide a field experiment by different utilities for implementing and testing CVR, and it has reached the conclusion that appropriate design of CVR could be an efficient method for energy conservation. It can be said that the reduction in voltage will decrease the revenue income from the user, which creates a negative relationship between the utilities and the CVR, also it explains that using CVR helps the utility to accommodate more users without expanding their infrastructure, which contributes to the image of using the CVR technique.

Authors in [13] found that using CVR will have a better effect while interacting with some level of DG penetration, DG penetration will reduce the violation of the voltage profile, although more penetration level will negatively affect the power factor of the network, While the author of [14] illustrates all the sides of implementing the CVR methodology using a real case study, dealing with different scenarios in order to reach the proposed dynamic one with a small percentage error, taking into consideration many factors. Also, the author in [15] explains that improving an algorithm consists of two stages in order to maximize the penetration level of RES. The first stage deals with maximizing export power and minimizing import energy, while the second stage is based on implementing CVR to reduce the consuming energy. Author in [16] emphasize that CVR has rekindled interest in recent years, it is a cost-effective solution to provide clients with energy saving benefits. As an example CVR tests were conducted by implementing a 2.5 percent reduction in voltage, could save energy by 1% in Australian residential circuits [17]. However, one of the most difficult aspects of CVR use is measuring and verifying its impacts, while the authors of [18] provide an algorithm that detects whether CVR is turned on or off, making it easier to study its impact. Suitable load modeling is an important factor that enhancing a specific measurements and verifications of CVR impacts [19].

This research will highlight the capabilities and investigate the effects caused by executing CVR as an action of the DSM on the operation of PV-integrated distribution systems. Moreover, an adaptive algorithm of CVR on the suitable ZIP load modeling profile (static and dynamic) will be proposed and tested.

Chapter III: Demand Side Management

3. Demand side management

The demand side, main utility, and environment are the main components of the whole electrical system. The importance of the role that demand side management (DSM) plays comes from the fact that using some DSM techniques and algorithms could provide a benefit for all the components of the electrical system.

3.1. DSM definition

The DSM concept has many different definitions depending on the case and the way of dealing with DSM, and the benefit or function it could provide, so despite the non-singularity of international-definition, this study will mention some definitions for DSM.

In the past, the DSM concept represented the actions and activities done only on the side of demand, as was clear in [20]. The authors of [20] considers the DSM to be the measurement of how much it reduces the demand side energy at the peak-times, While other researchers were not going far enough by adding the consumers' actions as a response to price and transferring the loads to the off-peak-times [21]. The definition that completely collected all the sides of the DSM concept where provided by the authors of [22] to be as the following: “the planning, implementation monitoring of those utility activities designed to influence customer use of electricity in ways that will produce desired changes in the utility’s load shape, i.e., changes in the time pattern and magnitude of a utility’s load. Utility programs falling under the umbrella of demand-side management include: load management, new uses, strategic conservation, electrification, customer generation, and adjustments in market share”.

3.2. DSM benefits

Different publications that talk about DSM introduce a variant range of the benefits and the contributions that the DSM could provide for the whole electrical system [23]:

- Cost-effective solution.
- Enhancing energy efficiency.
- Reducing the black-out cases and the CO2 emission by enhancing the distributed generation technology.
- Prevent the costly reinforcement that is only needed for the peak-loads intervals.
- Reduces the bill costs by using the energy efficiently and finding the optimal time for use.

3.3. DSM techniques

The optimal implementation of DSM affects the consumption and the total load of the system, so the expected reduction of the electricity costs that occurs depending on the peak-load reduction. The DSM reshapes the load profile by manipulating the end-users' electricity usage in order to have the optimal load profile. Depending on the seasonal and daily electricity usage, it could clarify six methods and types of DSM: peak-clipping, load shifting, strategic load growth , strategic conservation, valley filling, and flexible load shape [23].

3.3.1 Peak clipping

Peak clipping is a familiar technique of reshaping the load profile throw decreasing the electrical peak-demand [23] as shown in the figure3.1, peak clipping method depends on using the Direct-Load-Control (DLC) to reduce the peak load during specific interval of time [23], DLC could be introduced as a function of the DSM-program, which can be clarified as a regulating the users appliances by the utility from far away, while suitable using of DLC could provide an effective loss of operating cost for the utility [24].

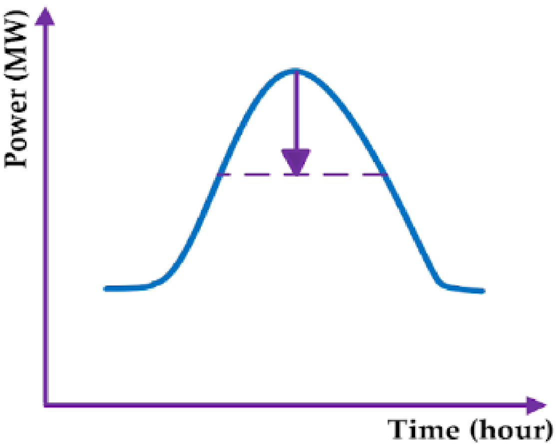

Figure 3-1: DSM peak clipping [25].

3.3.2 Valley filling

Valley filling aims to balance the difference load level the valley and the peak of the load by transferring the load from peak-time in order to fill the valley with transferred load [26] as presented in the figure3.2, this method can applied when the average price of electricity is more than the incremental cost for a long time [27].

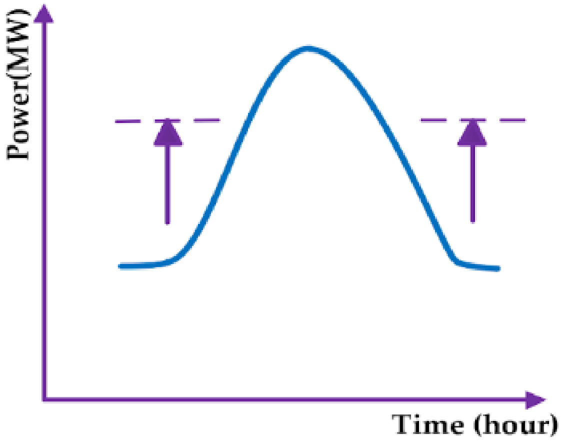

Figure 3-2 : DSM valley filling [25].

3.3.3 Load shifting

Load shifting method is widely used with the DSM-programs, it's based on shifting the load from peak-time into off-peak-time as seen in the figure3-3 , so it consider as an efficient technique that mange the load [26].

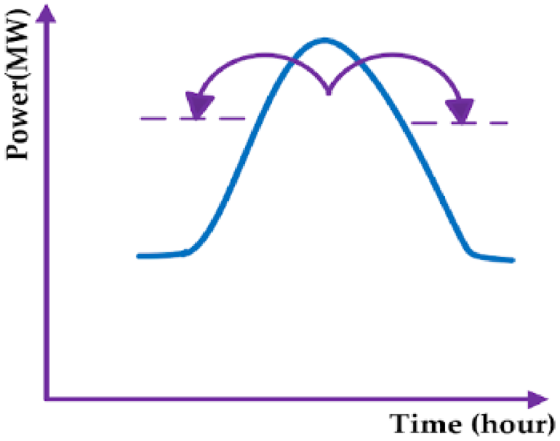

Figure 3-3 : DSM load shifting [25].

3.3.4 Strategic conservation

This method aims to consume the energy efficiently through the application that reduce the load to achieve the strategic conservation which reduce that overall demand as represented in the figure3-4, the proposed and designed load-shape depending on the utility load management [26].

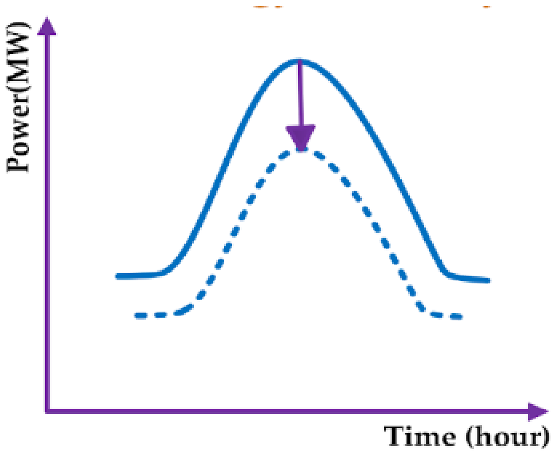

Figure 3-4 : DSM strategic conservation [25].

3.3.5 Strategic load growth

This technique stimulates the energy companies to rise their generation of energy for consumers, so it improves the daily-response and reshape the load profile taking in consideration the large load-demand beyond the Valley-Filing method as its clear in the figure3-5, rising load market sharing, providing the load demand through implementing needed infra-structure, and developing the service area economically [26].

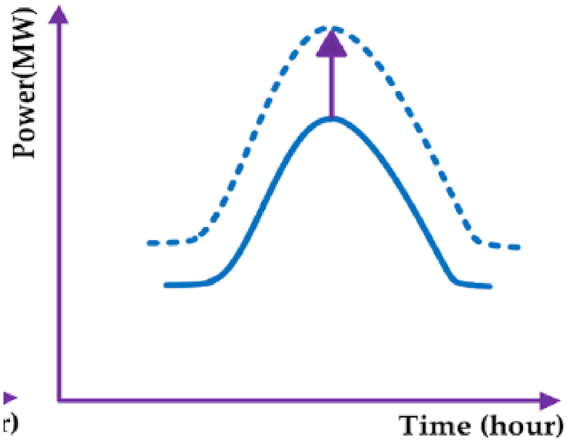

Figure 3-5 : DSM strategic load growth [25].

3.3.6 Flexible load shape

This method aims to provide the reliability for the smart grid, which means that the utility should analyses the load profile in order to inform the consumers with the flexible loads, and the consumers who respond and deals with this activates of controlling their load consumption in the peak load intervals [26] as its clear in the figure3-6.

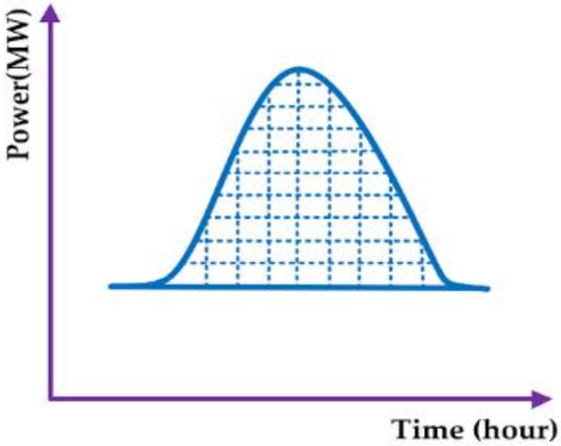

Figure 3-6 : DSM flexible load shape [25].

