T.C.
ISTANBUL AYDIN UNIVERSITY
INSTITUTE OF GRADUATE STUDIES

DESIGN A MODIFIED PREDICTIVE CONTROLLER FOR ORGANIC PHOTO VOLTAIC IN OUTDOOR CONDITIONS

MASTER’S THESIS

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Department of Electrical and Electronics Engineering
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ONAY SAYFASI

DECLARATION

I declare that all knowledge in this document has been achieved and presented with academic rules and moral standards. I proclaim that, in accordance with the requirements of these rules and management, I have fully quoted and recommended all data and results that are not related to this thesis.

Fouad Aboubacar Simbala DJANKA

FOREWORD

At begging, I am great thankful to Allah Almighty, who offered me the ability to a accomplish my thesis. Without His blessing, I wouldn’t be able to do so. At second, I would like to thanks my supervisor Asst. Prof. Dr.Eylem Gülce ÇOKER for her great support during the whole year until my publication and accomplishing of this thesis. Also, great thanks to some other people who were behind me in this success and endless support such as, my beloved Mom, wife Amani, friends and Company Omraniyoun. This thesis was done for my Master in Electrical and Electronic Engineering about design a Modified Predictive Controller for Organic Photo Voltaic İn Outdoor Conditions and its importance and several condition.

JANUARY , 2024 Fouad Aboubacar Simbala DJANKA

DESIGN A MODIFIED PREDICTIVE CONTROLLER FOR ORGANIC PHOTO VOLTAIC IN OUTDOOR CONDITIONS

ABSTRACT

The use of renewable resources such as solar arrays has many advantages, including reducing the consumption of fossil fuels and the emission of environmental pollutants, improving the level of grid stability and reducing power losses in transmission and distribution lines. On the other hand, increasing the penetration level, leads to significant changes in the level of low voltage distribution network, so that if not controlled properly, it may lead to the voltage exceeding the allowable range. For this purpose, it is necessary to adopt solutions to overcome these challenges. In this Thesis, combination of dynamic voltage restorer and MPC-based maximum power point tracking is used for controlling the level of voltage profile. In order to achieve practical results, the state of the voltage profile level for a part of the residential distribution network of Makkah city from Saudi Arabia has been investigated, and in this regard, MATLAB and DIgSILENT softwares have been used to perform simulations. The time step is equal to one hour and the results have been implemented in the form of three scenarios. According to the obtained results, by applying the mentioned control method, not only more than 7% of voltage range changes are reduced, but by reducing the level of voltage unbalance, the reliability and stability level of the network is also increased.

Keywords: MPPT Controller, Predictive based, Outdoor Conditions, Organic Photovoltaic, Voltage profile.

DIŞ KOŞULLARDA ORGANİK FOTOĞRAF VOLTAİK İÇİN DEĞİŞTİRİLMİŞ BİR ÖNGÖRÜCÜ KONTROL CİHAZI TASARLAYIN

ÖZET

Küreselleşme ile birlikte birçok alanda değişiklik yaşandığı gibi yönetim anlayışlarında ve rekabet etme alanlarında da değişiklikler ortaya çıkmaktadır. Şirketlerin yeni düzene ve gelişmelere ayak uydurabilmesi, değişime gelişime uyum sağlayabilmeleri şirketlerin gelecekleri ve gelecek nesillere aktarımını etkilemektedir.

Türkiye de faaliyette bulunan şirketlerin %95'inin aile şirketleri olmasından dolayı aile şirketleri Türkiye de oldukça önemli bir konumdadır. Aile şirketleri tüm bunların yanında ekonomide de büyük bir öneme sahip durumdadır. Şirketlerin devam etmesi, gelecek nesillere aktarımı ve sürdürebilirliği için ise aile şirketlerinin de değişime ayak uydurarak kurumsallaşmaya doğru gitmesi gerekmektedir.

Değişime ayak uyduramayan birçok şirket rekabet edememekte ve yok olma tehlikesi ile karşı karşıya kalmaktadır. Tüm bunların yaşanmaması ve ayakta kalabilmek için gelişmeye açık olunması gerekmektedir. Aile şirketlerinde kurumsallaşma ihtiyacının neden ortaya çıktığı, neden bu yönde bir değişime ihtiyaç duyulduğu ve aile şirketlerinin olumlu olumsuz etkileri ortaya koyulacaktır ve bu çalışma sonucunda aile şirketlerinin yapısı, neden değişmesi ve kurumsallaşması gerektiği üzerine ortaya koyulacaktır.

Anahtar Kelimeler: Aile Şirketi, Kurumsallaşma, Çalışan Bağlılığı, İnsan Kaynakları Yönetimi, Motivasyon, Performans.

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LIST OF ABBREVIATIONS

PV : PhotoVoltaic

DVR : Dynamic Voltage Restorer

MPPT : Maximum Power Point Tracking

GHG : Green House Gas

DG : Distributed Generation

ADN : Active Distribution Network

DR : Demand Response

VVF : Voltage Unbalance Factor

LPF : Low Pass Filter

MPC :Model-Based Control

SVC :Static Var Compensator

AVR :Automatic Voltage Regulators

STS :Static Transfer Switches

NERC :National Energy Policy Consortium

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I. BASIC CONCEPTS

A. Introduction

Today, severe concerns about the increase in greenhouse gas emissions and the phenomenon of global warming, along with the growth of equipment technology related to renewable energy and the provision of incentive plans by governments, have increased the process of using clean and environmentally friendly resources (Tiba,2021). More than before ever, the universe which we belong to is threatened by our heavy reliance on fossil fuels, particularly oil and coal. Air contamination, ecological destruction besides climate change become the reason for this dependency. In addition to these problems, the melting of glaciers and the rise of the sea level are also other problems of climate change. For these reasons, extracting energy depending on renewable sources remains important. The sources of renewable energy are clean beside that it ground minimal damage toward the ambience. These resources also are endless in addition will be used for numerous years for future generations. In other words, energy is seen as a vital component for national development and as a major driver of economic prosperity.

The need for energy has grown dramatically in recent years due to urbanization, industrialization, population expansion, and improved living standards, particularly for electrical energy. Fossil fuels (oil, coal, natural gas, etc.) were the primary source of electric energy in the previous century, and they continue to be important in this sector now. Environmental issues including greenhouse gas (GHG) emissions, global warming, and climate change have also become more pressing in such a scenario. Fossil fuel combustion produces hazardous gasses into the atmosphere, such as carbon dioxide, that have an adverse influence on the environment. For these reasons, in order to reduce the amount of fossil fuels used, the contemporary world aims to enhance the penetration of renewable resources. In 2015, the conference of Climate Change by

United Nations which hold in Franc, most countries agreed to take steps to limit global warming in order to ensure a clean and living world for future generations.

One of the most important topics raised is the use of renewable energy sources besides improving efficiency of power plants (Zervos,2016).European Union has set a target for using renewable energy sources toward reducing greenhouse gas resurrection by at least 40% by 2030 and 80% by 2050. By 2030, about 30% of the total energy production should be extracted from renewable energy sources and by 2050, it is necessary to increase it to 100% (Zervos,2010). Similarly, most countries agreed toward increasing the sources of renewable energy usage. Indeed, renewable energy sources have piqued the interest of manufacturers, energy policymakers, and governments.

B. Solar Energy Characteristics

The sun, which is recognized as a source of energy, acts like a radiator whose surface temperature is equal to 5800 °K and produces a power of 1367 W/m2 in its atmospheric level (Gueymard,2004). Recent studies show that the earth receives a power amount of about 11*1010 MW at any moment from solar radiation (Kakimoto,2015). In fact, In the modern world, less energy is required than is absorbed from the sun (Wengenmayer,2011). Because solar energy offers so many advantages for the environment and the economy, it has garnered a lot of interest from investors, governments, and international organizations in the last 10 years. One of the most important sources of renewable energy available is solar energy, which according to statistical data, the average amount of solar irradiation received daily in Mecca city is estimated at 5 Kwh/m^2. Based on this, a significant potential for the installation and operation of solar power systems in this city is envisioned, so that by installing a panel with a capacity of 1 kW, more than 1.5 MWh of energy can be extracted per year. On the other hand, the use of such resources on a large scale causes problems in the field of regulating the voltage profile, injecting harmonic disturbances and complexity in the control of protection systems. Also, the unbalance and voltage sag not only reduce stability of the power system, while also have destructive effects to the equipment such as induction motors, power electronic converters and speed regulation drives (Bot,2022). For instance, the reduction of the voltage amplitude (between 60% to 90%

of the nominal voltage in the time interval between 10 to 100 ms) leads to significant losses in sensitive manufacturing industries (T.C.Archana,2015). According to the recommendation of the international electrotechnical commission (IEC), the permissible voltage unbalance in the distribution network should be less than 2% (Pachanapan,2017).

Fig. (1-1) shows the global installed capacity of photovoltaic panels (PV) over three decades. In this figure, an exponential growth in the capacity of solar power plants from 2000 to 2022 can be seen. In total, the total capacity of installed solar panels has increased from 1 Giga Watts to 1 Tera Watts in the world. Compared to other renewable energy sources, PV arrays have a low efficiency rate, and in this situation, the use of maximum power point tracker (MPPT) controllers for extracting maximum power in all operating conditions, especially in conditions where the amount of radiation is low, is very important.

C. Principals of MPC method

Real-time dynamic optimization using a nonlinear model as well as nonlinear optimization method is a very complex and computationally procedure. With the advancement in processors' capabilities and the invention of new algorithms, researcher's effort finally led to the practical implementation of feedforward control algorithms based on nonlinear models in the mid-1990s. After that, this field has attracted huge number of scientific researches. For example, between 1995 and 1998, 93 cases of practical implementation of these algorithms have been reported. The predictive controller is a special form of control in which the prediction of the future behavior of the system plays a role in determining the control signal, and if a higher efficiency than the nonlinear control is required, this control method is used. This controller is used for systems whose future behavior is different from their current behavior.

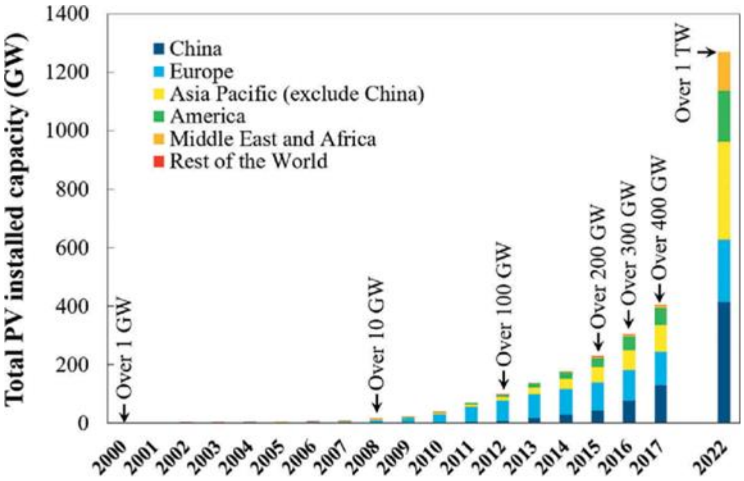

Figure 1: The global total capacity of solar PV installed from 2000 to 2017 and the forecast capacity by 2022 under optimal conditions (Solar Power Europe,2022)

Researches that took place in the 1960s and 1970s in relation to the pre-interface controller provided a proper structure for the emergence of model-based predictive controllers. In these years, basic methods were used by different companies. But the first presentation of a practical and scientific design of predictive controllers based on the model, is presented by Richart in 1976. After that, other different methods were quickly presented in different industrial applications. Until the early 1990s, linear models were often used in predictive model controllers due to their simplicity, but since in nonlinear systems, the need to identify the model continuously and online is felt, research in the field of predictive controller based on the non-linear model started in the 1990s (Jin,2017). All the ideas that arise both on a larger scale and on a smaller scale in the family of predictive control methods have the following basic properties:

1. Utilizing a model to forecast the process's output in subsequent times.
2. Generating a control sequence in order to reduce the target function
3. Using the creeping strategy (in order to move the process horizon and the need to calculate the initial control signal for each stage in the sequence.)

The MPC approach was initially designed and implemented in petrochemical and chemical industries as well as power plants, but today it is used in a wide range of different industrial environments such as food industries, metallurgical industries, vehicle manufacturing, wood and paper industries, and cement industries (Qin,2000). Numerous industrial implementations, especially in the petrochemical industry, and various software packages offered by reliable control and automation companies, confirm the importance of model-based predictive controllers. Due to the importance of these controllers, after stating the brief history above, the basic principles and definitions of these controllers will be introduced, then, while examining the block diagram, the different parts of these controllers and their advantages and disadvantages will be examined.

The MPC as a model-based control method has achieved remarkable success in industrial applications, especially in variable working conditions and the presence of limitations (Abdel-Rahim,2020). This controller has been improved in recent decades. A brief overview of predictive model controller applications and techniques can be found in (Rampradesh,2021). In the controller of the predictive model, at each moment of the sampling time, the control laws are obtained by solving an optimal control problem with a limited horizon, and in this controller the situation is considered as an initial condition for the next moment. This controller needs an accurate model of the system. In most of the applications where the MPC is used, the models are considered linear and the predictability of the system behavior can be done for a predefined predictive horizon. As a result, this controller shows poor performance for nonlinear systems that used a linear model for control (Potts,2014). In many applications, such as radiation and temperature variables, which have complex and highly nonlinear behavior in photovoltaic cells, a linear model for the system cannot meet the control objectives. Researchers have studied different mathematical models to identify complex nonlinear systems in predictive controller (Zeilinger,2014). But these methods, unlike linear systems modeling methods, did not provide a specific method to identify the system. The MPC method has many advantages over other methods, among which the following can be mentioned:

1. This method is attractive even for people who do not have high control knowledge because the concepts in it are set very simply while being intuitive.
2. This method can be used to control a wide range of mechanisms from systems with simple relationships to complex systems, as well as systems with high delay time or non-minimum phase to unstable systems.
3. Using this method, you can easily work with multiple input-multiple output (MIMO) systems.

4. This system inherently has the ability to compensate for dead times.
5. This system naturally provides the control input in such a way that the ability to compensate for measurable disturbances is created.
6. The resulting controller provides a simple linear control law to implement.
7. Expanding the predictive method in order to consider the limitations is conceptually simple and the ability to consider the limitations systematically in the design is provided.
8. If the reference input is known in the future (such as robotic science or automatic processes), using this method will be very effective.
9. The methodology of the predictive control approach is designed in an open form and based on certain principles, which enables the expansion of this method in the future.

