An-Najah National University
Faculty of Graduate Studies

Impact of Distributed Generation Model on Power Flow's Parameters of Electrical Power System: A Case Study of Photovoltaic Based Distributed Generation Units

By

Shahd Azzam Abed Allateef Sukkar

Supervisor

Dr. Maher Khammash

Co-Supervisor

Dr. Tamer Khatib

This Thesis is Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Electrical Power Engineering, Faculty of Graduate Studies, An-Najah National University, Nablus-Palestine.

2018

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This Thesis was Defended Successfully on 18/ 7/ 2018 and approved by:

Defense Committee Members	**Signature**
1. Dr. Maher Khammash / Supervisor	**...…..………**
2. Dr. Tamer Khatib / Co-Supervisor	……………..
3. Dr. Mahmoud Salah / External Examiner	**…...…………**
4. Dr. Kamel Saleh / Internal Examiner	**…...…………**

Dedication

My thanks are mostly given for Allah, and then to my husband and children who have supported me during all the phases of my master study. My thanks are also given to my parents, parents in law and colleagues.

Acknowledgment

I would like to thank my research supervisors Associate Professor Dr. Tamer Khatib and Assistant Professor Dr. Maher Khammash. My thanks are also given to the staff of Electrical Power Engineering master program at An-Najah National University and everyone who has helped me in conducting this research.

الإقرار

أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان:

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اقر بأن ما اشتملت عليه هذه الرسالة إنما هي نتاج جهدي الخاص باستثناء ما تم الإشارة إليه حيثما ورد، وإن هذه الرسالة ككل أو أي جزء منها لم يقدم من قبل لأي درجه علمية أو بحث علمي أو بحثي لدى أي مؤسسة تعليمية أو بحثية أخرى.

Declaration

The work provided in this thesis, unless otherwise referenced is the researcher's own work and has not been submitted elsewhere for any other degree or qualification.

Student's name: **اسم الطالب:**

Signature: **التوقيع:**

Date: **التاريخ:**

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List of Abbreviations

AC	Alternative current
ANN	Artificial Neural Network
CERTS	Consortium for electric reliability technology solution
CT	Current transformer
DC	Direct current
DG	Distributed Generation
DFIG	Doubly Fed Induction Generator
EHV	Extra High Voltage
FC	Fuel Cell
GRNN	Generalized Regression Artificial Neural Network
HV	High Voltage
IEEE	Institute of Electric and Electronic Engineering
KCL	Kirchhoff Current Law
KW	Kilo –Watt
MG	Micro – Grid
MNRE	Ministry of New And Renewable Energy
MT	Micro – Turbine
MW	Mega – Watt
MVA	Mega Volt Ampere
MVar	Mega reactive power
NOCT	Nominal Operating Cell Tempreture
P	Active Power
PCC	Point of Connection
PV	Photovoltaic
PVDG	Photovoltaic distributed generation
pu	Per Unit
Q	Reactive Power
Si	Silicon
T	Task
T.L	Transmission Line
WP	Work Package
WT	Wind Turbine

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ABSTRACT

In this thesis generalized regression neural network based model for photovoltaic based distributed generation units is proposed. The proposed model has two inputs which are solar radiation and ambient temperature, while, the output is the output current. Matlab environment is used to train, test and validate the proposed model. After that the developed model is applied to IEEE- 14 bus system so as to improve the voltage profile, decrease power losses and increase the reliability of the system.

But the grid needs some modifications to make the addition is acceptable, the total power losses of the power system after these modifications are about 45.96 MW and 182.551 MVAr. The performance of the electrical power system with the proposed model of distributed generation unit is compared with the performance of the electrical power system considering a conventional model of the distributed generation unit that is talked about fixed power from the photovoltaic. Results show that Bus 4 is the suitable bus for an installation of distributed generation unit. Thus a photovoltaic

system with capacity of 30 MWp is connected to the system by considering the proposed model and the conventional model (fixed power injection). It found that total real power losses of the system after adding the fixed distributed generation unit is about 37.288 MW. Meanwhile, the total reactive power losses are found to be 148.97 MVAr. On the other hand, by utilizing the proposed model (GRNN model), the total power losses of the system is found to be about 40.3 MW and 160 MVAr. Therefore, there is a difference of 3 MW between the two methods, Meanwhile using fixed output power for photovoltaic system will get an imaginary improvement because this method doesn’t take into account weather variations and absence of sun tonight , the utilization of conventional models for photovoltaic based distributed generation is not recommended as it exaggerates the improvement of the system and consequently affect negatively the reliability of the system

Chapter One
Introduction

1.1 Background

Electric energy represents a big percentage of the total energy consumption all over the world. Currently this consumption represents 12% of total energy consumption. In the meanwhile, electrical power demand will be increased with the rapid growing of worldwide population and loads. According to research, by 2025, the percentage of the electrical energy demand will be increased to be 34% of total consumption [El-Nozahy and Salama, 2013].