3.4. DSM strategies

Smoothing the electrical system operation, rise the energy-efficiency, and guiding the habits and the behavior of the consumer into the write direction of conserving the power which make the suppliers and the governments are interesting on implementing the DSM through four strategies; demand-response, energy efficiency, time of use, and spinning-reserve [28].

3.4.1 Demand response

Demand-response is a specific steps and rewards that aims to encourage the end-user to control their load profile by reducing or shifting their load during the peak intervals. Demand response creates an opportunity that apply the end user to contribute in improving the electrical system operation [28].

3.4.2 Energy efficiency

The Energy-efficiency program aims to enhance the efficiency of the electrical system also decreasing the load through the peak time [29].

3.4.3 Time of use

This strategy is based on dividing the 24-hour day into different time intervals, each with a different price for the electrical consumption [28], which gives the supplier the ability to raise the price of the peak time intervals.

3.4.4 Spinning reserve

The spinning reserve strategy is responsible for achieving the load-generation balance that couldn’t be available when a sudden interruption occurred while some generation was out. This strategy is based on using and activating the spare energy sources[28].

3.5. DSM challenges

Despite the slow implementation of DSM, it is not a modern technology, but the conditions that should be available to enhance the implementation of DSM could be taken into consideration to prevent it from being challenged, which includes:

3.5.1 Information and communication technology infrastructure

The implementation of DSM should be supported by smart metering, wide band communication, and sensors to create an interactive environment between the customer and the supplier that enhances the desired benefits of DSM; however, this infrastructure poses a significant challenge for the utility in implementing DSM [23].

3.5.2 Complexity and competitiveness of DSM programs

Dealing with DSM-based programs increases the complexity of the system, although the benefits that it could provide for the total system, also sometimes DSM couldn’t compete the traditional approaches [23].

3.5.3 Interactivity and sharing of implementation

The shortage of understanding the benefits of DSM-approaches will reduce the implementation of DSM-based programs, which decreases the value of DSM [23].

Chapter IV: Conservation Voltage Reduction

4. Conservation voltage reduction

4.1. CVR definition

CVR which is also known as voltage optimization, is a technique based on reducing the voltage at a certain feeder to an acceptable value that allows the user appliances to work, probably In order to conserve energy, this reduction in voltage will result in fewer appliances consuming power, which finally contributes to reducing the user’s bill cost on one hand, and on the other hand, contributes to reducing the expanding infrastructure of the utility grid [1].

4.2. The effect of CVR

In order to understand the CVR effect on the consuming power for some specific end-user home appliances, assuming that appliances have no reactive power, then by Joule’s law the consumed power by these appliances will be reduced according to voltage reduction. If the load is constant-impedance, all of the above is true, but if the load is not, the load will compensate for the reduction of voltage by increasing the current in the status of constant-power load, which increases the line losses. Also, if the loads have a feedback control, this means that the working time of the device will increase in order to achieve the set point that it is working for, so it could be considered as constant-energy loads. Finally, constant-current loads will conserve less energy when using the CVR technique [30].

4.3. The benefit of CVR

The benefits of implementing CVR could be divided into three categories: first of all, for the end user, this will reduce bill costs, and it will extend the life of the appliances, allowing them to serve the user for a longer period of time, for the utility, this will reduce the cost of unnecessary generating power that should be generated to accommodate new user’s needs, finally for the environment, this will mean generating fewer CO2 emissions.

4.4. CVR strategies

While searching through the early studies and researches, there were two mentioned strategies for implementing the CVR technique [31], the first was modeling a distribution feeder and setting the Load-Tab-Changer (LTC) or regulator in order to guarantee the voltage value at the end of the line to be 0.9 per unit while adjusting the supplier according to the load changes. This method is called Line-Drop-Compensation (LDC), while the second method is called Voltage-Spread-Reduction. This method is based on limiting the voltage value to be from +/- 0.05 to +/-0.025 using the LTC or regulator.

The third new strategy, which is based on using an Adaptive-Voltage-Control system to set the voltage value while implementing the CVR using new available technology for communication and automatic control [32].

4.5. CVR factor

The CVR Factor is a metric for assessing the effectiveness of voltage reduction from an energy standpoint, which can be calculated by finding the ratio between the demand reduction and the voltage reduction, as given:

$$\text{CVR Factor} = \frac{\%\ \text{Demnad Reduction}}{\%\text{Voltage Reduction}} \tag{4.1}$$

The increase in the CVR factor means that there is an increase in the amount of conserved energy [33], so the CVR factor can be calculated as given:

$$\text{CVR Factor} = \frac{\%\ \text{KWh Savings}}{\%\text{Voltage Reduction}} \tag{4.2}$$

CVR_f is calculated to find the percentage (energy, active power and re-active power) conserved while 1% voltage reduction because of CVR implementation, as seen:

$$\text{CVR}_{\text{f(P)}} = \frac{\%\ \Delta\text{P}}{\%\Delta\text{V}} \qquad \text{CVR}_{\text{f(Q)}} = \frac{\%\ \Delta\text{Q}}{\%\Delta\text{V}} \qquad \text{CVR}_{\text{f(E)}} = \frac{\%\ \Delta\text{E}}{\%\Delta\text{V}} \tag{4.3}$$

The optimal $\mathrm{CVR}_{\mathrm{f(P)}}$ value fluctuates from 0.1 to 0.9 for the overall system, but it might vary from 0.2 to 4 for a $\mathrm{CVR}_{\mathrm{f(E)}}$ [14], as it is obvious. With $\mathrm{CVR}_{\mathrm{f(P)}}$ approaches to 0.9, the efficiency of implementing CVR improves.

4.6. Load modeling

There were many variations of the load, with several scenarios of different load behaviors in the network throughout the 24 hours while there was a variation of the voltage values. In order to have an accurate study of the impact of CVR, there should be an accurate model of the load, this accurate estimation of the load modeling will face two difficulties. The first was the variation of the load features and behaviors through the hours of the day, also the days of the week and seasons, and the second was the normal fluctuation of the load [34].

Load modeling aims to estimate the mathematical relationship between the supplied-voltage and the active or reactive power in order to describe the behavior of the load under the variation of the supplied-voltage. The load could be divided into two different parts depending on the impact of the voltage variation over the load. The first one was the static load modeling, and the second part was the dynamic load modeling [34].

4.6.1 Static load modelling

Static models express active and reactive power as functions of bus voltage magnitudes and frequency at any given time. Static loads which are considered an independent time loads, such as resistive loads, can be represented using these models [34].

4.6.2 Dynamic load modeling

For proper representation in voltage stability studies, dynamic load models are required. The active and reactive powers are expressed as a function of voltage and time in dynamic models. This loads considered a dependent time loads as an Induction motors are an example of a commonly used dynamic model [34].

4.6.3 ZIP load modeling

It was noticed that some representation load modeling is familiar for use in dynamic and static studies, which is called ZIP load modeling, where the time-independent characteristics could be categorized as constant-impedance (Z), constant-current (I), or constant-power (P), according to the relationship between the supplied-voltage from the first side and the active-reactive load power on the other side, which is known as load-model 8 in the Open-DSS software that will be used through the simulation.

ZIP load modeling as seen in figure4-1 could be represented as given [34]:

$$P_{load} = P_{nom}\left[Z_p\left(\frac{V}{V_0}\right)^2 + I_p\left(\frac{V}{V_0}\right) + P_p\right] \tag{4.4}$$

$$Q_{load} = Q_{nom}\left[Z_q\left(\frac{V}{V_0}\right)^2 + I_q\left(\frac{V}{V_0}\right) + P_q\right] \tag{4.5}$$

where

$$Z_p + I_p + P_p = Z_q + I_q + P_q = 1$$

and

Z_p, Z_q : Factors represents the waiting of constant impedance load for both active/reactive power in the formula.

I_p,I_q: Factors represents the waiting of constant current load for both active/reactive power in the formula.

P_p,P_q : Factors represents the waiting of constant power load for both active/reactive power in the formula.

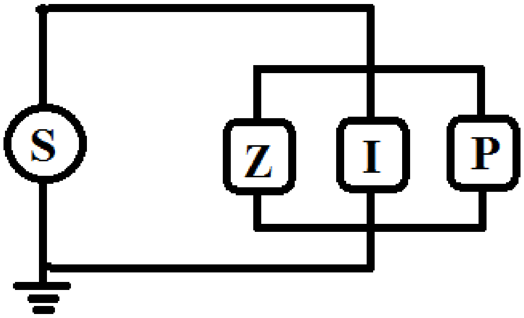

Figure 4-1: ZIP load modeling.

The laboratory experiments justify that there is no constant power, constant current, and constant impedance under all circumstances, there is a percentage variation of the factors on each side of the load characteristics, so were held in order to find each factor of the ZIP model of the load.

In equation 4.3, if $\mathrm{Z_p} = 1,\ \mathrm{I_p} = 0, \mathrm{P_p} = 0$ then the load with these coefficients is considered as a constant impedance load, while if $\mathrm{Z_p} = 0,\ \mathrm{I_p} = 1, \mathrm{P_p} = 0$ it is considered as a constant current load, finally if $\mathrm{Z_p} = 0,\ \mathrm{I_p} = 0, \mathrm{P_p} = 1$ it is considered as a power load, and the same for the reactive power coefficients [19].

4.7. Tap changing transformer

The device that can be added to the power-transformer in order to control the output voltage of that transformer, called a “tap-changer”. The Tap-Changer increases or decreases the turns-ratio between the transformer windings, which, as a result, the output voltage will vary accordingly [35].

This technology has been implemented by the main utility to maintain the voltage through the network under the allowable limits of the voltage standards. There are two types of this technology: Off-Load Tap-Changer and On-Load Tap-Changer (OLTC). OLTC was the one used in this research in order to control the voltage profile of the network as a way of implementing CVR depending on the improved algorithm.

The reactance OLTC model was utilized in the simulation by the Open-DSS software to lower the power consumed when we have several switching times to achieve the required point of tap change.

4.8. International voltage magnitude standards

Under normal operating conditions, these standards provide the essential characteristics of the voltage at a network user's supply terminals in public low-voltage and medium-voltage electricity distribution systems. The standards specify the ranges or values within which voltage characteristics should be expected to maintain, but they do not define a typical situation in a public supply system.

The American National Standard Institute Ansi-C84.1 code [9] and the European National standard EN 50160 code [10] are the most widely used voltage standards. The Ansi-C84.1 code says that the appliances can probably work while the voltage swings between (+/-5%), however swings between (+/-10%) for the EN 50160 code. The referenced one in this study is the EN 50160 code.

Chapter V: CVR implementation methodology

5. CVR implementation methodology

The IEEE 30 bus test system is used in this study to assess and evaluate the value of using CVR as a DSM technique. This chapter explore the software that was used. The network and load data are represented, while the specified coefficients for ZIP load modeling are also described. The desired load tap changing transformers that will be impacted by the developed CVR algorithm are also represented, and the CVR algorithm will be clear in the last section.