For this reason, the modeling methods of nonlinear systems have been studied in the nonlinear predictive controller and the use of an efficient and effective modeling method for nonlinear systems as a significant success in the nonlinear predictive controller. Model Predictive control, abbreviated as MPC, was created in the late 1970's and has expanded dramatically since then. The term predictive control does not mean the application of a single control method, indeed this process consists of a wide ambit of control methods that obviously use the process model in order to attain the signal of control and via slashining the objective behavior. The application of mentioned design methods leads toward obtaining linear controllers which contain alike structure in practical terms besides the degree of liberty provided by them are optimal. The main difference between different MPC algorithms is applied in the model in order to show the method, noise besides cost functions that should be minimized. The goal of developing the MPC approach is to achieve control systems that can continue to work for long periods of time without any disruptions.

D. Problem Statement

Using an energy in competent way would lead to more than conserving fossil fuels besides energy, while it has also a financial benefit. Implementing efficient solutions of energy would help in solving several financial issues. Utilizing solar panels' energy has grown in importance. The MPPT control system may be used to maximize the output power that the PV module delivers. This comprises a control unit that facilitates the power transfer to maximize the power extracted from a PV array as well as a power transfer from the PV output to the load. The voltage power curve has just one peak point under normal circumstances and the absence of dust. Conventional techniques of tracking the maximum power point are well-executed and typically have an efficiency of around 99%. However, obtaining the maximum power point becomes extremely difficult when the PV array is covered with dust because of the nonlinear voltage power curve. Using an appropriate MPPT approach that can accurately monitor the maximum power point is crucial in this situation. Because the standard algorithms have a high risk of becoming stuck in the local extremum points and are unable to distinguish between the local and global peak locations, they are unsuccessful in this situation. In this thesis we will track the maximum power point by first outlining the fundamental ideas of meta-heuristic algorithms.

Over the past years, the development and use of practical and economic methods to improve voltage quality that can reduce line congestion and compensate for reactive power and voltage shortages have received a lot of attention. In this regard, various equipments like static var compensator (SVC), static transfer switches (STS), STATCOM, automatic voltage regulators (AVR) have been used. Among the types of equipment used, dynamic voltage recovery (DVR) is considered as the best option to reduce voltage fluctuations and disturbances at the low voltage level due to many advantages, including better functional and dynamic characteristics, smaller size, economy, and the ability to transmit reactive power continuously (Solar Power Europe,2022). Finally, by reviewing the literatures, it was revealed that using the capacity of IDVR, for sharing the adjacent lines capacities along with real-time control of renewable energy sources in order to to reduce the voltage sags and unbalance conditions has not yet been comprehensively investigated.

E. Research Importance

Electricity is a commodity that cannot be stored on a large scale with an appropriate economic solution, and this special feature makes the issue of price and demand forecasting in order to establish a balance between them with minimum generation cost to be of great importance. vAlso, equipping active distribution networks with intelligent power electronic devices called dynamic voltage recovery (DVR) can improve the level of performance and controllability of the network and provide high flexibility in both normal and emergency conditions, especially when make an error. Voltage fluctuation in the power network is one of the types of disturbances that can severely affect the reliability of the network. The standard range of voltage fluctuations in distribution networks is approximately 3% of voltage level. In fact, one of the main reasons for widespread power outages in today's world is improper planning of reactive power and voltage. For this reason, the National Energy Policy Consortium (NERC) has obliged energy companies to comply with stricter rules regarding the maintenance of voltage level and reactive power exchange in order to prevent such huge damage to the national grid as much as possible. be prevented One of the possible answers to deal with such outages is to use flexible switches in the network. By using DVRs, efficient management can be applied on power distribution in the network so that not only the limits of voltage regulation are respected, but also the power losses are significantly reduced.

F. Thesis Innovations

- Modeling the performance of DVR for controlling voltage deviations inside distribution network
- Improving capacity of using solar arrays with MPC-based MPPT approach
- Implementation of the proposed approach in the form of three different scenarios on a part of the distribution network of Makkah city

G. Thesis Structure

- The second chapter will provide an introduction to photovoltaic systems. The key elements of these systems will be outlined and thoroughly examined in the sections that follow. I will discuss batteries, inverters, and their interactions in the sections that follow.
- The idea of maximum power point tracking will be discussed in the third chapter, after which the chaotic and observing method and the incremental guidance method will be thoroughly explained. Flowcharts corresponding to

the functions of these two algorithms will be constructed, and their performance in fixed step and adaptive step modes will be reported.

- In the fourth chapter, a genetic algorithm will be used to first construct a model for extracting the greatest power under normal conditions while taking into account the intrinsic fluctuations of solar energy radiation. The findings will then be presented. The impact of dust on the panels will be examined in the following, along with the evaluation and comparison of actual measurement findings. After that, computer modeling will be created and put into practice in order to construct the genetic algorithm-based maximum power point tracking algorithm. The results will be analyzed along with other publications at the end of this chapter.
- The fifth chapter will begin with an analysis of the designs included in the thesis, followed by recommendations at the conclusion of the chapter.

II. POWER QUALITY

A. Introduction

Distributed generation (DG) is considered as a growing solution to solve the energy crisis and reduce environmental pollution, which is increasingly being integrated with active distribution networks (ADN). The widespread penetration of DGs can bring a positive contribution to improving the reliability of the power supply system and improving the economic level of the network (Yang,2017). However, the inherent fluctuation of the output power of DGs such as wind turbines and photovoltaic panels, which is combined with multiple loads on the demand side, can provide significant uncertainties to establish the balance of supply and demand. The rapid development of new control sources based on modern power electronics technologies has brought opportunities to improve the performance of ADNs (Albadi,2008). However, due to the many problems in effective coordination and proper planning for multiple controller resources, accurate control over operation considering the high flexibility of the network has become a serious challenge in microgrids (Bollen,2014). Therefore, it is very important to integrate multiple controllable resources in a single analytical framework in order to extract the best benefit from the potential benefits of controllable resources. The increase in the penetration level of of single-phase photovoltaic sources has created new opportunities and challenges in the performance, control and quality of the residential low voltage network. This increase can cause voltage imbalance, increase in voltage amplitude and reverse power distribution, which violates LV network standards. It is shown in (Yang,2017) that energy storage systems can be used as one of the reliable and appropriate solutions to reduce the problem of voltage sags. Furthermore, smart inverters are still frequently used to limit active power in addition to controlling reactive power due to improvements in the field of power electronics. In light of this, three techniques for controlling reactive power have been proposed: power factor with respect to injected active power (PF(P)), fixed power factor type control (PFP), and voltage-dependent reactive power management

(Q(v)). Additionally, a comparison is made between the online tap changer (OLTC) and various voltage control techniques.

B. DG Challenges

Solving the issue of voltage sag, the optimal configuration of energy storage systems can be a solution.vA voltage regulation method with optimal configuration is analyzed in (Samarakoon,2010). Based on the case study, a voltage regulation method is presented that combines reactive power controlled by photovoltaic inverter (PV) in nodes near the end of distribution feeders in order of reducing the problem of voltage drop. Results obtained in (AEMO) show that internal consumption with storage is the recommended solution to eliminate overvoltage and prevent reverse power distribution and reduce power losses. The paper focuses on evaluating five voltage control coping techniques. In this paper, five operating modes are defined with the aim of reducing overvoltage, which are as follows:

- Reduction of PV array’s penetrations
- Control of reactive power
- Automatic adjustment of transformer’s voltage
- Injecting the excess power into the grid
- Increase storage capacity

The simulation findings indicate that lowering the voltage imbalance and improving the voltage profile are the outcomes of raising the penetration level of the solar-wind hybrid system. For several minutes, the system voltage loss is more than permissible due to the tap changer function, which stops additional voltage drop. An online tap changer should be installed in the distribution transformer in the event of an imbalance (J.W.Taylor,2012). Writers of (A.Miller,2002) declares the energy storage systems are a potential remedy, particularly for power quality problems brought on by the increasing reliance of renewable energy sources on the grid. On the other hand, an inadequate positioning of the energy storage device may result in a significant decrease in power quality problems. Furthermore, an energy storage system that is too large may be exceedingly costly (A.Miller,2002). Writers of (Bollen,2014) introduces and describes a new method of utilizing an index-based single-point reactive power regulation strategy to sufficiently absorb reactive power at a chosen point to minimize the voltage increase. The suggested index determines the ideal location to implement this voltage-reactive power (Volt/Var) control approach using short circuit analysis.

It is possible to identify a subset of bidirectional PV inverters that are significantly impacted by grid performance goals and voltage protocols by using the suggested single-point reactive power control method. The quantity of active and reactive power supplied by the PV system in the chosen node can also be ascertained using this method. The inverter needed to remove the overvoltage in the distribution feeder has been measured and minimized using the voltage impedance gain index.. In the following, a comparison is presented to express the cost-effectiveness in demand to show the economic advantage of single-point reactive power control compared to droop control strategies. In (Albadi,2008), a single-phase photovoltaic inverter that is connected in different phases as desired is suggested as an efficient way to improve the voltage profile along the feeder and reduce the unbalanced voltage. To balance the negative and zero sequence components of the voltage and control it within the allowed range, photovoltaic inverters are coupled in a triangle or star-zigzag pattern, respectively. The suggested community-based algorithm adjusts reactive power control settings based on local measurements and data exchange with related agents, treating every PV system as an intelligent agent. In (S.Crone,2009), with evaluating the voltage profile in residential radial networks despite the high penetration coefficient of PV, compared the capability of voltage control solutions from the point of view of economic issues. In this paper, voltage control solutions such as adjusting the tap changer during no-load and using decentralized parallel capacitors have been compared to the tap changer with the ability to operate in on-load situation(Goetzberger,2003).

Small-scale PV units make up a sizable fraction of installed PV units. These units are typically connected to low pressure (LV) distribution systems, which are not built to manage a large amount of the energy produced by PV. The effectiveness, benefits, and drawbacks of the various overvoltage prevention techniques and tactics for LV networks with PV are thoroughly examined and analyzed in (G.A.Darbellay,2000). The article presents a mathematical framework that serves as the basis for describing the voltage produced by high photovoltaic penetration as well as classifying, highlighting, and contrasting various strategies aimed at facilitating PV penetration at higher levels. Strengthening the network, using electrical energy storage, using PV inverters to absorb reactive power, using medium-to-low voltage transformers in conjunction with online tap changers, lowering active power, and demand response (DR) are some of the methods under investigation. Voltage sensitivity analysis is used to facilitate local, distributed, and centralized voltage control approaches for coordination amongst voltage control units. The analysis indicates that increasing PV acceptance capacity in weak voltage networks may be accomplished effectively and dependably by coordinating voltage control units and using a mix of overvoltage protection techniques. In (A.Kraskov,2004) the possibility voltage improvement methods such as increasing the line conductor cross section, using capacitor and automatic tap changer has evaluated. It has also reviewed emerging voltage reduction methods such as reactive power control of PV inverter, use of distributed storage system and coordination between equipment control systems and PV inverter.

Writers of (M.A.Hall,2000) has classified the ways of improvement as follows, considering the voltage imbalance resulting from PV penetration in LV networks:

- Increasing the cross section of the feeder conductor
- Using of power electronics
- Designing a new control scheme for PV converters

C. Artificial Neural Network

The neural network method (ANN) has been proposed as the most effective and common method among researchers since 1980. This method has been used in many different predictions so far. We may include this technique's optimal performance for complicated, nonlinear systems that are independent of prior assumptions as one of its advantages over other approaches. This method uses neural network (ANN) training on the gathered data initially. After that, each category's weight coefficients are determined to generate the output power (W). The output of the neural network is actually obtained from the weighted sum of the inputs and the use of an activation function. Training and evaluating the output are two crucial components of the neural network. The training data set and learning algorithm are used to train the network in the initial stage. By choosing suitable weight values, the neural network training process attempts to create an accurate mapping between inputs and outputs. In this case, the error is computed after comparing the network's output to the actual output value. Consequently, the resulting error is used to update the neural network's weight and bias values.

In the test phase, the final output results are compared with the actual results and if the error created is less than the determined threshold value, it can be used to predict the future horizon. In this project, the amount of radiation in the last week has been applied as input to the network, and the received output is equal to the estimate of the amount of radiation in the next 24 hours. The MATLAB program serves as the implementation environment for the intended strategy, which uses the recurrent neural network technique to produce outputs with the lowest feasible error. The necessary information and connections are found in scientific publications, and by employing the recurrent deep neural network technique, an effort is made to increase the method's efficiency and result accuracy. The criterion used is to minimize the root mean square error (RMSE). In fact, optimization in the first category is designed and implemented to reduce as much as possible the estimation of solar radiation with measured values. Next, using the heuristic algorithm, the duty cycle is determined so that the voltage difference obtained with the maximum power point voltage (Vmpp) is minimized (Figure 2-1). In other words, in this project, a neural network is used to estimate the quantity of radiation over the following 24 hours based on the solar data that is now available. Following, the voltage value at the computed maximum power point (MPP) and the duty cycle of the inverter are determined based on the estimated data and the solar panel's current-voltage curve. Ultimately, the precision of the suggested technique is ascertained by contrasting the outcomes of the given method's approach with the findings of other papers.