5.1. The simulation software

This software was developed as an open-source tool for electric power system simulation, by the Electric Power Research Institute, dealing with variant time. It can be used independently or it can be linked to other software like MATLAB [34].

This software was developed specially for analyzing distribution systems through converting all the systems to scripts. It has an object-oriented structure and controls can be modeled independently of the devices being controlled [36], all of these make Open-DSS the preferred software for this study.

5.2. Network and load profile data

The IEEE 30-bus test system was the case study that will be considered to be dealt with through this research. The IEEE 30-bus test system represents a simple approximation of the American Electric Power system as it was in December 1961. The equivalent system has 15 buses, 2 generators, and 3 synchronous condensers. Three voltage bases of 132, 33, and 11 kV, as well as a 100 MVA apparent power basis, are included in the test system. The data was taken from the IEEE 30-bus system data [37].

The layout diagram that represents the IEEE 30-bus test system is clear in the figure5-1 as seen below:

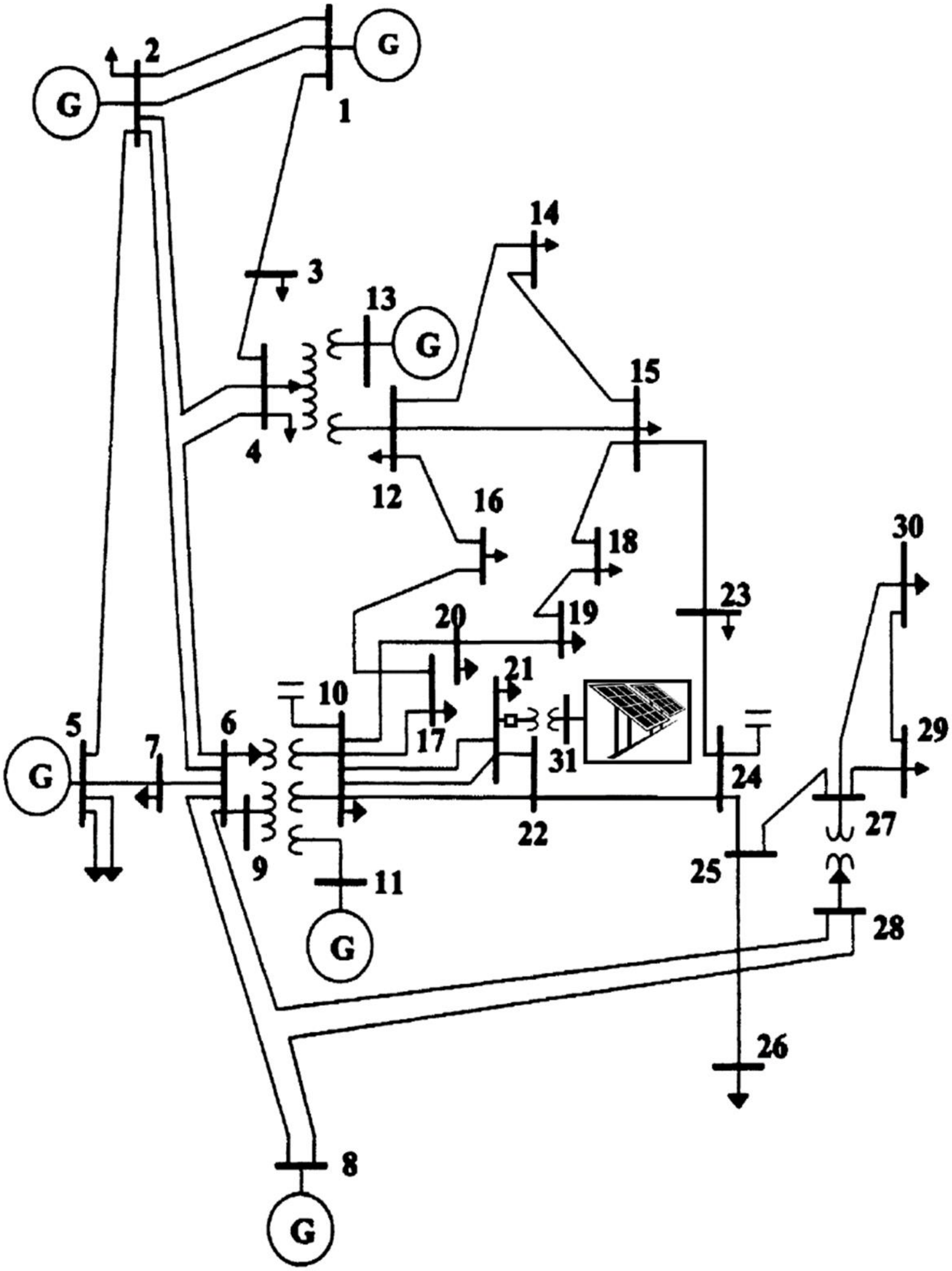

Figure 5-1: IEEE 30 Bus test system [38].

5.3. ZIP load modeling coefficients

Different behaviors were taken by the researchers by dealing with ZIP modeling. Some of them deal with each load alone and calculate the coefficients as seen in the table5-1, while the others classify the load profile into three classes (residential, commercial, and industrial loads) and calculate the coefficients of the ZIP load modeling as seen in the table5-2, so in this study the residential load model coefficients will be taken.

Table 5-1: Typical load coefficients [39].

Load Type	Zp	Ip	Pp	Zq	Iq	Pq
Fan	-0.47	1.71	-0.26	2.34	-3.12	1.78
Air conditioner	1.17	-1.83	1.66	15.68	-27.15	12.47
Led Light	0.58	1.13	-0.71	1.78	-0.8	0.02
Television	0.11	-0.17	1.06	1.58	-1.72	1.14
Incandescent Lighting	0.47	0.63	-0.1	0.55	0.38	0.07
Elevator	0.4	-0.72	1.32	3.76	-5.74	2.98

For more other devices ZIP-coefficients, the author of [39] provide tables that explain and represents that coefficients.

Table 5-2: ZIP load modeling coefficients for different classes [40].

Class	Z_p	I_p	P_p	Z_q	I_q	P_q
Residential	0.85	-1.12	1.27	10.96	-18.73	8.77
Commercial	0.47	-0.53	1.06	5.30	-8.73	4.43
Industrial	0	0	1	0	0	1

Table5-2 displays the results of a yearly average ZIP coefficient calculation for the three cases presented, based on the devices used in many semesters and the time-duration of use [40].

5.4. Desired on-load tap changing transformer for CVR

In this study, the Load Tap Changing transformers of 33kV zone are desired. These tab changing transformers are four; OLTC between Bus-6 and Bus-10, OLTC between BUS-9 and Bus-10, OLTC between Bus-4 and Bus-12, OLTC between Bus-28 and Bus-27. The layout diagram in the figure5-1 explains the position of these transformers.

5.5. CVR algorithm

Different scenarios were established with different conditions. The first was to deal with the original system without any additions. The second was to add a PV, while the third was the system without a PV but with CVR, and finally, the system with adding the PV and implementing the CVR.

The implemented CVR algorithm through the tested scenarios is shown in the figure5-2. The first step of this algorithm is based on selecting two reference values. One represents the expected value of the voltage at the assigned bus (V_b), and the other represents the minimum voltage value, that is allowed to be reached at any bus in the system (V_{min}). Measuring and recording the voltages at the different buses of the system is the next step. Then, finding the minimum voltage value of the different buses (V_{min}). After that, deciding whether to increment or decrement the tab-changer, if it is lower than (V_b) should be incremented, while if it is bigger, should be decrement. Again, repeat this process after 30 minutes (this time to follow the variation of load shape, so it could be one hour if the variation wasn’t fast).

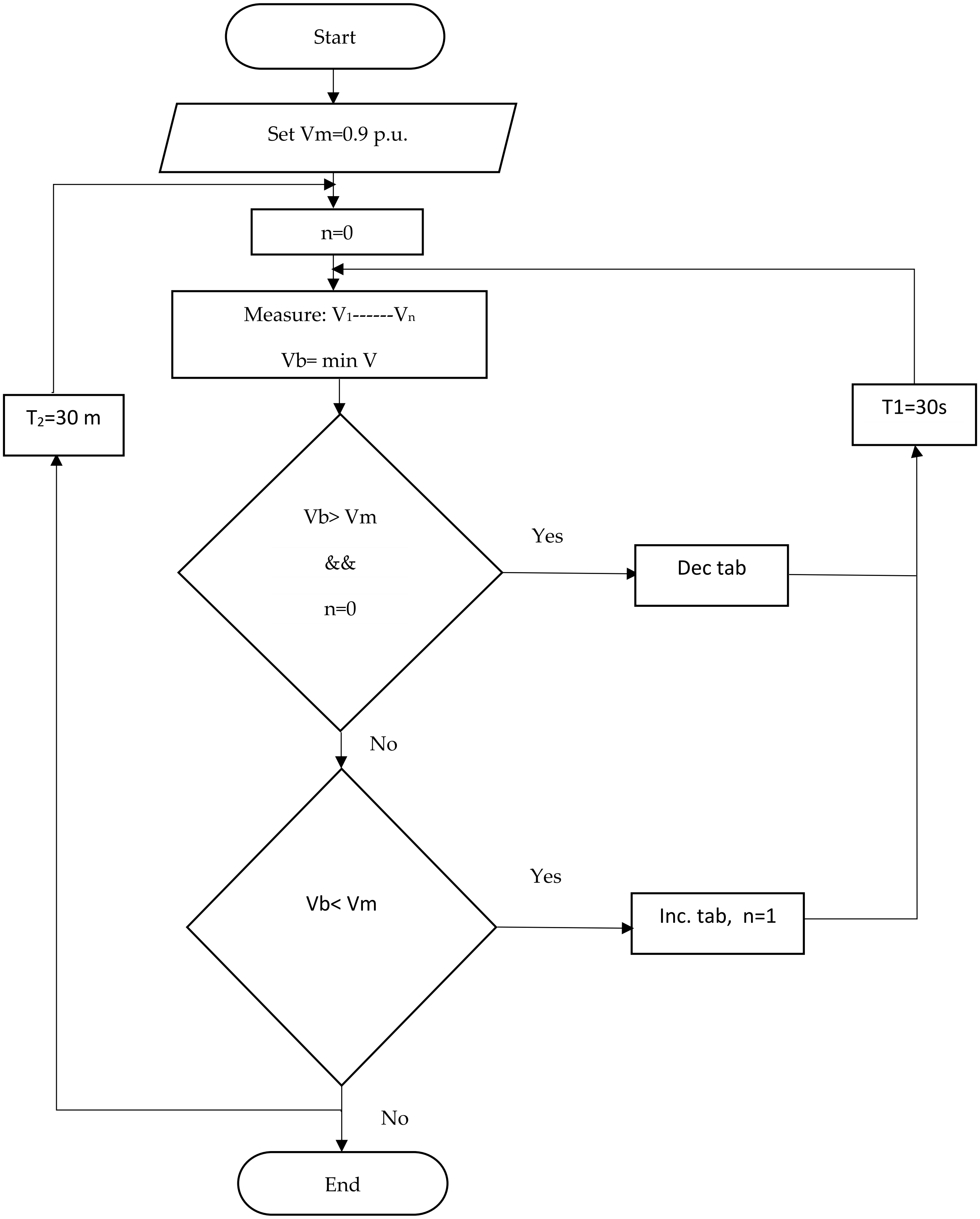

Figure 5-2: CVR algorithm.