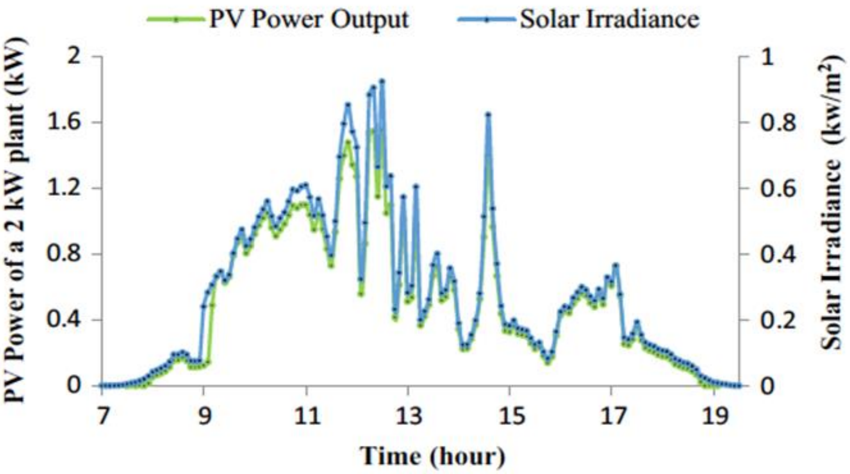

Figure 2: The matching pattern of PV output power vs. solar irradiation (A.Miller,2002)

D. Dynamic Voltage Restorer

From the point of view of distribution network protection, the most important modes of network operation are normal, abnormal, and error conditions. Under normal conditions, power plants and operators fully fulfill their operations and all consumers receive electric power at the rated voltage/frequency. Under abnormal conditions, a number of consumers receive electrical energy at a voltage or frequency other than nominal values. In this case, a number of network restrictions have been violated. If such conditions continue for a short period of time, it will lead to errors and malfunctions of the system. In this regard, corrective measures can be in the form of adjusting the equipment, disconnecting a part of the load and connecting the backup capacity. All these preventive measures are taken to prevent errors and equipment damage. In this situation, effects such as increased wear and tear may be applied to the equipment.

The increase of voltage-sensitive equipment in distribution networks has caused the attention of distribution companies to solve power quality problems related to network voltage, such as lack of voltage. An element based on a converter connected in series with the name dynamic voltage restorer has been presented in order to protect sensitive loads from lack of voltages (Yang,2017). Serial connection of DVR allows it to inject serial voltage into the network. Since the amplitude and phase of this injection voltage can be changed in series, the exchange of active and reactive electricity between the distribution system and the DVR can be managed. Passive AC elements are not necessary to provide reactive power, but an external power source is required to exchange the DVR's active power with the network. The type of voltage disturbance (depth of voltage deficiency), the amount of power needed by the load under protection, and the direction and range of injected voltage all affect how much active and reactive power the DVR provides. The operational characteristics of energy distribution networks are actually altered by the explosive rise of distributed generation (DG) resources linked to the grid. In the future, it may be possible to use microgrid systems to purposely isolate (or "island") portions of the network, which will necessitate the redesign of protection measures and highly flexible distribution management systems. The results of the simulations show that the use of a DVR for distribution systems based on distributed generation can be fruitful for voltage regulation besides can also be a suitable assurance for voltage quality for sensitive loads. In addition, the DVR algorithm is a straightforward and efficient one.

E. In-line DVR

In-line dynamic voltage restorer (IDVR) suggested makes use of several inverters coupled to a DC voltage link. To put it another way, the IDVR under consideration is made up of several DVRs connected to various lines in order to make up for the low voltage in the feeders that connect each one. A fault's spread of voltage insufficiency is dependent on both the feeders' voltage level and fault current. For example, the lack of voltage occurring in transmission lines may have a greater impact and spread than distribution systems. Since the feeders to which the IDVR is connected are fed from different posts and may have varied voltage levels, a voltage deficiency occurring in one of the feeders will have little effect on the other feeders. Therefore, when a fault occurs within one of the feeders, to lower the voltage created by injecting power from the DC link to the malfunctioning feeder, the DVRs in the healthy feeders can be programmed to inject active power to the energy storage device in the DC connection. control and keep its voltage constant under these changes. A basic IDVR consists of two DVRs as shown in Figure 2-2. As can be seen, the supply lines which is feeders have varying voltage levels., which means that the lack of voltage appearing in one of the feeders will have less impact on the other feeder, allowing them to be regarded as two diverse sources. (Baghaee,2008).

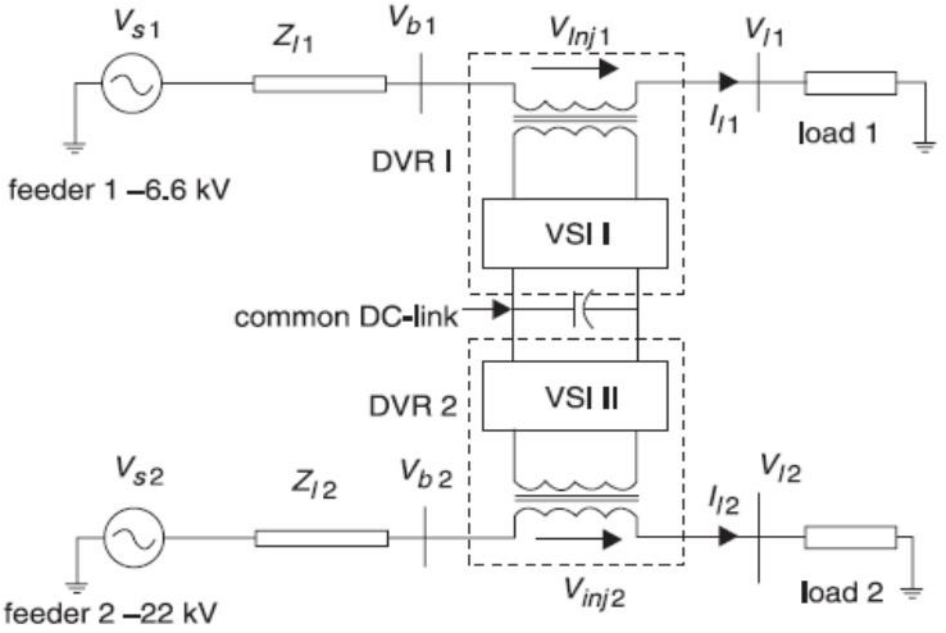

Figure 3: Schematic of In-line DVR (A.Miller,2002)

A DVR's ability to compensate is based on its maximal active power output and its ability to inject voltage. As a result, one could argue that the storage element's capacity limits how long voltage shortfall compensation can last. The DVR also offers the option of making up for any long-term voltage deficit if the DC link energy storage element is powered by an external source. For this reason, many researchers have paid consideration towards the energy storage used in DVR besides optimizing its use for compensation. Due to the limited energy capacity of the energy storage element in conventional DVRs, in recent years the concept of IDVR in which some amount of voltage recoverers are linked to the distribution network through a common DC link has been presented. Similar to the concept of In-line power flow controller (IPFC) in which numerous inverters linked to common DC connection are used for series compensation in multi-line transmission systems. In IDVR, several DVRs which separately have the task of protecting sensitive loads connected to distribution feeders, are fed from a DC link with an energy storage element. Take two sensitive loads in an industrial estate, for instance, that are fed by two separate feeders, possibly at different voltage levels. Separate DVRs are attached to each of these feeders, protecting sensitive loads that are connected to them. IDVR is created if the DC links of these two DVRs are joined to a single DC link. Because sharing the DC connection greatly increases its storage capacity compared to utilizing a separate storage element for each DVR, this can lower the cost of power quality improvement equipment.

III. RESEARCH METHODOLOGY

Distributed generation (DG), which also includes renewable generation sources, is recently being integrated with the distribution network at a growing rate. In this regard, traditional distribution networks are becoming active distribution networks (ADN) with the help of technologies for storage, distribution of energy produced by local sources and momentary management of power exchange. Due to the asymmetric three-phase structure and the presence of single-phase loads with different natures, distribution networks have an inherent imbalance, which becomes worse with the presence of renewable resources. This state of imbalance in ADNs leads to increased losses and ineffective use of the used equipment. Most of the presented approaches consider three-phase distribution networks as balanced, but in reality this assumption is not true and the results obtained in these cases have many obvious differences with the actual results. In fact, the performance optimization of active distribution networks cannot be well modeled without considering the three-phase imbalance.

A. PhotoVoltaic Panel Model

Photovoltaic system model basically depends on the parameters placed in the datasheet of the factories that produce it. Among the many models presented for PV arrays in scientific articles, the five-parameter model consisting of two diodes is the most common model used by designers (Das,2018). This model not only does not require high computing time, but also creates a balance between precision, efficiency and simplicity. Its mathematical model is in the form of Equ. (3-1). Current and voltage calculation in these conditions are performed according to Equ. (3-2) to Equ. (3-4). Figure 3-1 displays the proposed system's input block diagram. PV arrays, a boost converter, and a prediction controller make up this system.

$$Power = I_{PV} * V_{PV}$$

$$I_{pv} = I_{ph} - I_0\left(e^{\frac{V_{pv} + R_{sg} I_{pv}}{N_s V_T}} - 1\right) - \frac{V_{pv} + R_{sg} I_{pv}}{R_{sgh}} \tag{3-1}$$

$$i_L(k+1) = i_L(k) + \frac{T_s}{L} v_{pv}(k) - \frac{T_s}{L} v_o \tag{3-2}$$

$$v_{pv}(k+1) = -\frac{T_s}{C_1} i_L(k) + v_{pv}(k) + \frac{T_s}{C_1} i_{pv}(k) \tag{3-3}$$

$$v_o(k+1) = -\frac{T_s}{C_2} i_L(k) + (1 - \frac{T_s}{RC_2}) v_o(k) \tag{3-4}$$

V_{pv} : Module voltage for photovoltaic cell

I_{pv} : Output current of the photovoltaic cell

I_{ph} : Short circuit current

I_0 : Reverse saturation current

A PV system's P-V curves exhibit several peaks, including multiple local peaks and a single global peak, when it is exposed to dust. The presented algorithms are very likely to be trapped in one of the local peak points. The reason for this is that they cannot differentiate between the local peak points and the global peak point. As a result, the algorithm oscillates around local peaks and remains in that area, and a significant reduction in PV efficiency is observed (Das,2018).

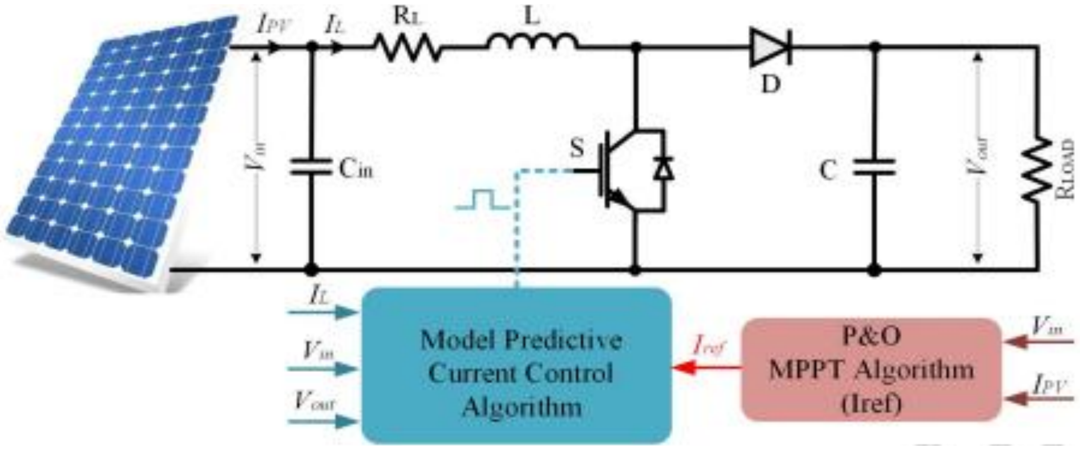

Figure 4: Block diagram of the proposed system (Ro,1998)

B. IDVR model

Dynamic voltage restorer (DVR), which is known as the most versatile member in the family of compensators, can protect sensitive loads against undesirable fluctuations by injecting a voltage in series. In other words, voltage improvement is done through voltage injection by a transformer which is placed in series with the network. In order to solve the disturbances created in the voltage profile, many approaches have been used, such as the use of series active power filters and the injection of negative voltage sequence in series with distribution network lines and DG control for compensating voltage unbalance in DG terminals. In the described methods, a huge amount of the capacities for the interface converters are need for compensation, which causes interference in the field of power supply through DGs. Figure (3-2) shows the schematic of how IDVR is connected to the transmission system.

In the inline dynamic voltage restorer (IDVR), in order to connect two adjacent feeders, two DVRs are used that are coupled in sequence through a typical DC link. During regular operations of the network, the inverters are inactive, but if there is a voltage shortage in one of the nearby feeders, taking into account the load factor of the connected lines and at the same time considering the available capacity, the required power deficit is provided as much as possible.

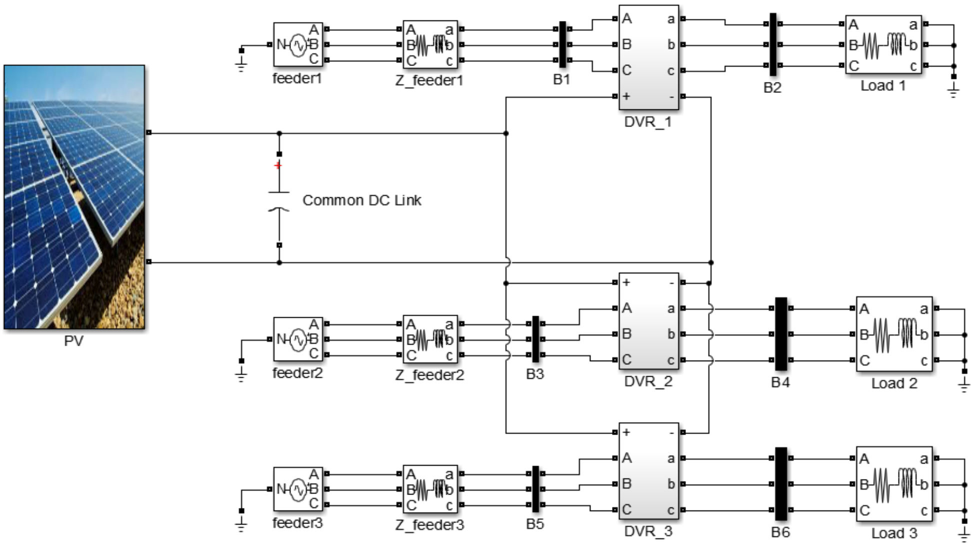

Figure 5: Schematic of IDVR series connection to distribution network

The period of IDVR operation is exactly after the voltage sag occurs in the network. In fact, before the protection system works, IDVR compensates the voltage deficiency as much as possible by using the power absorbed from nearby lines or the power produced from PV arrays and energy storage sources. In fact, in this situation, the settings of the protection systems are made in such a way that they operate according to the IDVR function. In order to simultaneously compensate active and reactive power within the network independently of each other, capacitor banks and auxiliary self-contained reactors can also be used.

C. MPC-based MPPT approach

For Boost converter behavior modelling, proper discrete time is required. Therefore, according to presented model for the boost converter, Equation (3-5) to (3-8) can be expressed to describe the system. Equ. (3-5) and (3-6) expressing the performance of the system in the OFF state and Equ. (3-7) and (4) for the ON state are presented (Priyadarshi). If the time-discrete model is transformed into the form of state space matrices, then the corresponding matrices presented as Equation (3-9). The implementation of the MPPT approach through applying the FS-MPC method could be done both in accordance with current and voltage.

$$\boldsymbol{i_{pv}(k+1) = i_{pv}(k) + \frac{T_s}{L}\left(v_{pv}(k) - v_c(k)\right)} \tag{3-5}$$

$$\boldsymbol{v_c(k+1) = \left[1 - \frac{T}{RC}\right] v_c(k) + \frac{T_s}{C}\left(i_{pv}(k)\right)} \tag{3-6}$$

$$\boldsymbol{i_{pv}(k+1) = i_{pv}(k) + \frac{T_s}{L}\left(v_{pv}(k)\right)} \tag{3-7}$$

$$\boldsymbol{v_c(k+1) = \left[1 - \frac{T}{RC}\right] v_c(k)} \tag{3-8}$$

$\boldsymbol{T_s}$: Sampling period

$\boldsymbol{k+1}$: Forecasting time step

$\boldsymbol{k}$: Current time step

Based on current, the objective function in this stage is in the form of Equation (3-10) and based on voltage, Equations (3-11) to (3-12) represent the PV voltages and the cost function for choosing ideal switching mode. Finally, the design of final function is presented in the form of Equation (3-13). In this situation, the reference voltage value is generated via the P&O method. for the FS-MPC loop, and the optimal state value is determined in the estimation stage according to the design of the objective target (Ahmed,2022).

$$\boldsymbol{A_d} = \begin{bmatrix} \mathbf{1} & -\frac{T_s(1-d)}{L} \\ \frac{T_s(1-d)}{C} & \mathbf{1}-\frac{T_s}{RC} \end{bmatrix}, \boldsymbol{B_d} = \begin{bmatrix} \frac{T_s}{L} \\ \mathbf{0} \end{bmatrix}, \boldsymbol{C_d} = [\mathbf{0} \quad , \quad \mathbf{1}], \boldsymbol{D_d} = \mathbf{0} \tag{3-9}$$

$$\boldsymbol{g_i} = \left|\boldsymbol{i_{pv}}(\boldsymbol{k}+\mathbf{1}) - \boldsymbol{i_r}\right| \tag{3-10}$$

$$\boldsymbol{v_{pv}}(\boldsymbol{k}+\mathbf{1}) = [\mathbf{1}-\boldsymbol{d}]\boldsymbol{v_c}(\boldsymbol{k}+\mathbf{1}) \tag{3-11}$$

$$\boldsymbol{g_v} = \left|\boldsymbol{v_{pv}}(\boldsymbol{k}+\mathbf{1}) - \boldsymbol{v_r}\right| \tag{3-12}$$

$$\boldsymbol{g_{i,v}} = \left|\boldsymbol{v_{pv}}(\boldsymbol{k}+\mathbf{1}) - \boldsymbol{v_r}\right| + \boldsymbol{\lambda}.\left|\boldsymbol{i_{pv}}(\boldsymbol{k}+\mathbf{1}) - \boldsymbol{i_r}\right| \tag{3-13}$$

$\boldsymbol{v_r}$: Reference Voltage

D. Objective function

One module's voltage decreases as it gets less light as a result of dust. As a result, it functions as a load rather than a generator. After this, a hot spot is produced, and in order to prevent damage, a bypass diode is typically employed in parallel with each PV module. Furthermore, each string—a grouping of series modules in a current path—ends with a blocking diode to stop reverse current from occurring due to voltage mismatches between parallel strings.

On the other hand, Tracking the real maximum power point of MPP can occasionally be difficult due to the non-linearity of the I-V characteristic of the PV curve caused by various environmental conditions (especially the amount of radiation, the amount of ambient temperature, and the presence of dust). Dust accumulation on a portion of the solar panel complicates tracking. To solve the above challenge, a novel approach is presented in this project. The steps of the proposed approach are as follows:

1. Prediction of the solar panel current by the neural network unit based on the temperature value and the ambient radiation level and sending it to the controller unit.
2. Measuring the actual voltage and current at panel level besides sending it to the controller unit

3. Calculation of current and voltage changes according to Equation (3-14) to Equation (3-15)
4. IV. Calculation of voltage value at the highest point of power by a predictive controller system for future time steps using Equation (3-16)
5. V. Adjusting the duty cycle of the inverter based on the Equation (3-17) (this relation shows the objective function that seeks to reduce the disparity between the current and voltage of working point with reference current and voltage in any situation.

$$\frac{di_L}{dt} = \frac{v_{pv}}{L} - \frac{v_o}{L} \tag{3-14}$$

$$\frac{dv_{pv}}{dt} = -\frac{i_L}{C_1} + \frac{i_{pv}}{C_1} \tag{3-15}$$

$$\frac{dv_o}{dt} = \frac{i_L}{C_2} - \frac{v_o}{RC_2} \tag{3-16}$$

$$\min O.F = W_A.|V_o(k+1) - V_{MPP}|^2 + W_B.|i_o(k+1) - i_{MPP}|^2 \tag{3-17}$$

In the first stage of the proposed approach, the 3-phase output voltage and current (Load side) are measured and transferred to the αβ reference frame, Consequently, the voltage and current's positive and negative sequences are retrieved. The voltage unbalance factor (VUF) regulator block imports the α components of the voltage's positive and negative sequences (Figure 3-3).

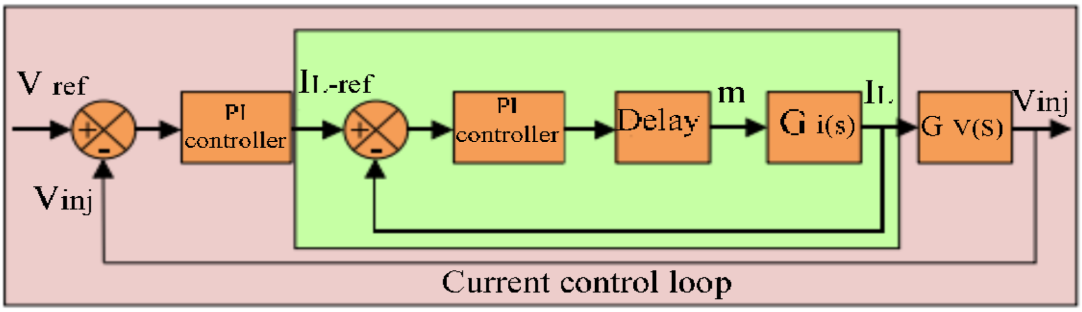

Figure 6: Schematic of IDVR + MPC-based MPPT controller

The average values of the rectified waveforms are calculated by applying two absolute value functions and low-pass filters (LPF). According to the theories of symmetric components (J,D.Glover,1993), an unbalanced electrical system can be evaluated by two balanced systems of positive/negative sequences which separated from each other. Therefore, the single-phase diagram of the IDVR inverter can be used to model the positive/negative sequences control system. In this case, the dynamics of the output voltage can be calculated by as Equation (3-18). In this situation, the VUF at the common coupling point is calculated according to Equation (3-19). Assuming Equations (3-21) and (3-22), Equation (3-23) can be obtained.

$$V_o = \frac{V_{dc}}{LCs^2 + r_L C_s + 1} d - \frac{L_s + r_L}{LCs^2 + r_L C_s + 1} i_o \tag{3-18}$$

$$VUF = \frac{\bar{V}_a^-}{\bar{V}_a^+}.100 = \frac{abs\left(V_a^-\right).LPF}{abs\left(V_a^+\right).LPF}.100 = \frac{abs\left(V_a^-\right).LPF}{230\sqrt{3}.\frac{2}{p}}.100 \tag{3-19}$$

$$VUF^* = 0.5\% \tag{3-20}$$

$$abs\left(V_a^-\right) = \pm V_a^- \tag{3-21}$$

$$UCR_a = \left[0.5V_a^- \pm 0.39\left(V_a^-\right)^2 .LPF\right].PI \tag{3-22}$$

$$V_{DVR} = V_{load} + Z_s . I_{line} - V_s \tag{3-23}$$

d : Duty cycle

r_L : Inductive filter resistance

$\bar{V}_a^-$: Mean value of PCC negative sequence

$\bar{V}_a^+$: Mean value of PCC positive sequence

V_{DVR} : Output voltage of DVR

V_{load} : Load voltage

Z_s : Line impedance

I_{line} : Line current

V_s : Grid voltage during fault condition

In this project, the objective is defines as minimizing both the voltage drop and unbalance status between 3 phases in the distribution feeders. Therefore, the objective function is defined as Equation (3-24). The initial phrase on right side expresses amount of voltage drop and the second one ie related to the voltage unbalance conditions. It should be noted that both expressions are in P.U. system. For measuring the unbalance status, the definition of the US National Energy Agency was used (Equation (3-25)) (Savaghebi,2012).

According to the European standard EN50160, the acceptable range for unbalance conditions in low voltage networks must be less than 2% in more than 95% of the 10-minute intervals during a week. In this situation, chaos-based genetic algorithm has been used. The inclusion of chaotic mappings in the main structure of heuristic algorithms is used in order to improve the process of producing random numbers to create next generation (each state can be created just once time).

$$\min \; J = \Delta V_{p.u} + \Delta U_{p.u} \tag{3-24}$$

$$\Delta U = \frac{max\{\Delta|V_i^{AB}|, \Delta|V_i^{BC}|, \Delta|V_i^{CA}|\}}{|V_i^{ave}|} \tag{3-25}$$

$$V_i^{ave} = \frac{|V_i^{AB} + V_i^{BC} + V_i^{CA}|}{3} \tag{3-26}$$

$\Delta|V_i^{AB}|$: Absolute value of amplitude deviation of line AB from rated for bus i

V_i^{ave} : Mean. of 3 phase voltage for bus i

The steps of the proposed approach are as follows:

- Real-time measurement of voltage, current and power values on the load side
- Extracting positive/negative voltage & current sequences and transferring to the regulator block
- Using the IDVR control system to correct the unbalance error values and reduce/increase the voltage range level with the help of series voltage injection (the first priority is to use the energy produced from PV arrays with using MPC-based MPPT controller, if not sufficient, using adjacent transmission lines with considering operation constraints

E. Model of Distribution Network

Figure (3-4) shows a part of the radial distribution network of Makkah, which was obtained by GIS software. In this Fig., the parts of residential units, the location of the distribution network route and the number of branches are specified. Also, the profile of solar irradiation in Makkah was used as an input.

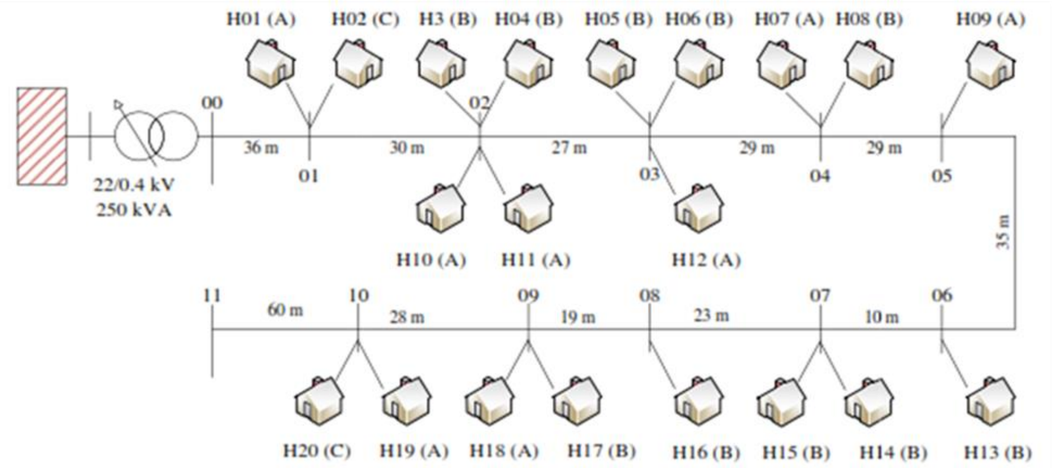

Figure 7: Schematic of the under study distribution network

IV. RESULTS AND DISCUSSION

The residential distribution network under study is three-phase four-wire and feeds single-phase household loads. In this situation, the inequality between household loads in different time durations causes an unbalance in the distribution voltage level. With increasing the penetration of solar PV panels, the voltage unbalance criteria especially for residentials which are located far from the distribution feeders shows a significant decrease. These challenges and related solutions are defined as three scenarios which are expressed in the following section. In this project, the distribution network is modeled in DigSilent software and the results of the scenarios are described below.

A. Scenario 1: Normal load without PV panels

In this scenario, it is assumed that no consumer uses solar panels. Deviations in the voltage for buse 8, bus 9 and bus 10 are shown in Figures (4-1), (4-2) and (4-3), respectively. As it is clear in these figures, in this condition, there is not any violation of the standard threshold value (1.05 P.U.). Grid voltage profile graphs for three grid phases are shown in Figures (4-4) to (4-6).