Total losses of the system, conserved energy and the voltage profile are the main results that will be highlighted and taken into account to be recorded, discussed, and compared for the previously mentioned scenarios.

Chapter VI: Results and Evaluations

6. Results and evaluations

The IEEE 30-Bus test system was simulated with Open-DSS and MATLAB to implement the proposed CVR-Algorithm, which reduced the voltage by adjusting the assigned four tab-changing transformer taps with 33-kV region, which has the highest loads, each load of IEEE 30-Bus system is represented with the appropriate ZIP-model for three different cases; residential, commercial and industrial [34]. In addition, the PV unit was integrated in Bus-21 as an optimal place.

Different cases and Scenarios were used to test the verification of the proposed algorithms, as seen bellow:

- Residential load case:
    - Base case (without PV) scenario.
    - CVR without PV scenario.
    - CVR with PV scenario.
- Commercial load case:
    - Base case (without PV) scenario.
    - CVR without PV scenario.
    - CVR with PV scenario.
- Industrial load case:
    - Base case (without PV) scenario.

  - CVR without PV scenario.
  - CVR with PV scenario.

While it was discovered that adopting CVR was more efficient in the residential scenario, there was a desire to learn more about the impact of the integrating PV's penetration level. As follows:

- Residential load Case:
  - CVR with PV 10%.
  - CVR with PV 20%.
  - CVR with PV 30%.
  - CVR with PV 40%.
  - CVR with PV 50%.
  - CVR with PV 60%.
  - CVR with PV 70%.
  - CVR with PV 80%.

For each scenario the process will pass through specific steps as seen below:

- Reset all the tab changers that mentioned before.
- Implementing the proposed CVR algorithm.
- Simulate and record the data each half hour of the day.

- Calculate and evaluate the effect of the CVR algorithm for one day on the total energy losses, the consumed power, and the conserved energy.

6.1. Residential load case

To execute the residential case, a ZIP modeling for the load that acts like a residential load should be used, which will done using the ZIP modeling factors represented in the table5-2. All the loads of the system where follows that model.

6.1.1 Residential load with CVR without PV Scenario

The following buses: 10, 12, 14, 15, 16, 17, 18, 19, 20, 21, 23, 24, 26, 29, and 30, which they are in the 33-kV interest zone. The voltages on the aforementioned buses are shown to drop when the CVR-Algorithm is implemented as its clear in figure6-1, while there are almost no change at the values for the other busses.

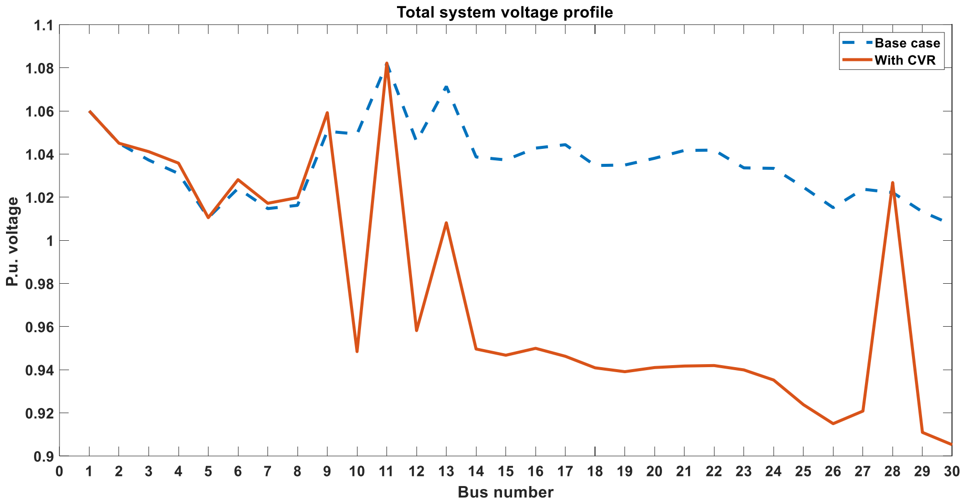

Figure 6-1 Base vs. CVR voltage profile

While implementing the CVR algorithm, figure6-1 stresses that no buses have a voltage of less than 0.9 per unit. It was the situation when the voltage was reduced at the impacted buses in order to keep all voltage profiles above 0.9 per unit.

During the 24 hours of the day, the voltage profile of each impacted bus changes. The voltage profile shape varied with the load profile (lower voltage during peak hours), but after adopting the CVR algorithm, the voltage profile has a more constant form over the course of 24 hours, which is beneficial for both the devices and the network. Note figure6-2 and figure6-3.

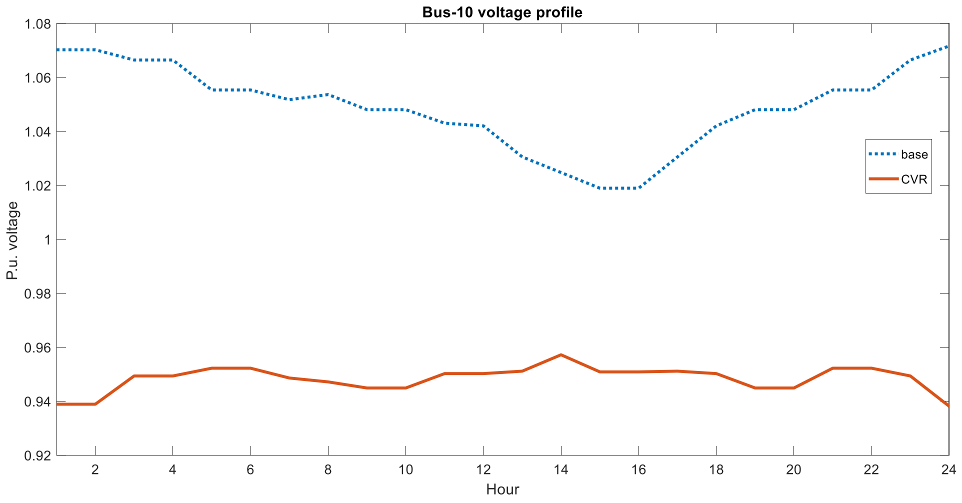

Figure 6-2 Bus-10 voltage profile

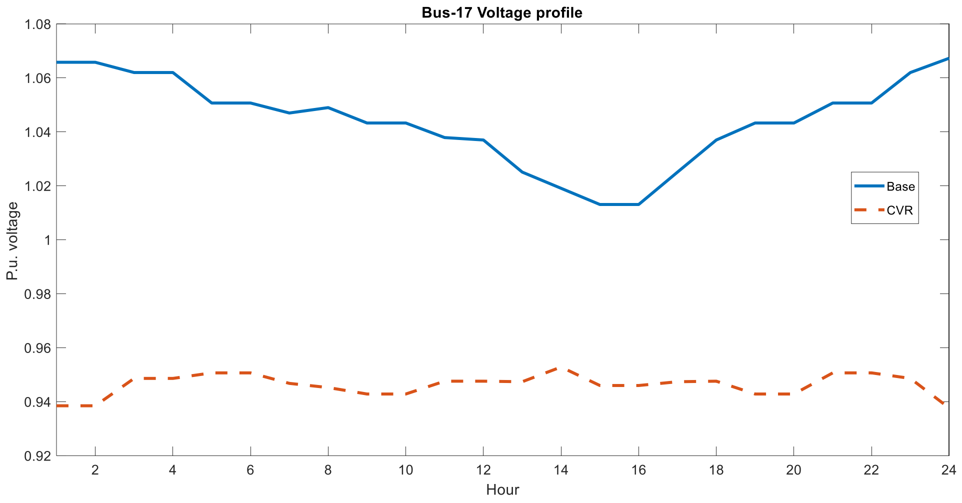

Figure 6-3 Bus-17 voltage profile.

The active and reactive powers have decreased considerably as a result of the voltage reduction, which will be repeated for the other scenarios, but with different value. This reduction is clear in figure6-4 which shows the percentage reduction of active power consumption. The daily reduction in the consumed power is varies from %5.3 to %11.8.

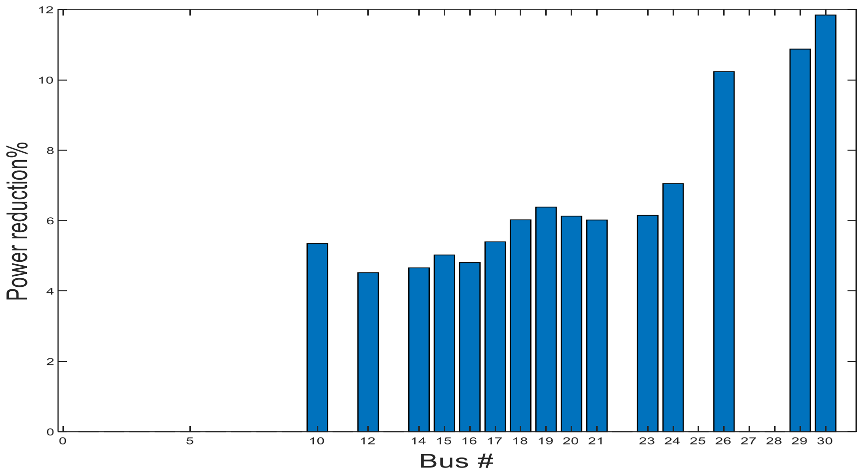

Figure 6-4 percentage active power reduction residential with CVR without DG

At the same time, the re-active power is affected by implementing the CVR algorithm but with a different percent as shown in figure6-5.