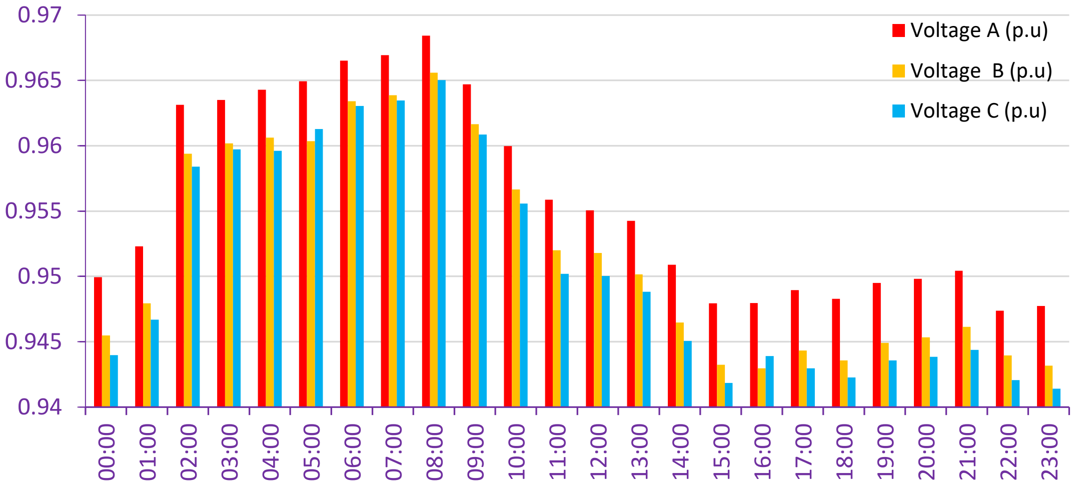

Figure 8: Deviation of the voltage in bus 8 (without using of solar panels)

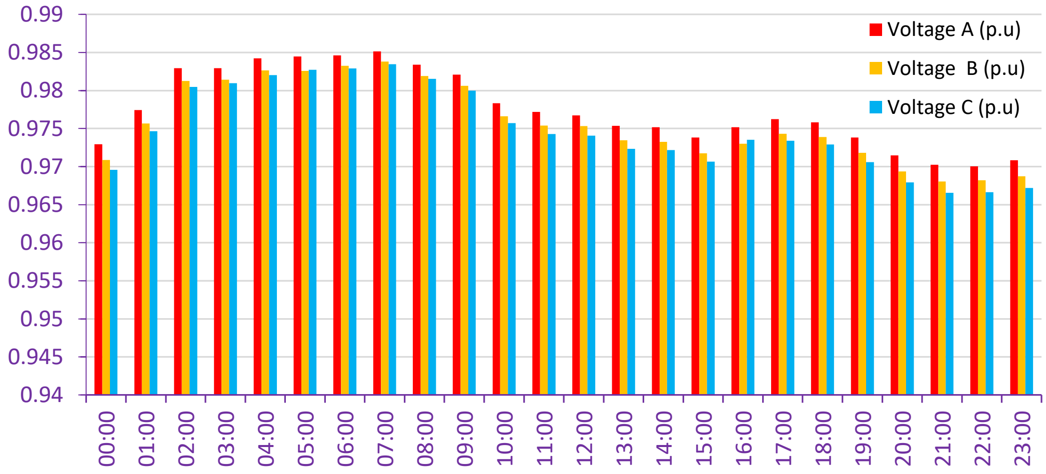

Figure 9: Deviation of the voltage in bus 9 (without using of solar panels)

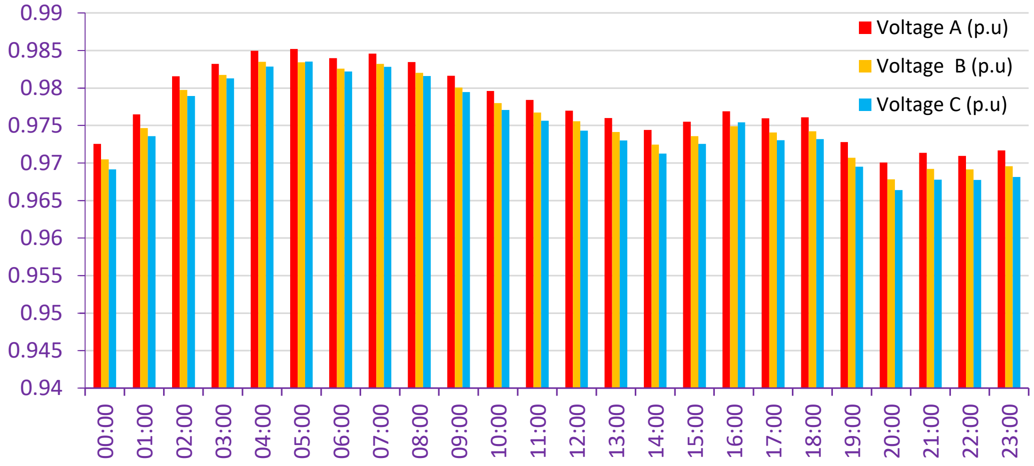

Figure 10: Deviation of the voltage in bus 10 (without using of solar panels)

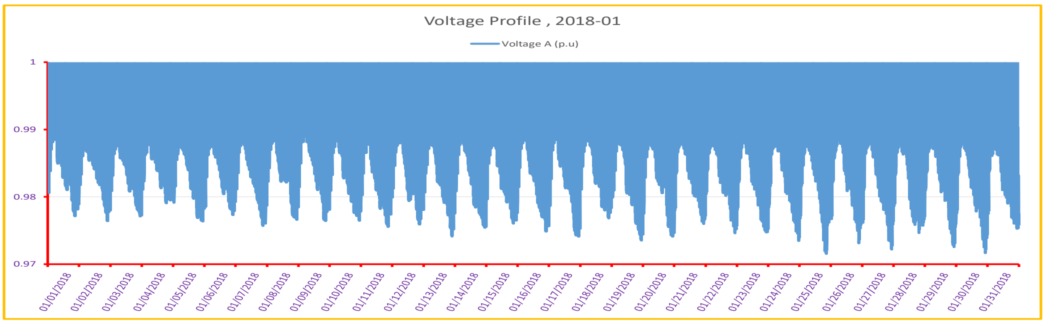

Figure 11: Voltage of Phase A (without using of solar panels)

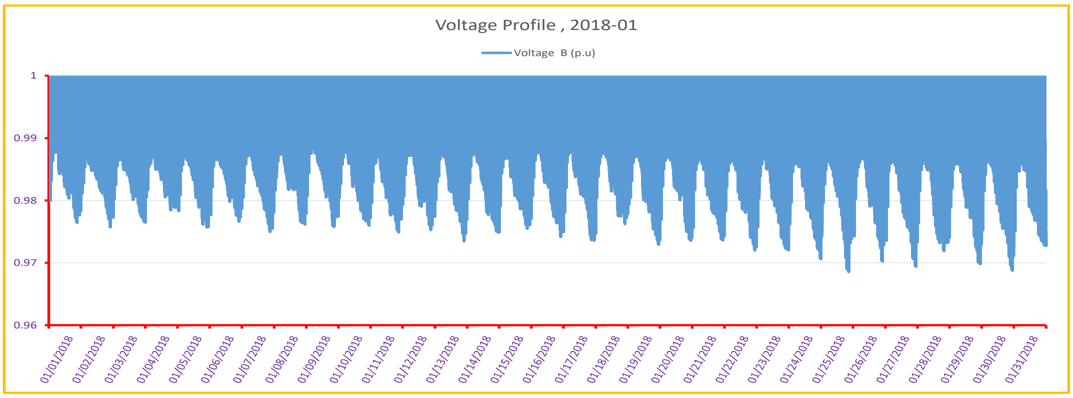

Figure 12: Voltage of Phase B (without using of solar panels)

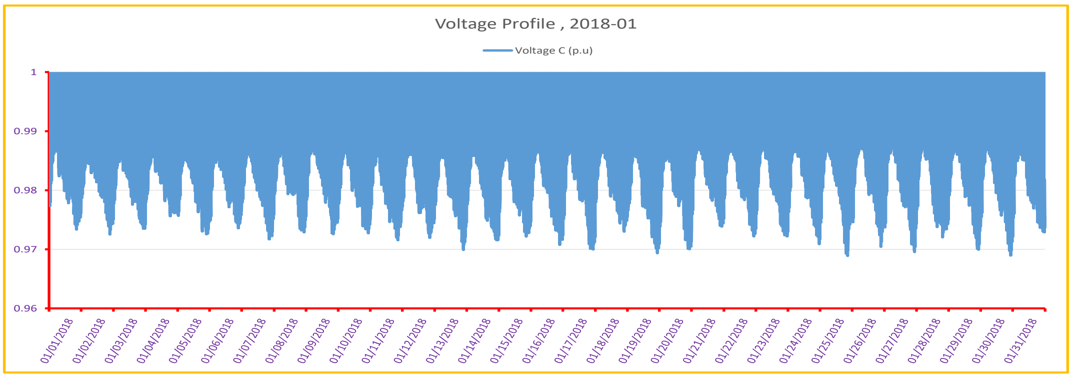

Figure 13: Voltage of Phase C (without using of solar panels)

B. Scenario 2: Using PV without controller

In this scenario, it is assumed that different percent of the consumers are equipped with solar arrays with a capacity of 5kW. In this situation, a significant voltage unbalance can be observed in the buses at the end of the feeder. For instance, the results obtained for bus 9 are shown in Figure (4-7). In this condition, the deviation of all three phases violates the allowable range. The amount of variation in the amplitude of phase A voltage for bus 10 is also shown in Figure (4-8). The three-phase voltage changes separately for 20%, 40%, 50%, 60%, 80% and 100% penetration percentages of solar PV panels are shown in figure (4-7) to figure (4-24), respectively.

These results are calculated for all the days of 2018, for example, only the results of the first month are shown.

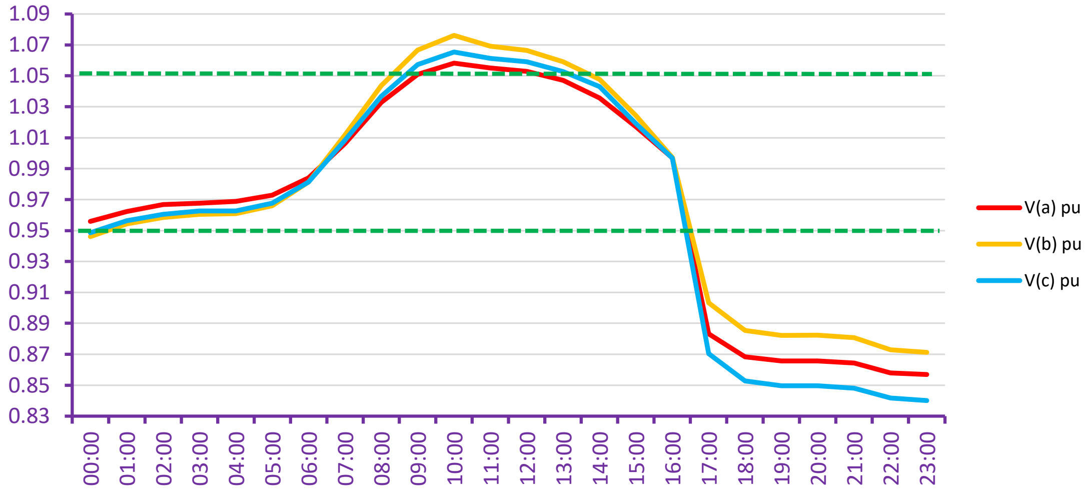

Figure 14: Voltage unbalance in bus 9 (50% penetration of solar panels)

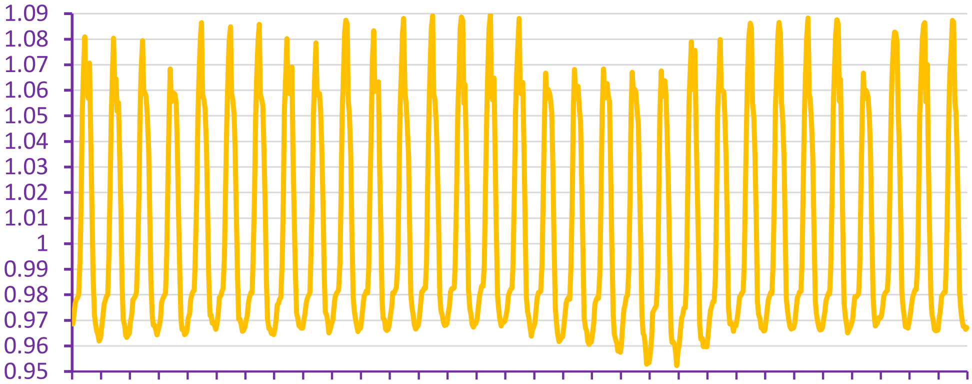

Figure 15: Voltage deviation of phase A in bus 10 (50% penetration of solar panels)

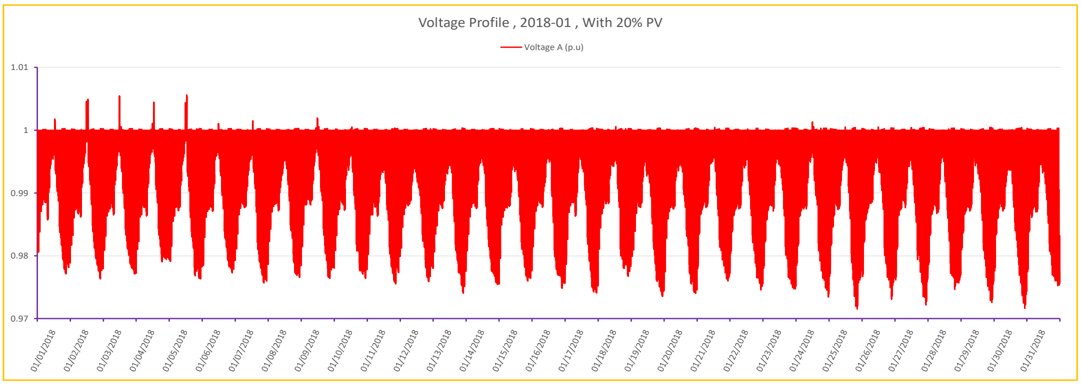

Figure 16: Voltage of Phase A (with 20% using of solar panels)

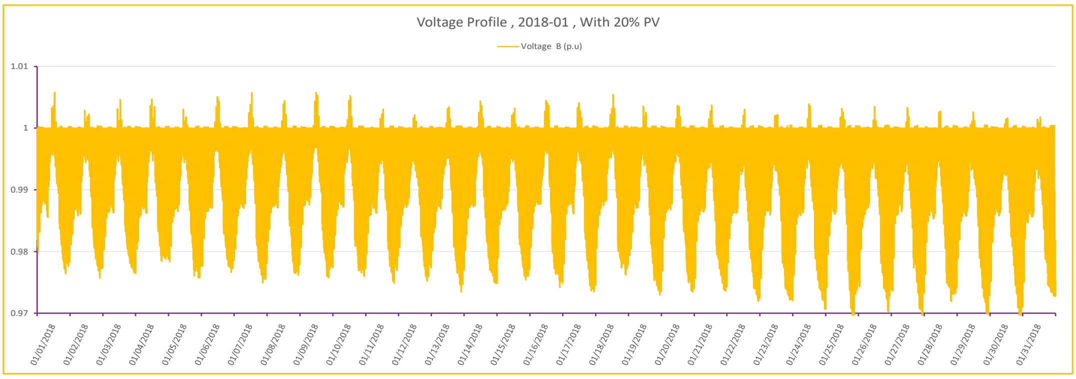

Figure 17: Voltage of Phase B (with 20% using of solar panels)