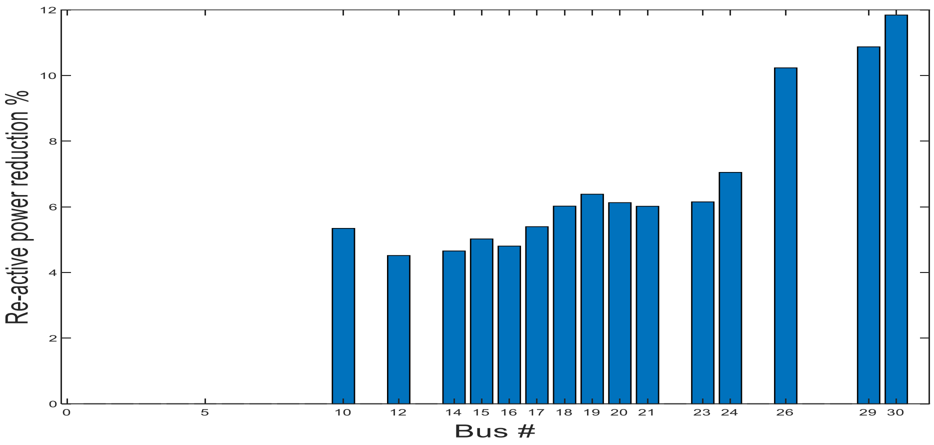

Figure 6-5percentage re-active power reduction residential with CVR without DG

The main target that emphasizes the efficiency of the CVR algorithm is the energy conserved. Table6-1 explores that the daily energy saved is %2.372 and, at the same time, there is a reduction in energy losses.

Table 6-1: Total energy analysis (residential load with CVR)

case	Total Load Energy (kWh)	Total Loss Energy (kWh)	Saved Load Energy (kWh)	Saved Loss Energy (kWh)	Percentage Energy Saved (%)
Base	3674220	124627.8	--	---	
With CVR	3587075	119583.8	-87145.2	-5044	2.371801

6.1.2 Residential load with CVR and PV Scenario

The integration of PV system with 10 MW at the BUS-21 which is the optimal place[7]. The per unit output power diagram of the PV based DG is clear in figure6-6. This integration will improve the system voltage profile and minimize overall power losses as it was clear in figure6-7; on the other hand, it will reduce the effect of CVR implementation by raising the voltage as seen in the figures 6-8, 6-9, lowering the CVR-factor by decreasing the reduction of the conserving energy as seen in table6-2, which refers to the contribution of the PV based DG of rising the voltage depending on its penetration level.

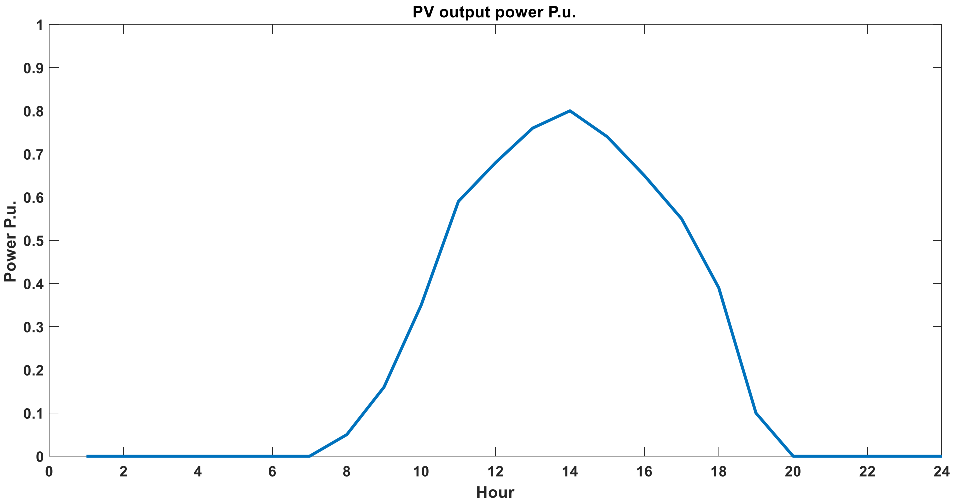

Figure 6-6 PV output-power profile

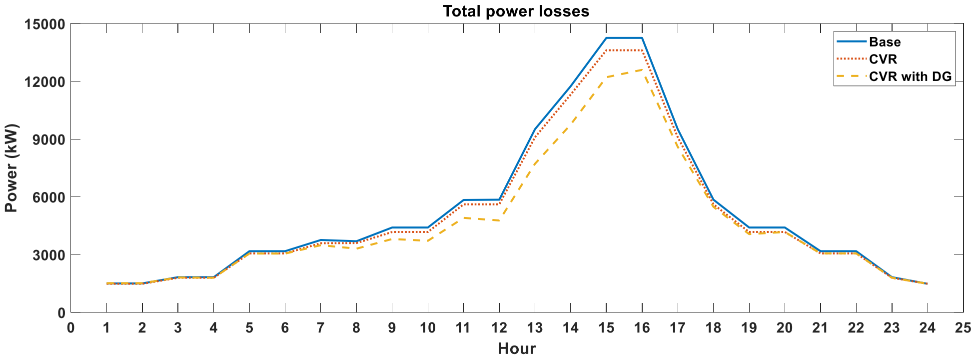

Figure 6-7: Total power losses

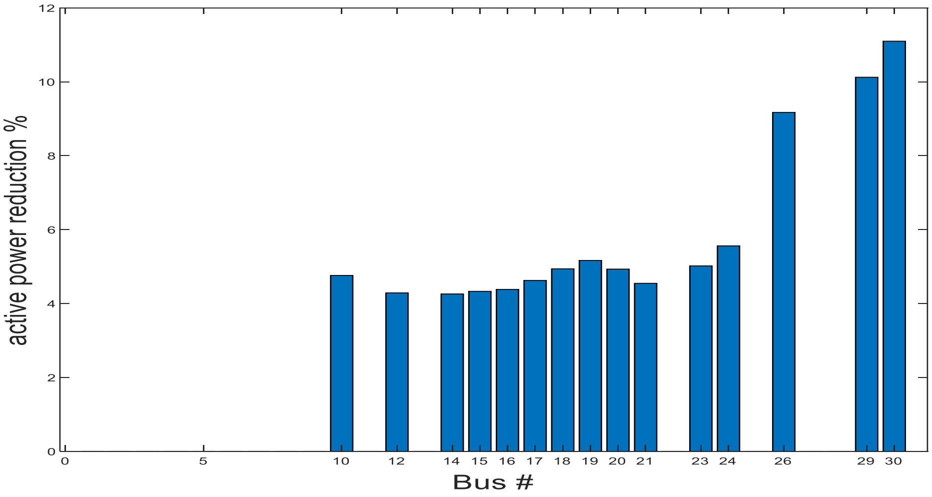

Figure 6-8 Percentage active power reduction residential with CVR and DG

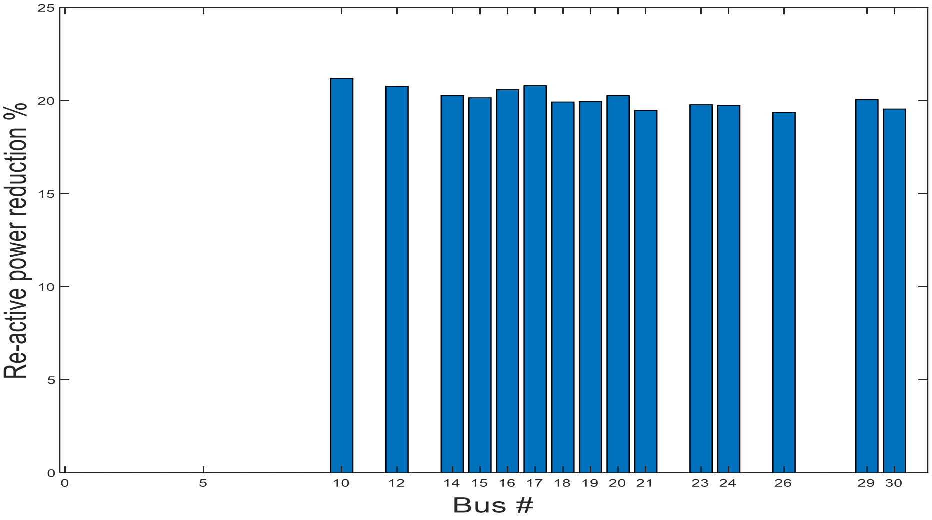

Figure 6-9 Percentage re-active power reduction residential with CVR and DG

Table 6-2: Total energy analysis (residential load with CVR and PV)

Scenario	Total Load Energy (kWh)	Total Loss Energy (kWh)	Saved Load Energy (kWh)	Saved Loss Energy (kWh)	Percentage Energy Saved (%)
Base	3674220	124627.8	--	---	
CVR + DG	3599972	110801	-74248.6	-13826.8	2.020799

6.1.3 Evaluation of CVR factor

As previously said, CVR_f will provide a sense of the efficiency of implementing the CVR; when it is high, the saved energy is large; in the two scenarios prior to the integration of PV, the saved energy is lower, but the total power losses are lower, and the saved energy losses are larger, as shown in figure6-7.

The calculation of CVR_f using the equation (4.3) will support the results before as follows:

- CVR_{fP} (Without DG) = 0.739942
- CVR_{fP} (With DG) = 0.690238
- CVR_{fE} (Without DG) = 1.33517
- CVR_{fE} (With DG) = 1.2279
- CVR_{fQ} (Without DG) = 2.3818

- CVR_{fQ} (With DG) = 2.26042

The results of CVR_f calculation that without using DG the conserving demand will be 0.74 kW for every %1 voltage reduction, conserving energy 1.34 kWh for every %1 voltage reduction, and conserving demand of reactive power is 2.38 kW for every %1 voltage reduction.

It should be noted that the presence of PV affects the efficiency with which the CVR is implemented. As seen in the coming section below, the reduction will vary depending on the penetration levels. If the PV is integrated to the network while the CVR is being implemented, the penetration level should be optimized.

6.2. Commercial load case

To execute the commercial scenario, a ZIP modeling for the load that acts like a commercial load should be used, which may be done using the modeling in the table5-2. All the loads of the system where follows that model.

6.2.1 Commercial load with CVR without PV Scenario

The different percentage reduction values according to the variation of ZIP load modeling coefficients are shown in figures 6-10, 6-11, while table 6-3 explains the reduction of percentage of conservation energy, and this corresponds to the nature of commercial loads.

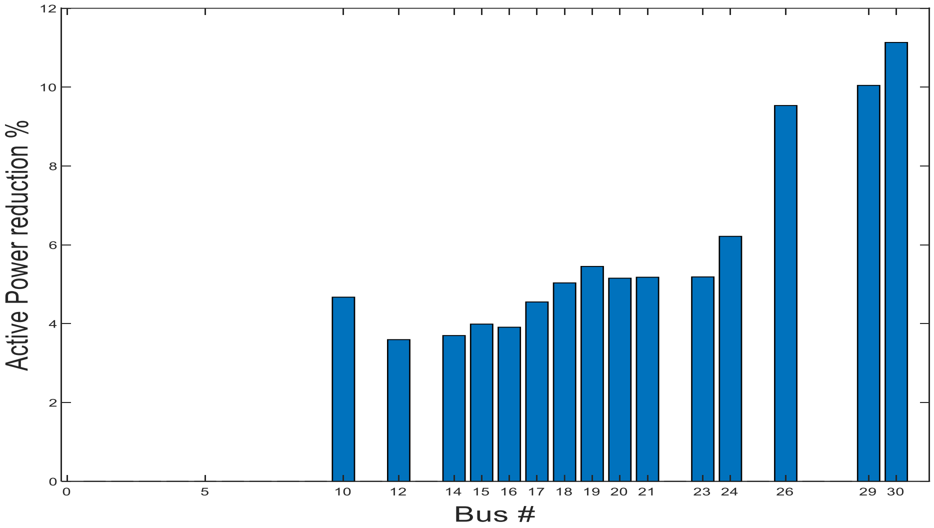

Figure 6-10 Percentage active power reduction commercial with CVR without DG

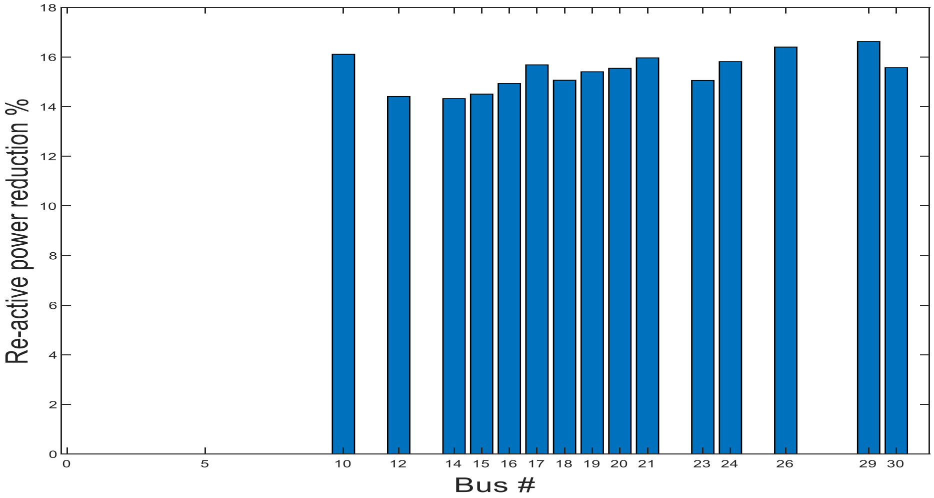

Figure 6-11Percentage re-active power reduction commercial with CVR without DG

Table 6-3 : Total energy analysis (commercial load with CVR)

case	Total Load Energy (kWh)	Total Loss Energy (kWh)	Saved Load Energy (kWh)	Saved Loss Energy (kWh)	Percentage Energy Saved (%)
Base	3669188	123977.9	--	---	
With CVR	3592725	120260.1	-76463.4	-3717.8	2.083932

6.2.2 Commercial load with CVR and PV Scenario

PV integration has the same effect on CVR implementation efficiency as the same case of residential loads; figures 6-12, 6-13, and table 6-4 highlight this effect.

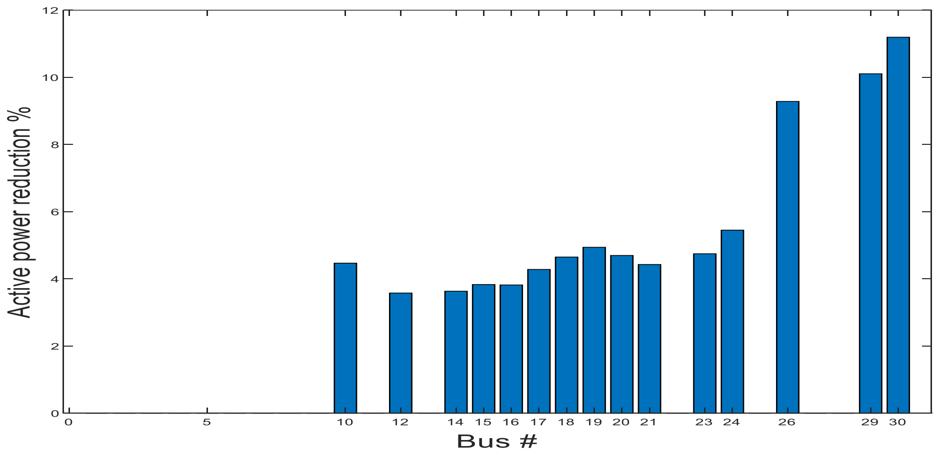

Figure 6-12 Percentage active power reduction commercial with CVR and DG

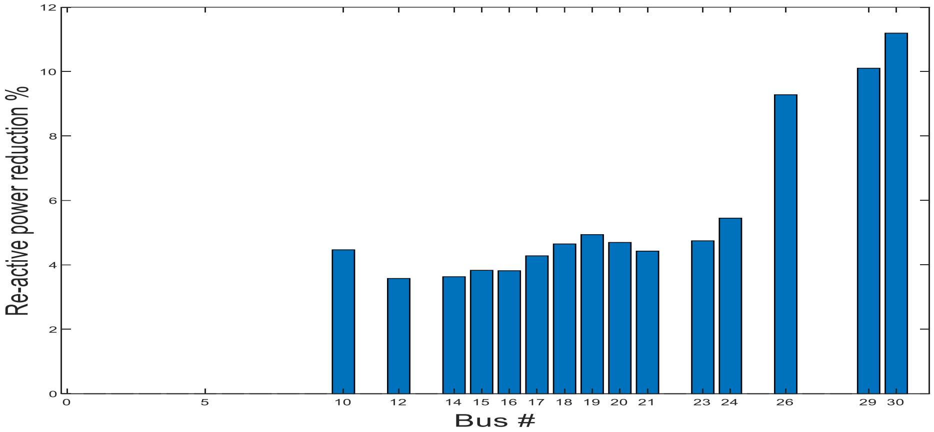

Figure 6-13 Percentage re-active power reduction Commercial with CVR and DG

Table 6-4 : Total energy analysis (commercial load with CVR and PV)

Case	Total Load Energy (kWh)	Total Loss Energy (kWh)	Saved Load Energy (kWh)	Saved Loss Energy (kWh)	Percentage Energy Saved (%)
Base	3669188	123977.9	--	---	
CVR+ DG	3597510	110890.8	-71678.4	-13087.1	1.953522

6.2.3 Evaluation of CVR factor

The calculation of $\mathrm{CVR_f}$ will support the results before as follows:

- $\mathrm{CVR_{fP}}$ (Without DG) = 0.665321
- $\mathrm{CVR_{fP}}$ (With DG) = 0.653951
- $\mathrm{CVR_{fE}}$ (Without DG) = 1.13044
- $\mathrm{CVR_{fE}}$ (With DG) = 1.08199
- $\mathrm{CVR_{fQ}}$ (Without DG) = 1.79185

- $\mathrm{CVR}_{\mathrm{fQ}}$ (With DG) = 1.76515

The results reveal that the CVR implementation performs better for residential loads than commercial loads, but still provides good energy and active/reactive power conservation values.

6.3. Industrial load case

To execute the industrial scenario, a ZIP modeling for the load that acts like a commercial load should be used, which may be done using the modeling in the table5-2. All the loads of the system where follows that model.

6.3.1 Industrial load with CVR without PV Scenario

The effect of using the industrial loads ZIP load modeling coefficients is shown in figures 6-14, 6-15, and table 6-5. The distinction is obvious when it comes to residential loads, which is due to the extremely different nature of industrial loads that contains more constant power loads.

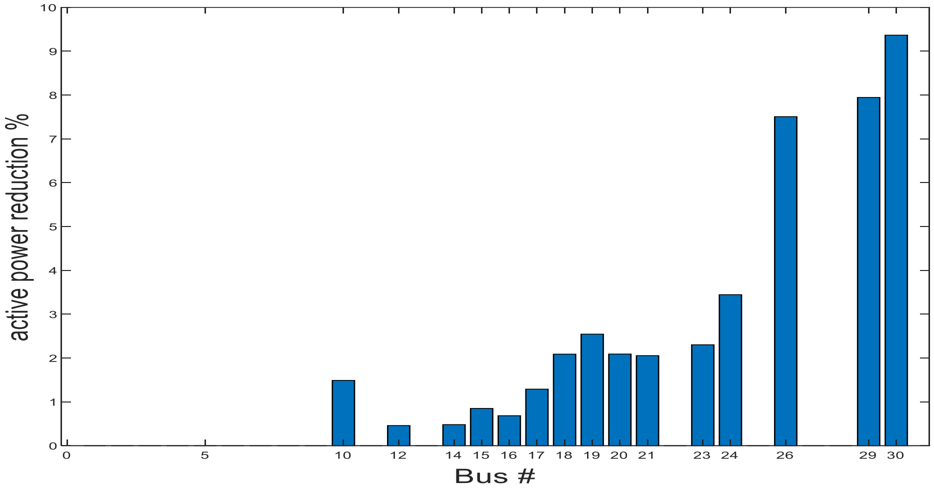

Figure 6-14 Percentage active power reduction industrial with CVR without DG

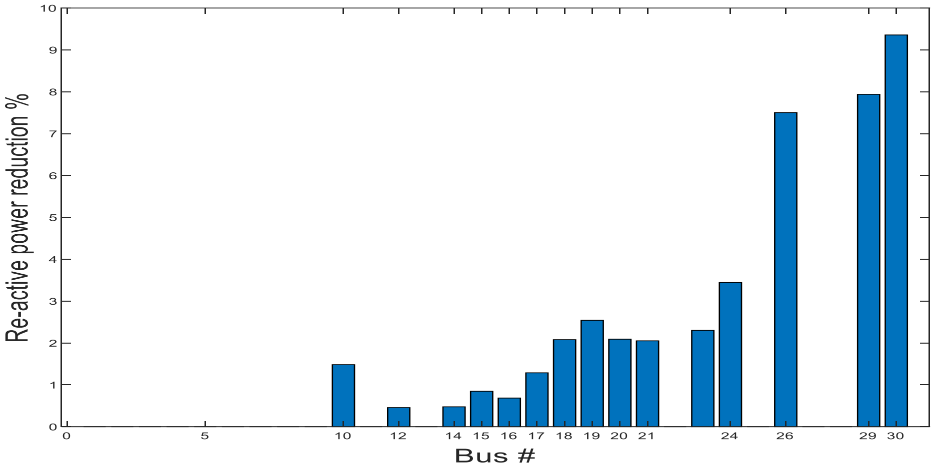

Figure 6-15 Percentage re-active power reduction industrial with CVR without DG

Table 6-5 : Total energy analysis (industrial load with CVR).