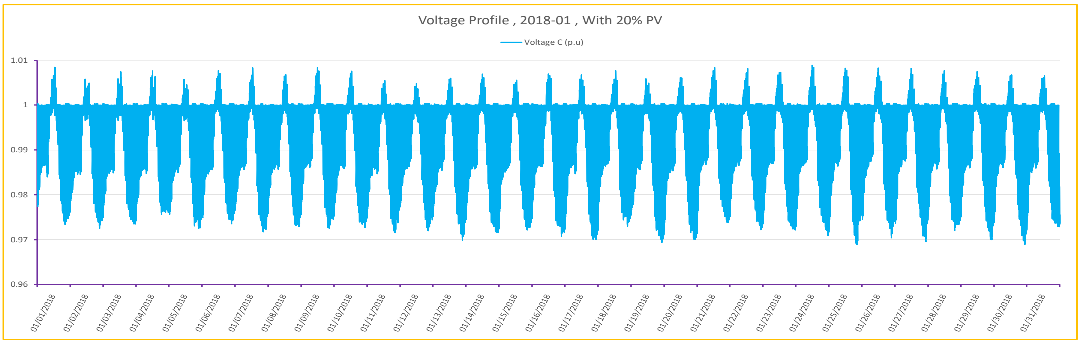

Figure 18: Voltage of Phase C (with 20% using of solar panels)

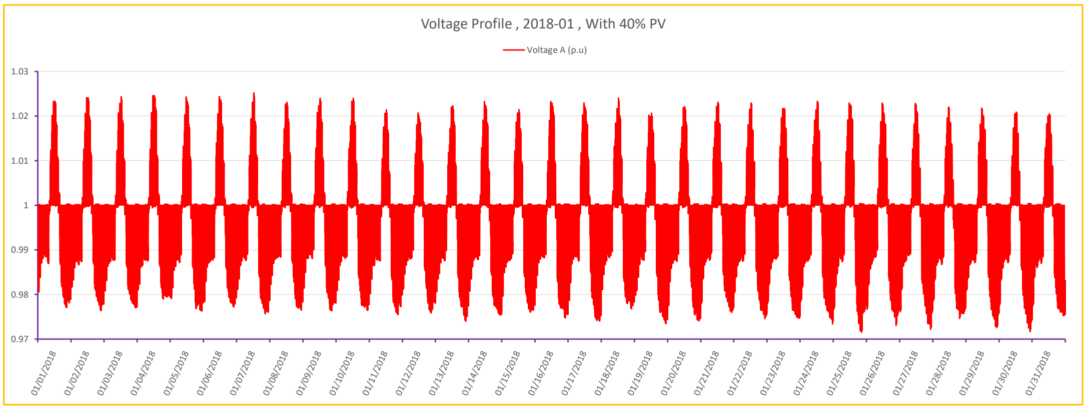

Figure 19: Voltage of Phase A (with 40% using of solar panels)

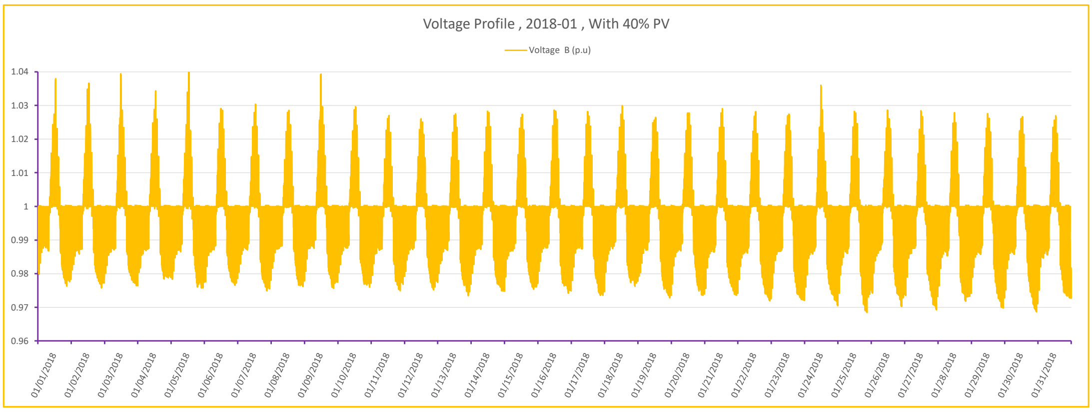

Figure 20: Voltage of Phase B (with 40% using of solar panels)

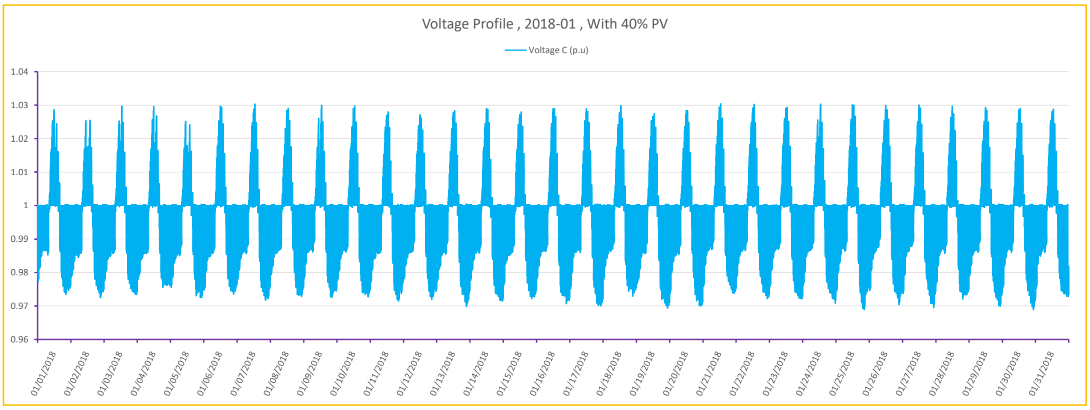

Figure 21: Voltage of Phase C (with 40% using of solar panels)

As can be seen in these figures, the increase in the penetration level of solar panels causes a significant increase in the voltage range, so that in some cases, this increase exceeds the set standard limit value (1.05 P.U). In figures (4-12) to (4-14) the voltage level of three phases A, B and C has been investigated for 40% penetration of solar panels, and according to the obtained results, the voltage range has changed between 97% and 1.04% In figures (4-15) to (4-17), the penetration level of solar panels has increased by 10% compared to the previous state. In this condition, for phase B, the value of the voltage fluctuation range has increased to the value of 1.045 per unit, which in this condition still meets the standard range of voltage range changes.

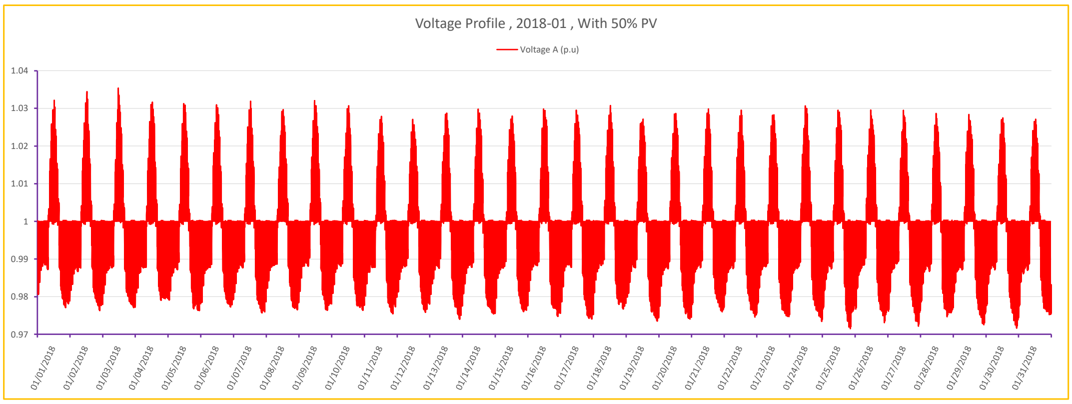

Figure 22: Voltage of Phase A (with 50% using of solar panels)

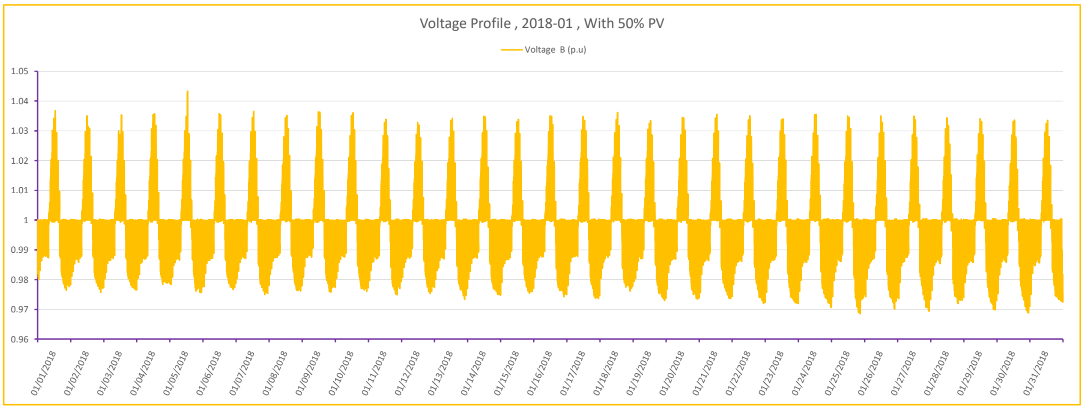

Figure 23: Voltage of Phase B (with 50% using of solar panels)

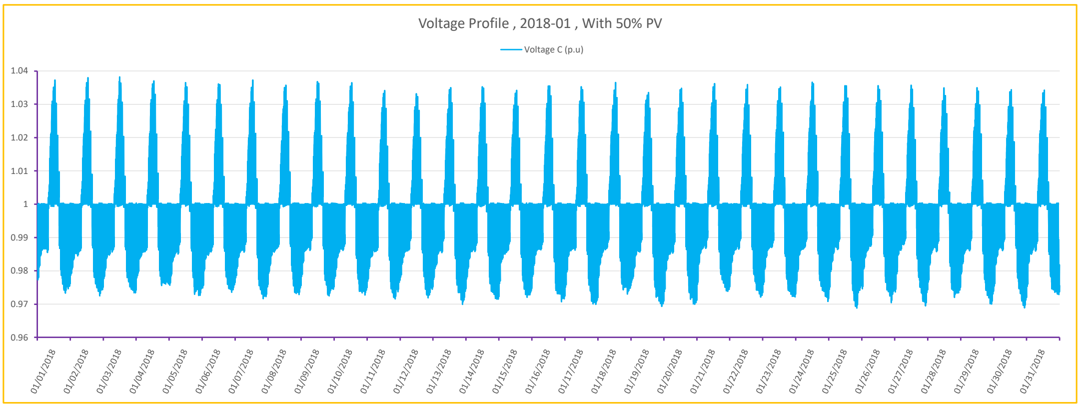

Figure 24: Voltage of Phase C (with 50% using of solar panels)

In figures (4-18) to (4-20), the penetration of solar panels has increased to 60%. In this situation, the voltage range exceeds the standard value for all three phases, and this indicates that without using a suitable solution, the network will face serious problems in this situation.

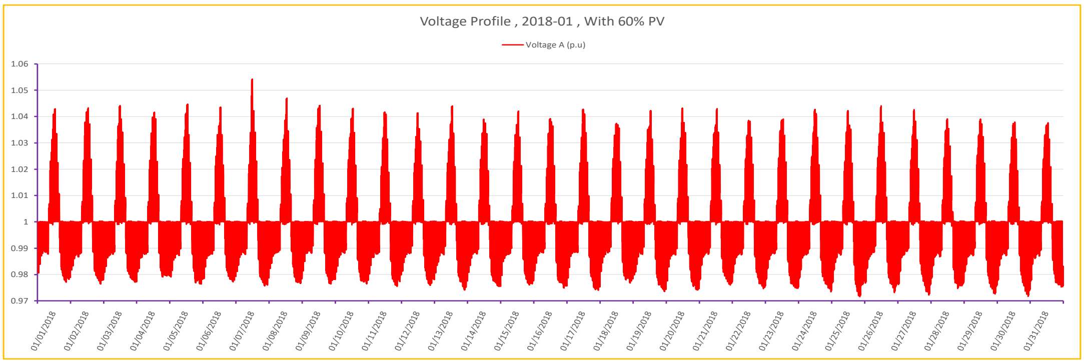

Figure 25: Voltage of Phase A (with 60% using of solar panels)

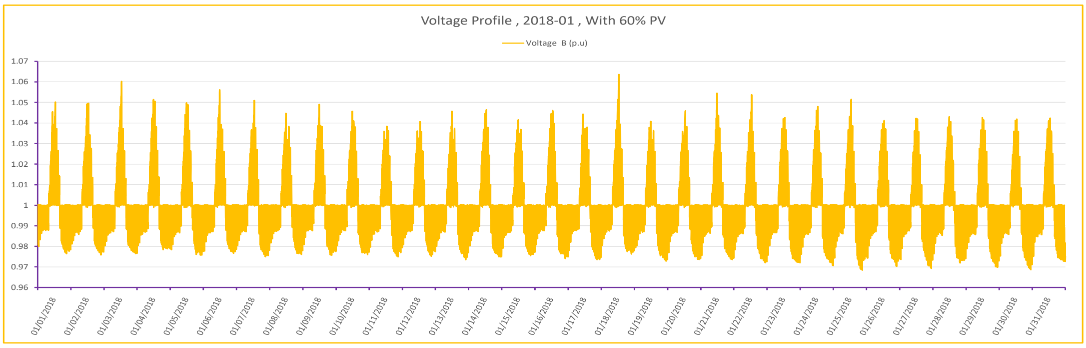

Figure 26: Voltage of Phase B (with 60% using of solar panels)

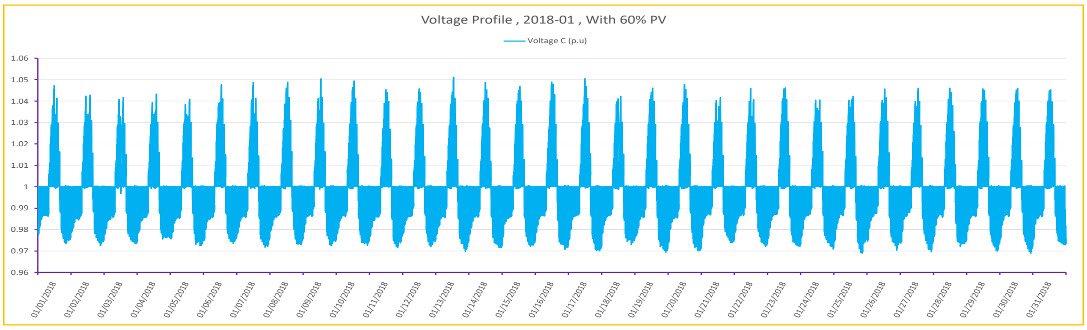

Figure 27: Voltage of Phase C (with 60% using of solar panels)

In Figures (4-21) to (4-23), the penetration percentage of solar panels has reached 80%. In this condition, the voltage range violation has increased to more than 3% of the set upper limit. The obtained results show that for all days, the voltage range has exceeded the standard values.