Case	Total Load Energy (kWh)	Total Loss Energy (kWh)	Saved Load Energy (kWh)	Saved Loss Energy (kWh)	Percentage Energy Saved (%)
Base	3636667	122143.4	--	---	
With CVR	3599253	121209.8	-37414.3	-933.6	1.028807

6.3.2 Industrial with CVR and PV scenario

Figures 6-16, 6-17, and table 6-6 show the effect of PV integration on the industrial load.

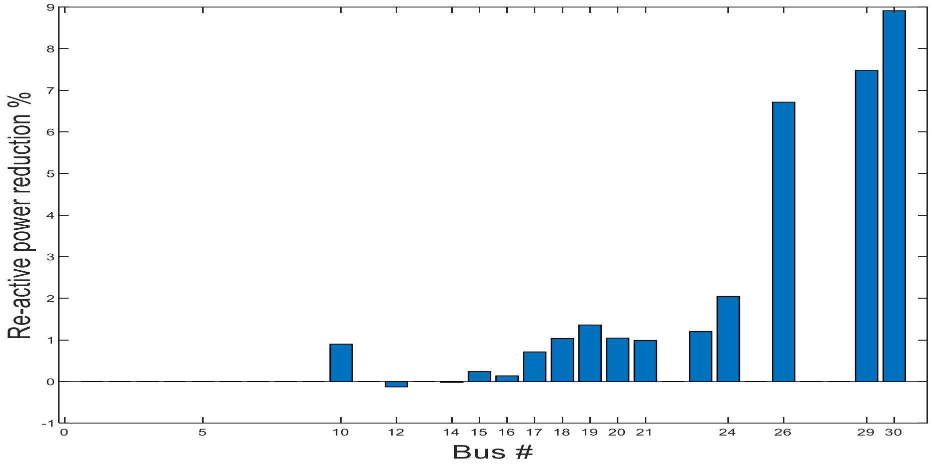

Figure 6-16 Percentage active power reduction industrial with CVR and DG

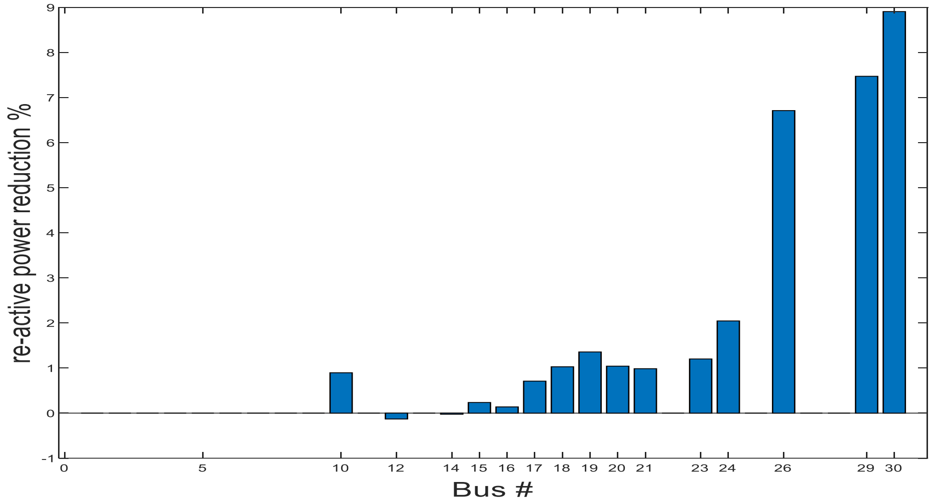

Figure 6-17 Percentage re-active power reduction of industrial with CVR and DG

Table 6-6 : Total energy analysis (industrial with CVR and PV).

Case	Total Load Energy (kWh)	Total Loss Energy (kWh)	Saved Load Energy (kWh)	Saved Loss Energy (kWh)	Percentage Energy Saved (%)
Base	3636667	122143.4	--	---	
CVR+DG	3623721	112871.2	-12946.4	-9272.2	0.355996

6.3.3 Evaluation of CVR factor

The calculation of $\mathrm{CVR_f}$will support the results before as follows:

- $\mathrm{CVR_{fP}}$ (Without DG) = 0.330889
- $\mathrm{CVR_{fP}}$ (With DG) = 0.249216
- $\mathrm{CVR_{fE}}$ (Without DG) = 0.567962
- $\mathrm{CVR_{fE}}$ (With DG) = 0.20001
- $\mathrm{CVR_{fQ}}$ (Without DG) = 0.33053
- $\mathrm{CVR_{fQ}}$ (With DG) = 0.247307

When comparing the results obtained for industrial loads to those obtained for residential and commercial loads, the results are not at the intended level ,because of the nature of the industrial loads that contains high percentage of constant power loads, but the conserved energy values still remain, indicating that CVR is worthwhile.

6.4. Impact of PV-penetration level

The fact that the distribution generators are one of the most technology which enhances the main utilities by improving the voltage profile, reduces the total power losses, and minimize the coast of network reinforcements, cannot be discussed. For the reasons stated above and others, distribution generators are a significant issue, as a result, it’s crucial to investigate the impact of PV-penetration level.

The impact of the PV penetration level will be explored in the previous simulation for the residential load as its clear in the table6-7.

Table 6-7: Comparison of various scenarios

Scenario	With/without DG	Percentage saving energy (%)	$\mathrm{CVR_f}$
Residential Load	Without DG	2.371801	0.739942
	With DG	2.020799	0.690238
Commercial Load	Without DG	2.083932	0.665321
	With DG	1.953522	0.653951
Industrial Load	Without DG	1.028807	0.330889
	With DG	0.355996	0.249216

While varying the penetration level from 10% to 80%, it’s worth noting that when the penetration level rises, the voltage profile rises as well, implying that the system is consuming more power, which effecting on the CVR_f. It was noticed that the best penetration level according to CVR_f was 30%, as seen in the figure6, This refers to that this penetration level compensated for the reduction of voltage under the set point, which is 0.9 per unit., while the penetration level over 30% or under will raise or lower the voltage profile in some buses over the set point, which reduces the positive effect of CVR.

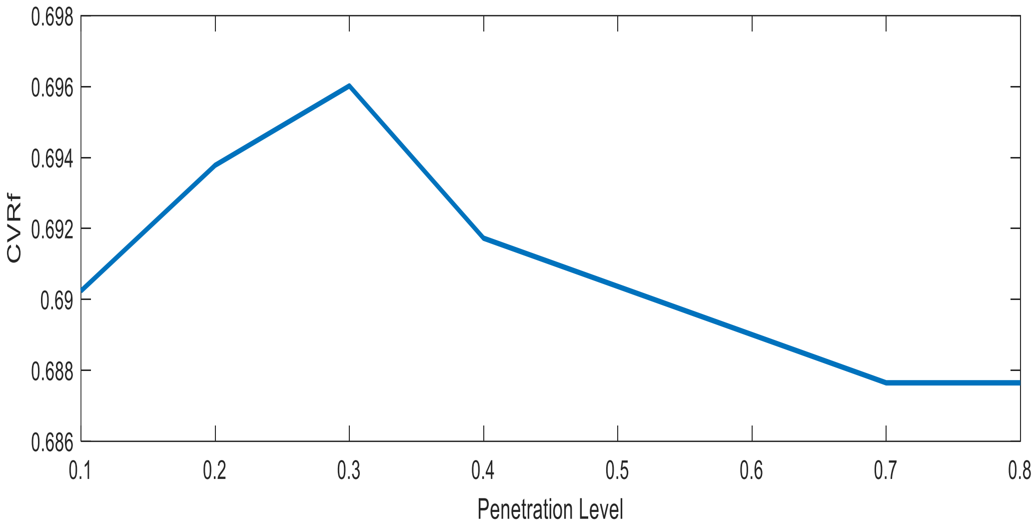

Figure 6-18: Impact of PV penetration level on CVR_f

It's worth noting that the goal of DG integration isn't to improve the effect of CVR implementation; as previously stated, PV integration diminishes the conserved energy caused by CVR. PV integration has numerous benefits and aims, and their presence in the smart grid is a priority for solving many problems of meeting the energy demand, and enhancing the efficiency and security of the electrical system, so the ability to execute CVR with an acceptable penetration-level of PV integration is the new challenge.

Chapter VII: Conclusions & recommendations for future work

7. Conclusions and recommendations future work

7.1. Conclusions

This thesis examines the DSM as a whole, as well as the implementation of CVR as a DSM activity over a ZIP Load as a combination of dynamic and static load. A proposed algorithm was given and explored with the purpose of optimizing the level of voltage decrease. It’s used in three different cases (residential, commercial, and industrial), both with and without the DG source. Proposed CVR-algorithm implementation was very efficient for residential loads (energy conserved for 1 percent voltage reduction was 1.33517 percent, with 4% total power losses reduction), acceptable for commercial loads (1.13044 percent of energy conservation, with 3.5% total power losses reduction), and not awful for industrial loads in the instance that was employed in this case-study (0.567962 percent of energy reduction for 1 percent of voltage reduction, , with 1% total power losses reduction). Because DG integration makes CVR deployment difficult, an optimal penetration level must be determined.

7.2. Recommendations for future work

As recommendations for this study, it is suggested to:

- Implement of the proposed CVR-algorithm in a practical case-study in Palestine.
- Address a multi-objective optimization algorithm that provide optimal location of tap-changing transformers in the presence of optimal capacity and location of PV based DG.
- Combine different DSM techniques according to the network variations in the presence of dynamic load models.

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Appendix

Appendix A: Residential load case

Table A-1 : Residential load active power (base case / with CVR)

Load bus #	Active power Base case (kW)	Active power With CVR (kW)	Reduction of Active Power (kW)	Reduction (%)
10	3175.675	3005.992	169.6833	5.343221
12	6127.092	5850.367	276.725	4.516417
14	3372.133	3215.163	156.9708	4.654941
15	4454.117	4230.45	223.6667	5.021572
16	1908.438	1816.771	91.66667	4.803231
17	4909.154	4644.321	264.8333	5.394684
18	1733.8	1629.417	104.3833	6.020494
19	5146.338	4817.779	328.5583	6.384314
20	1194.383	1121.204	73.17917	6.126941
21	9511.667	8939.4	572.2667	6.016471
23	1732.308	1625.758	106.55	6.150753
24	4705.313	4373.663	331.65	7.048416
26	1871.996	1680.421	191.575	10.23373
29	1283.421	1143.867	139.5542	10.87361
30	5647.383	4978.613	668.7708	11.84214

Table A-2: Residential load re-active power (Base case/ with CVR)

Load bus #	Reactive power Base case (kvar)	Reactive power With CVR (kvar)	Reduction of Reactive Power (kvar)	Reduction (%)
10	1202.404	928.9208	273.4833	22.74471
12	4553.333	3566.383	986.95	21.67533
14	943.6958	743.7417	199.9542	21.18841
15	1463.683	1154.383	309.3	21.13162
16	1071.092	837.9333	233.1583	21.76829
17	3440.838	2678.271	762.5667	22.16224
18	519.275	410.1792	109.0958	21.00926
19	1956.983	1543.708	413.275	21.11796
20	406.6958	319.2958	87.4	21.49026
21	6521.15	5119.713	1401.438	21.49065
23	919.7	727.6583	192.0417	20.8809
24	3821.725	3017.008	804.7167	21.05637
26	1243.796	991.8917	251.9042	20.25286
29	486.0083	385.475	100.5333	20.68552
30	1005.588	802.7125	202.875	20.17477

Table A-3: Residential load active power (base case/ with CVR and PV)

Load bus #	Active power Base case (kW)	Active power With CVR (kW)	Reduction of Active Power (kW)	Reduction (%)
10	3175.675	3024.479	151.1958	4.761061
12	6127.092	5864.263	262.8292	4.289624
14	3372.133	3228.458	143.675	4.260656
15	4454.117	4261.225	192.8917	4.330638
16	1908.438	1824.783	83.65417	4.383385
17	4909.154	4682.025	227.1292	4.626646
18	1733.8	1648.138	85.6625	4.940737
19	5146.338	4880.446	265.8917	5.166619
20	1194.383	1135.475	58.90833	4.932113
21	9511.667	9079.117	432.55	4.547573
23	1732.308	1645.346	86.9625	5.020036
24	4705.313	4443.625	261.6875	5.561533
26	1871.996	1700.283	171.7125	9.172697
29	1283.421	1153.488	129.9333	10.12399
30	5647.383	5020.571	626.8125	11.09917

Table A-4 : Residential load re-active power (base case/ with CVR and PV)

Load bus #	Reactive power Base case (kvar)	Reactive power With CVR (kvar)	Reduction of Reactive Power (kvar)	Reduction (%)
10	1202.404	947.5417	254.8625	21.19608
12	4553.333	3607.767	945.5667	20.76647
14	943.6958	752.3708	191.325	20.27401
15	1463.683	1168.733	294.95	20.15122
16	1071.092	850.6042	220.4875	20.58531
17	3440.838	2725.129	715.7083	20.80041
18	519.275	415.8125	103.4625	19.92441
19	1956.983	1566.5	390.4833	19.95333
20	406.6958	324.2792	82.41667	20.26494
21	6521.15	5251.113	1270.038	19.47567
23	919.7	737.8042	181.8958	19.77774
24	3821.725	3067.104	754.6208	19.74556
26	1243.796	1002.858	240.9375	19.37115
29	486.0083	388.5083	97.5	20.06138
30	1005.588	809.0208	196.5667	19.54745

Appendix B: Commercial load case

Table B-1: Commercial load active power (Base case/ with CVR)

Load bus #	Active power Base case (kW)	Active power With CVR (kW)	Reduction of Active Power (kW)	Reduction (%)
10	3178.283	3029.783	148.5	4.672334
12	6106.592	5887.063	219.5292	3.594954
14	3365.454	3240.988	124.4667	3.698362
15	4447.988	4270.55	177.4375	3.989164
16	1905.358	1830.854	74.50417	3.910244
17	4909.346	4685.921	223.425	4.551014
18	1733.671	1646.392	87.27917	5.034356
19	5148.508	4867.813	280.6958	5.451984
20	1194.663	1133.092	61.57083	5.153827
21	9528.346	9034.954	493.3917	5.178146
23	1732.425	1642.575	89.85	5.186372
24	4711.258	4418.438	292.8208	6.215342
26	1876.563	1697.654	178.9083	9.533833
29	1285.917	1156.754	129.1625	10.04439
30	5663.842	5033.246	630.5958	11.13371

Table B-2: Commercial load re-active power (Base case/ with CVR)

Load bus #	Reactive power Base case (kvar)	Reactive power With CVR (kvar)	Reduction of Reactive Power (kvar)	Reduction (%)
10	1172.017	983.1917	188.825	16.11112
12	4375.938	3745.354	630.5833	14.41025
14	918.4625	786.8917	131.5708	14.32512
15	1430.263	1222.746	207.5167	14.50899
16	1041.913	886.3333	155.5792	14.93208
17	3364.9	2837.063	527.8375	15.68657
18	511.625	434.5417	77.08333	15.06637
19	1932.963	1635.133	297.8292	15.40791
20	400.5917	338.3167	62.275	15.54576
21	6456.838	5425.754	1031.083	15.96886
23	907.4375	770.8083	136.6292	15.05659
24	3794.792	3194.579	600.2125	15.81674
26	1254.821	1048.992	205.8292	16.40307
29	489.3125	407.9625	81.35	16.62537
30	1172.017	848.975	156.6125	15.57423

Table B-3: Commercial load active power (Base case/ CVR and PV)

Load bus #	Active power Base case (kW)	Active power With CVR (kW)	Reduction of Active Power (kW)	Reduction (%)
10	3178.283	3036.229	142.0542	4.469525
12	6106.592	5887.983	218.6083	3.579875
14	3365.454	3243.158	122.2958	3.633858
15	4447.988	4277.5	170.4875	3.832913
16	1905.358	1832.571	72.7875	3.820148
17	4909.346	4699.117	210.2292	4.282224
18	1733.671	1653.025	80.64583	4.651738
19	5148.508	4894.063	254.4458	4.942127
20	1194.663	1138.538	56.125	4.69798
21	9528.346	9106.271	422.075	4.429678
23	1732.425	1650.158	82.26667	4.748642
24	4711.258	4454.363	256.8958	5.452807
26	1876.563	1702.342	174.2208	9.284041
29	1285.917	1155.946	129.9708	10.10725
30	5663.842	5029.708	634.1333	11.19617

Table B-4: Commercial load re-active power (Base case/ CVR and PV)

Load bus #	Reactive power Base case (kvar)	Reactive power With CVR (kvar)	Reduction of Reactive Power (kvar)	Reduction (%)
10	1172.017	989.4875	182.5292	15.57394
12	4375.938	3747.883	628.0542	14.35245
14	918.4625	787.9417	130.5208	14.2108
15	1430.263	1225.808	204.4542	14.29487
16	1041.913	889.25	152.6625	14.65214
17	3364.9	2853.004	511.8958	15.21281
18	511.625	436.5125	75.1125	14.68116
19	1932.963	1644.508	288.4542	14.92291
20	400.5917	340.325	60.26667	15.04441
21	6456.838	5494.05	962.7875	14.91113
23	907.4375	774.5792	132.8583	14.64105
24	3794.792	3220.175	574.6167	15.14225
26	1254.821	1051.767	203.0542	16.18193
29	489.3125	407.7	81.6125	16.67901
30	1172.017	848.3958	157.1917	15.63182

Appendix C: Industrial load case

Table C-1: Industrial load active power (Base case/ with CVR)

Load bus #	Active power Base case (kW)	Active power With CVR (kW)	Reduction of Active Power (kW)	Reduction (%)
10	3131.042	3084.433	46.60833	1.488589
12	6004.125	5976.575	27.55	0.458851
14	3317.771	3301.829	15.94167	0.480493
15	4388.413	4351.125	37.2875	0.849681
16	1877.008	1864.175	12.83333	0.683712
17	4838.6	4776.2	62.4	1.289629
18	1713.033	1677.263	35.77083	2.088157
19	5087.942	4958.463	129.4792	2.544824
20	1179.217	1154.563	24.65417	2.090724
21	9401.138	9208.004	193.1333	2.054361
23	1712.596	1673.167	39.42917	2.302304
24	4660.004	4499.454	160.55	3.445276
26	1868.663	1728.379	140.2833	7.507152
29	1281.371	1179.567	101.8042	7.944942
30	5659.338	5129.267	530.0708	9.366305

Table C-2: Industrial load re-active power (Base case/ with CVR)

Load bus #	Reactive power Base case (kvar)	Reactive power With CVR (kvar)	Reduction of Reactive Power (kvar)	Reduction (%)
10	1079.642	1063.638	16.00417	1.482359
12	4020.588	4002.213	18.375	0.457023
14	856.1667	852.0958	4.070833	0.475472
15	1337.9	1326.592	11.30833	0.84523
16	965.3333	958.7333	6.6	0.683702
17	3118.158	3078.017	40.14167	1.287352
18	481.7708	471.7542	10.01667	2.079135
19	1820.908	1774.642	46.26667	2.540856
20	375.1958	367.3542	7.841667	2.09002
21	6016.65	5893.229	123.4208	2.051321
23	856.2875	836.5958	19.69167	2.299656
24	3588.708	3465.163	123.5458	3.442627
26	1227.95	1135.821	92.12917	7.502681
29	480.5042	442.3625	38.14167	7.937843
30	1014.388	919.4792	94.90833	9.356221

Table C-3: Industrial load active power (base case/ with CVR and PV)

Load bus #	Active power Base case (kW)	Active power With CVR (kW)	Reduction of Active Power (kW)	Reduction (%)
10	3131.042	3102.842	28.2	0.900659
12	6004.125	6011.846	-7.72083	-0.12859
14	3317.771	3318.475	-0.70417	-0.02122
15	4388.413	4377.908	10.50417	0.239361
16	1877.008	1874.429	2.579167	0.137408
17	4838.6	4804.142	34.45833	0.712155
18	1713.033	1695.317	17.71667	1.034228
19	5087.942	5018.763	69.17917	1.359669
20	1179.217	1166.892	12.325	1.045185
21	9401.138	9308.238	92.9	0.988178
23	1712.596	1692	20.59583	1.202609
24	4660.004	4564.642	95.3625	2.046404
26	1868.663	1743.192	125.4708	6.714473
29	1281.371	1185.567	95.80417	7.476693
30	5659.338	5154.9	504.4375	8.913367

Table C-4: Industrial load re-active power (Base case/ industrial with CVR and PV).

Load bus #	Reactive power Base case (kvar)	Reactive power With CVR (kvar)	Reduction of Reactive Power (kvar)	Reduction (%)
10	1079.642	1069.975	9.666667	0.895359
12	4020.588	4025.829	-5.24167	-0.13037
14	856.1667	856.3792	-0.2125	-0.02482
15	1337.9	1334.746	3.154167	0.235755
16	965.3333	964	1.333333	0.138122
17	3118.158	3096.033	22.125	0.709553
18	481.7708	476.8167	4.954167	1.028324
19	1820.908	1796.208	24.7	1.356466
20	375.1958	371.2875	3.908333	1.041678
21	6016.65	5957.354	59.29583	0.985529
23	856.2875	846.0042	10.28333	1.200921
24	3588.708	3515.342	73.36667	2.044375
26	1227.95	1145.554	82.39583	6.710032
29	480.5042	444.6083	35.89583	7.470452
30	1014.388	924.0542	90.33333	8.90521