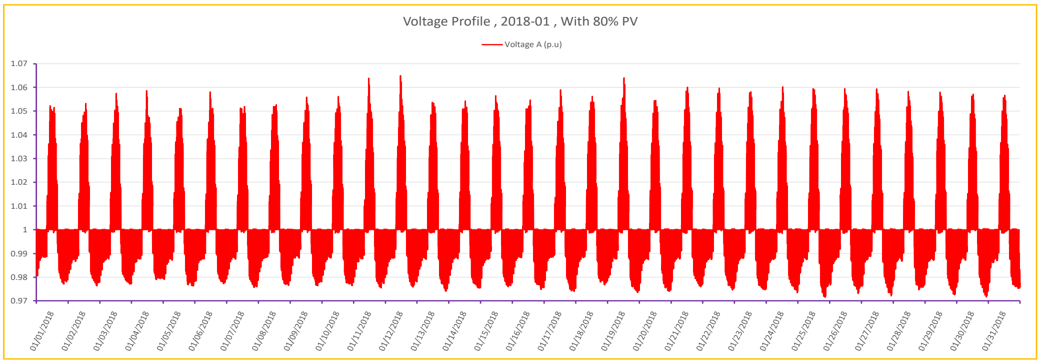

Figure 28: Voltage of Phase A (with 80% using of solar panels)

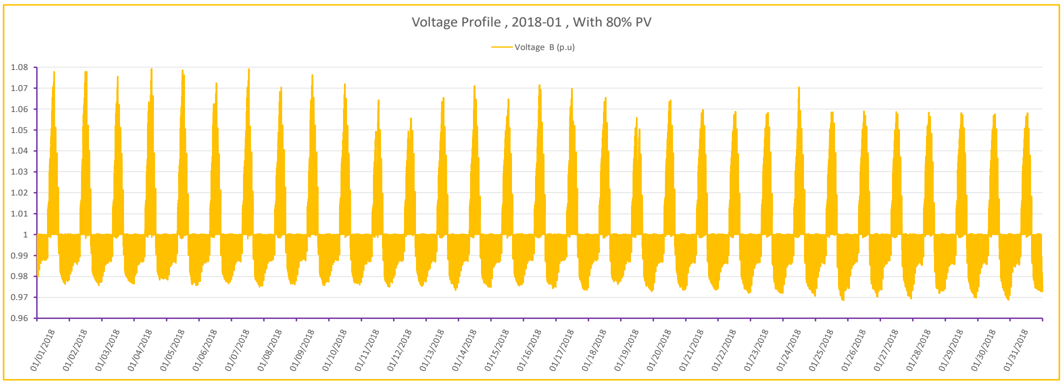

Figure 29: Voltage of Phase B (with 80% using of solar panels)

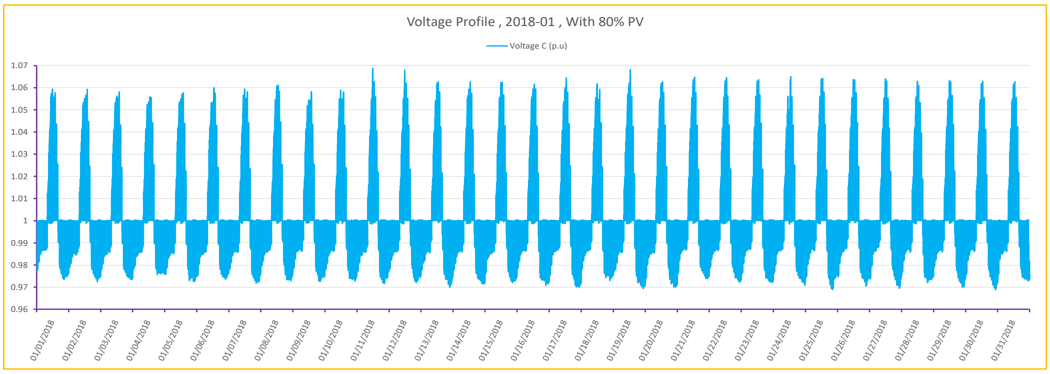

Figure 30: Voltage of Phase C (with 80% using of solar panels)

In Figures (4-24) to (4-26), all residents of the area are assumed to have solar panels. In this condition, the voltage range has increased up to 1.12% in phase C, which is the worst possible condition among all penetration percentage states.

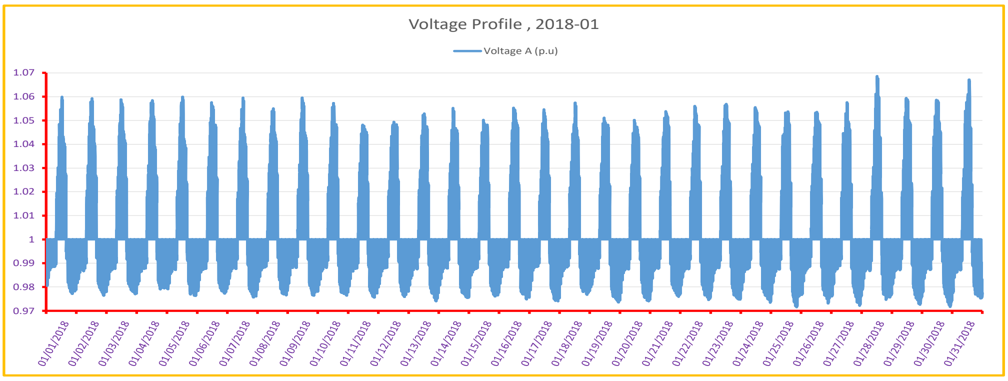

Figure 31:Voltage of Phase A (with 100% using of solar panels)

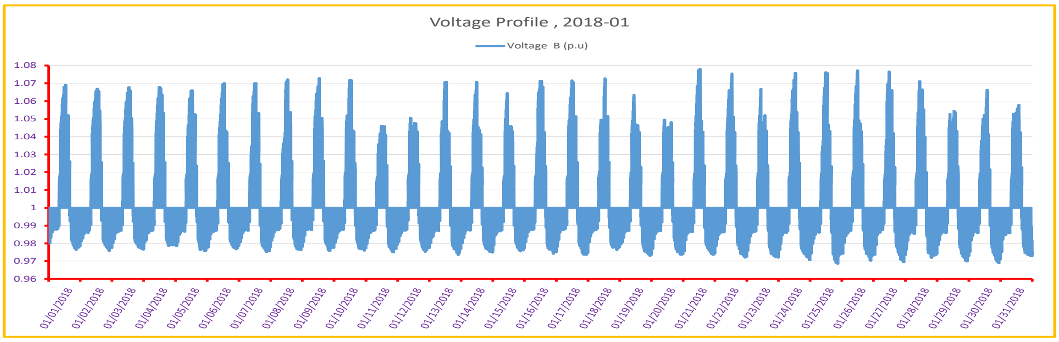

Figure 32: Voltage of Phase B (with 100% using of solar panels)

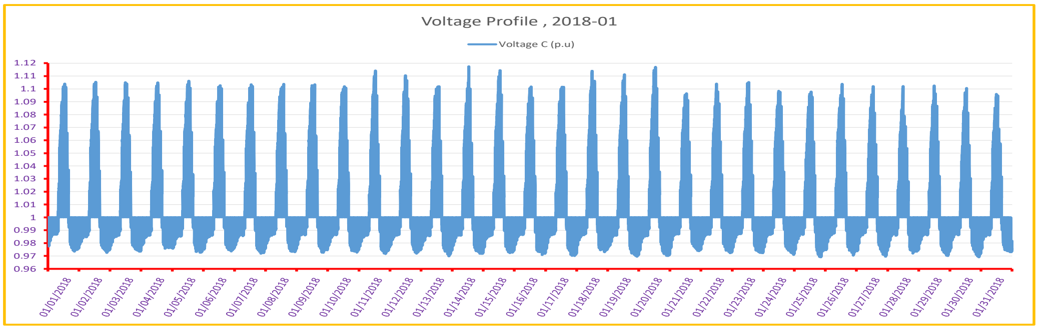

Figure 33: Voltage of Phase C (with 100% using of solar panels)

C. Scenario 3: Evaluation of IDVR Performance

For checking the power dispatched within the two systems, it is presumed, that in Figure (4-27), feeder number 1 is under fault condition and has a voltage deficiency. In figure (4-28) the values of voltage/current of source 1 are shown.

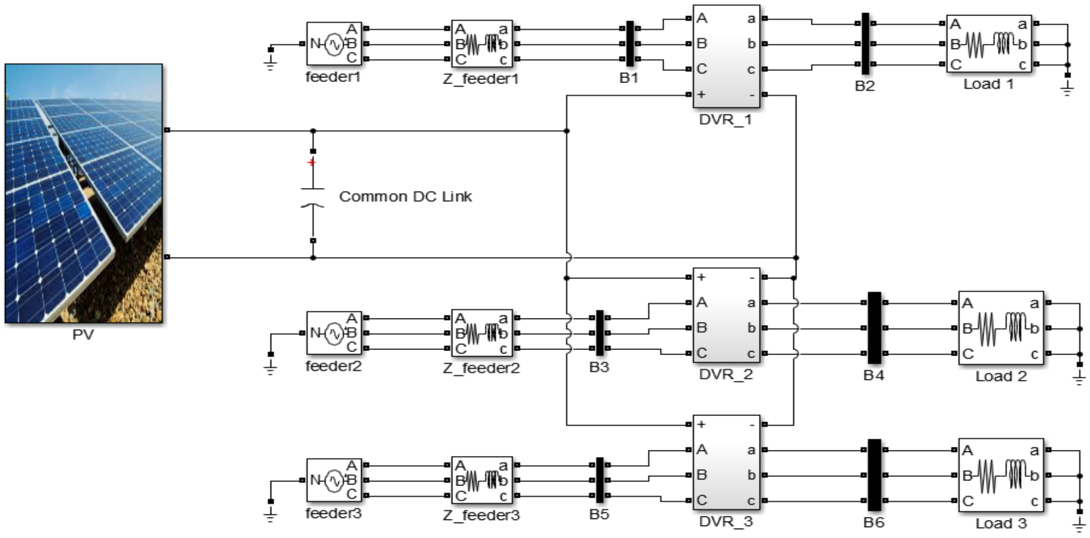

Figure 34: Schematic of distribution network with IDVR

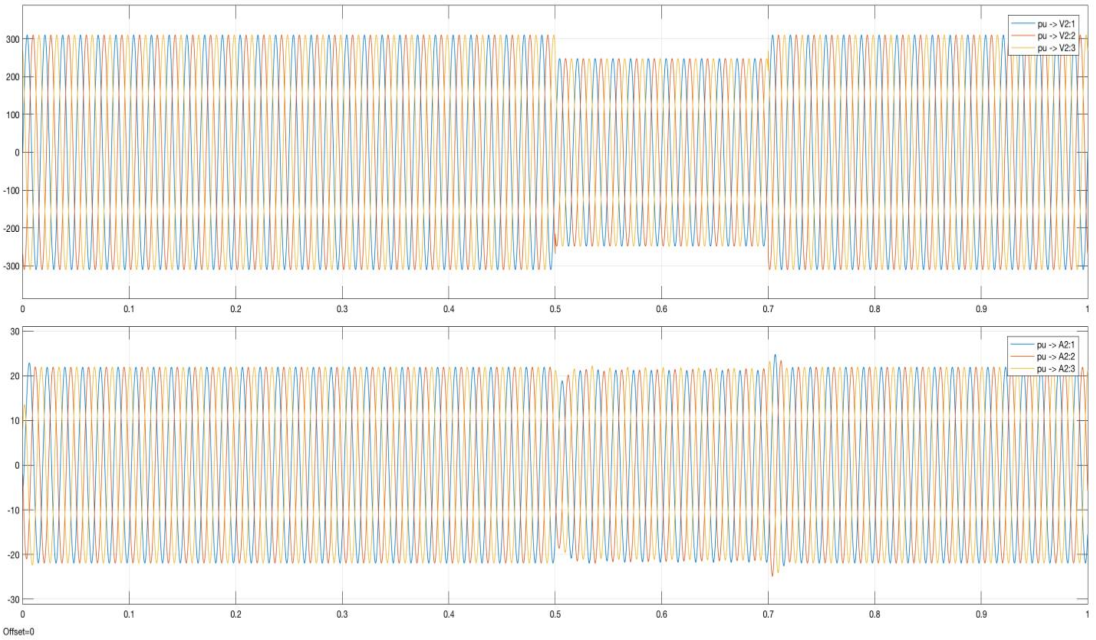

Figure 35: Voltage/current diagram of source 1

Therefore, DVR1 must operate in order to remove the voltage sag, while DVR2, which is in the normal condition, is controlled according to DC link backup for active power injection. Feeder No. 2 functions normally in this scenario since its load voltage is equal to the bus load voltage V2b. Consequently, in addition to meeting these requirements for feeder 2's load, the inverter attached to DVR2 has to supply the active power needed by the energy storage. The active power required by DVR2 to offset feeder 1's voltage sag as well as system losses, which include the converter's switching losses, is the same as the active power required. By using two or more DVRs (depending on the number of feeders with the possibility of high voltage shortage/surplus) linked into the DC link, it is possible to compensate the voltage shortage/surplus in a real network with considering all the uncertainties. The photovoltaic system can be considered as a local photovoltaic system installed in one of the feeders. In a laboratory scale, the capacity of this photovoltaic system is determined based upon specifications of the network designed toward the applied implementation of the project in the laboratory version. In the following, the amounts of injected power into load number 2 are shown in Figures (4-29). As seen in this figure, its diagram has been restored by injecting voltage. In the following Figure (4-30) the voltage value of load and source number 1 are shown.

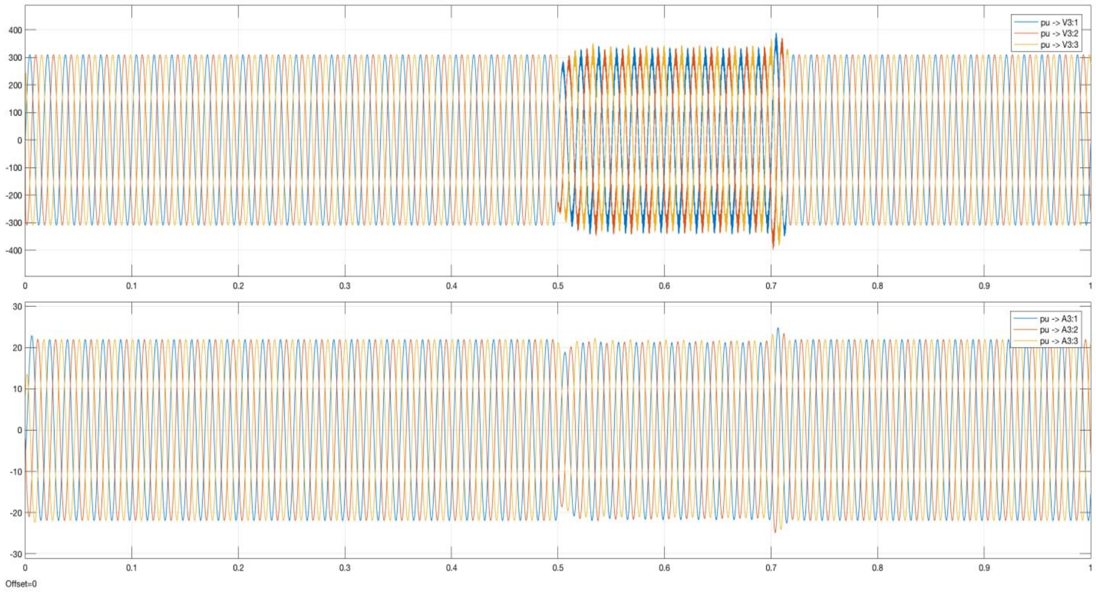

Figure 36: Voltage/current diagram of load 1

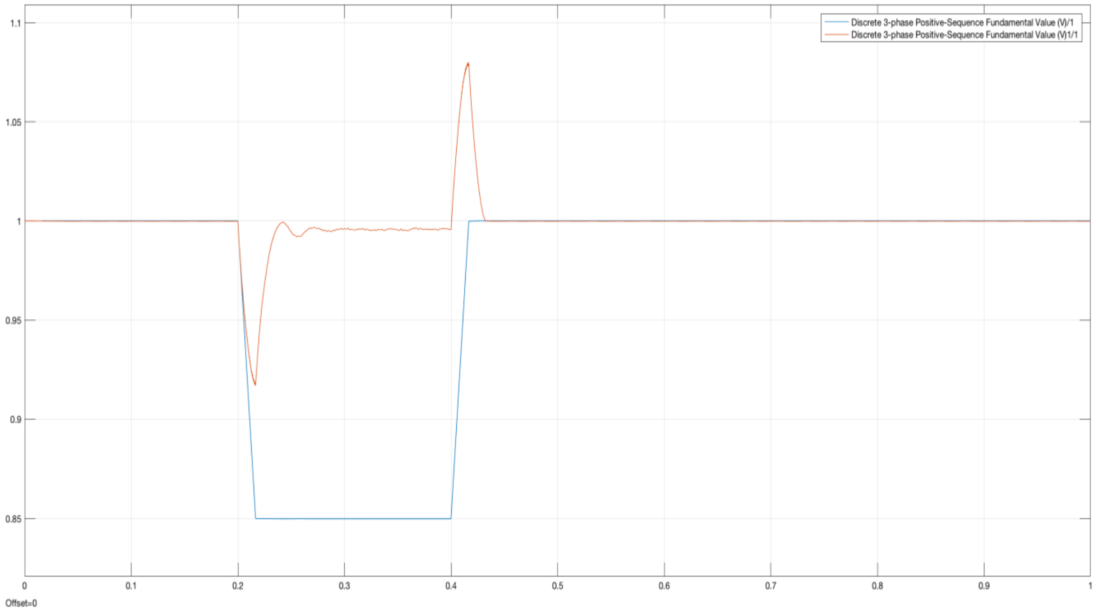

Figure 37: Voltage diagram of load and source No. 1

D. Scenario 4: Using PV with MPC-based MPPT controllers + IDVR

In this scenario, it is assumed that the penetration level of solar panels is equal to 50%, but the MPC-based MPPT controller is also used for monitoring the voltage profile. The results of using such controller in reducing the amount of violation in the voltage of phase A in bus 9 and the unbalance of bus 10 are shown in Figure (4-31) and Figure (4-32), respectively.

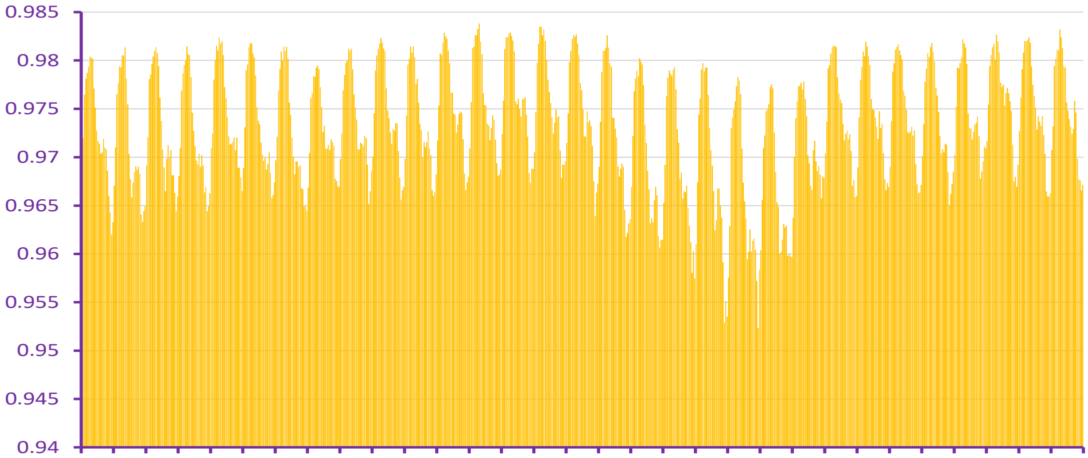

Figure 38: deviation of pahse A in bus 9 (50% penetration of MPC-based MPPT controllerd PV)

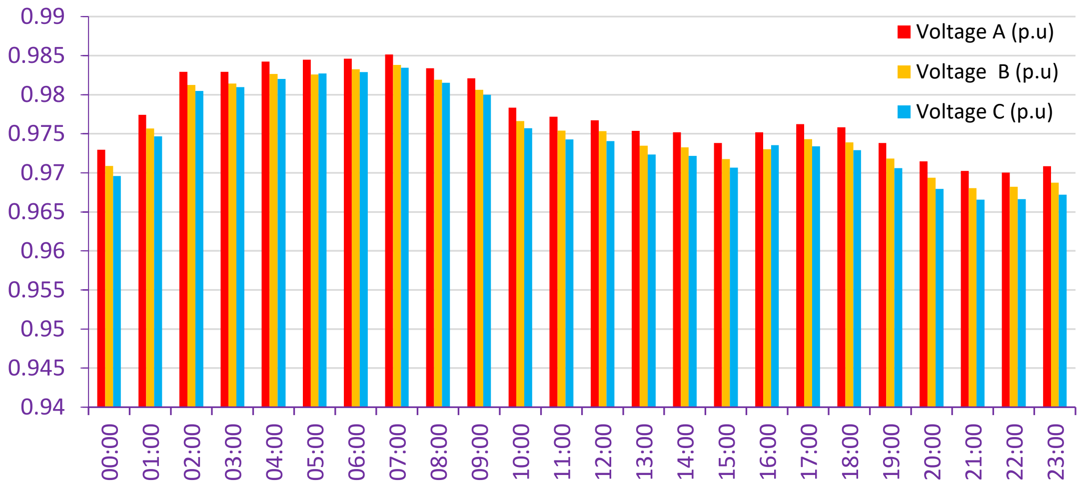

Figure 39: Unbalance condition in bus 10 (50% penetration of MPC-based controllerd PV)

Based on the obtained results, it is clear that the voltage amplitudes for all of the buses in the distribution network are within the allowable limits at all times. By using an approach such that, not only voltage deviation are maintained in these standards limit, but also the voltage unbalance criterias are reduced and located within the defined allowable range. Finally, the numerical results obtained through using of IDVR + MPPT tracker are presented in Table (4-1). As noticed in this table, by using IDVR + MPPT tracker at 50% penetration, more than 7% of the voltage deviation is reduced.

Table 1: Mean. of voltage amplitude for different phases (Penetration: 50%)

Network Characteristics	Phase A	Phase B	Phase C
Normal load without PV panels (bus 8)	0.987	0.982	0.980
Normal load without PV panels (bus 9)	0.983	0.980	0.978
Normal load without PV panels (bus 10)	0.977	0.974	0.972
Using PV without controller (penetration: 50%) (bus 8)	1.064	1.062	1.056
Using PV without controller (penetration: 50%) (bus 9)	1.076	1.075	1.071
Using PV without controller (penetration: 50%) (bus 10)	1.087	1.084	1.081
Using PV with MPC-based MPPT controllers + IDVR (bus 8)	1.032	1.030	1.028
Using PV with MPC-based MPPT controllers + IDVR (bus 9)	1.036	1.035	1.033
Using PV with MPC-based MPPT controllers + IDVR (bus 10)	1.044	1.041	1.038

V. CONCLUSION & SUGGESTIONS

A. Introduction

Electric companies continuously plan on the development of electric networks in order to provide the increasing power demanded by their subscribers. The classical method used is the construction of new stations or the development of existing infrastructure. With the implementation of new government policies in the field of using new resources, the use of scattered production resources has gained double importance. In fact, distributed production sources are small units that are located near consumption or load centers and produce electric power. Technologies used in distributed generation (DG) sources include small gas turbines, microturbines, fuel cells, wind and solar energy, etc. These sources can feed local loads separately and can inject their excess production power into the network. The integration of scattered production resources with the national network can expand energy production resources, improve efficiency, ease of installation and operation, improve security, increase power quality and reliability, and reduce environmental pollution. On the other hand, the connection of distributed generation sources (DG) to the distribution network causes significant changes in the operation of the network and several effects on its power quality.

Most of the studies conducted in the field of connecting distributed generation sources to the national grid have only considered active power exchange and less studies have been conducted on the potential of their participation in improving the voltage level and reducing losses. Improving the voltage profile, which is one of the most important indicators of power quality, plays an important role in the optimal use of the network. At the same time, by reducing the losses, the capacity of the network lines can be released, which causes higher efficiency in the performance of the distributed network equipment and postpones the investment in order to upgrade the network infrastructure.

Renewable energy sources (wind, sun, ...) as alternative energy sources for traditional power plants consuming fossil fuels have attracted a lot of attention. This issue is not only due to the decreasing trend of fossil fuel reserves, but also due to environmental pollution and problems caused by global warming. However, there are challenges in the field of controlling the production power of resources such as photovoltaic panels because their production power is highly dependent on environmental conditions and it is not possible to accurately predict it. In fact, due to the increase in the global need for energy and the predictions made regarding the continuation of this growth and the ever more serious issues related to the environment and air pollution due to the consumption of fossil fuels, as well as facing The depletion of these fuels has made mankind think of finding an alternative to fossil fuels. Using solar energy is one of the attractive solutions to replace fossil fuels. Converting solar energy into electrical energy is done using photovoltaic systems. Photovoltaic systems are semiconductor devices that are able to produce electrical energy directly from the sun's radiant energy.

One of the sources of generating electric power using renewable energy are photovoltaic systems that convert the radiant energy of the sun into electricity. Since the working efficiency of these cells changes drastically with changes in the radiation angle, the need for control techniques to track the point of maximum power is considered absolutely essential. In fact, tracking the maximum power point is an automatic control algorithm to adjust the power level, which obtains the maximum power output under moment-to-moment changes in the level of radiation, shade, temperature, and features of the photovoltaic module.

Serious challenges for such photovoltaic systems are the rapid changes in the radiation conditions and partial shading created on them. In this project, the Push-Pull converter will be used for the inverter. Changes in meteorological parameters depend on geographical location and weather conditions. Therefore, a meteorological parameter has different effects at different geographical levels. As a result, the correlation between meteorological parameters and the power output of solar panels is not the same in different regions. In this situation, the performance of a predictive model is highly dependent on the correlation between input and output values. With the widespread presence of PV in the distribution network, the voltage level undergoes many changes, so that in certain time intervals, it also violates the range of permitted changes. For this purpose, it is necessary to adopt solutions to overcome this challenge.

B. Conclusion

The integration of renewable production resources with the main grid can expand application of energy generation resources, improve the whole system efficiency and security, ease of installation and operation, increase power quality and reliability criterias, and reduce environmental pollution. The connection of renewable resources to the distribution network causes significant challenges in the network operation and effects on it's power quality. In respect with that, most studies have only considered active power exchange, so challenges such as the voltage profile reduction during the shortage of solar energy or load unbalance conditions caused by the increase of their penetration level should also be studied for practical implementations. In this paper, inline dynamic voltage recovery (IDVR) is used to overcome the mentioned challenges. The genetic algorithm based on chaos is also used to guide the IDVR proportional-integral controller system, which has a suitable convergence speed. For extracting the optimum power from PV arrays, mpc-based MPPT methodwas used. DIgSILENT Power Factory and MATLAB software were used to implement the simulations and the obtained results show that by applying the mentioned control method, not only more than 7% of the range of voltage changes is reduced, but also by reducing the level of voltage unbalance, the level of efficiency and network reliability also increase.

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