Electric energy is produced from many natural resources. Most of this energy is produced by conventional energy resources such as coal, oil and gas [Mehta, 2005]. Burning fossil fuel to generate electricity produces greenhouse gas emissions which have a big rule in global warming. Thus, these emissions must be reduced to prevent the global warming problem. Research shows that by 2050 the reduction of these emissions worldwide should be 80% of 1990’s recorded emissions levels [Meinshausen et. al. , 2009].

To protect the environment from these emissions, the dependency on fossil fuel to generate electricity must be reduced. This can be achieved by searching for alternative resources to produce electricity such as renewable energy resources like sun, wind and hydropower [Zahedi , 2011].

On the other hand, it is noted that the increasing power demand has increased the electrical energy production almost to its capacity limits including power generation and transmission capacities. In the meanwhile, power utilities must have a reserve margin of existing power generation at a sufficient level. Therefore, power utilities that are responsible of electrical power grid have to invest a lot of money to expand their capacity to meet the demanded power and to prevent the interruption of electricity [Bollen and Fainan, 2011]. This critical situation of electrical power systems leads to many challenges. One of the challenges that degrade the performance of power system is the voltage level. When the electrical power is transferred for a far distance, a voltage drop will occur and consequently power losses are increased. In addition, there are other issues such as harmonics which reduce power quality [Bollen and Fainan, 2011].

Following that, many solutions were suggested to solve these problems. One of these solutions is distributed generation (DG) [Singh and Sharma, 2017]. DG units are grid connected units which are located near customers and deliver power to the grid regardless of its capacity or type [Master, 2002]. Several benefits can be obtained from DG such as voltage support, improve power quality, loss reduction, support transmission and distribution infrastructure and increase system reliability. DG can be either based on fossil fuel such as micro turbine or based on renewable energy resources such as photovoltaic (PV) systems. However, the one that is most suitable to be used and support electrical power system without pollution is renewable resources [Master, 2002].

In general, the operation of an electrical power system depends on centralized power plants and flow a unidirectional from generation toward transmission and then distribution. In the meanwhile, the introduction of DG to the power system changes the nature of the system from passive networks to active networks. Active networks imply power flow in a bidirectional way due to the distributed resources along the network [Master, 2002].

The presentation of photovoltaic based distributed generation units in the distribution system may prompt many advantages such as voltage support, enhanced power quality, loss reduction, deferment of new or upgraded transmission and distribution infrastructure and improved utility system reliability [Barker, 2000]. PVDG is a grid-connected generation located near consumers regardless of its power capacity [Wanik, 2011], is an alternative way to support power demand and overcome congested transmission lines.

The combination of PVDG into a distribution system can have either positive or negative effects, contingent upon the DG working and the PVDG attributes. PVDG can be significant at least when it meets at any rate the fundamental prerequisites of the system working viewpoint and feeder outline [Begovic, 2001]. The impact of PVDG on power quality relies upon its interface with the utility system, the span of DG unit, the aggregate limit of the PVDG in respect to the system, size of generation relative to load at the interconnection point and feeder voltage regulation practice [Kim et. al., 2009]. Figure 1 shows a schematic diagram of a grid associated PV system which regularly contains a PV array, a DC interface capacitor, an inverter with filter, a step up transformer, and the grid [Bollen, 2003].

The DC power created from the PV array charges the DC connect capacitor. The inverter changes over the DC power into AC power, which has a sinusoidal voltage and frequency like the utility system. The diode hinders the reverse current move through the PV array. The transformer steps up the inverter voltage to the rated value of the system voltage and gives electrical detachment between the PV system and the array. The harmonic filter eliminates the harmonic components other than the fundamental electrical frequency.

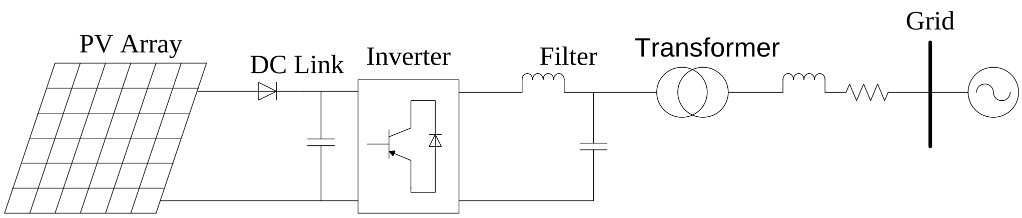

Figure 1.1: Schematic diagram of a grid-connected PV system.

In a conventional power plant, the output power can be controlled easily unlike the output power of a PV power plant due to the nature of the energy source (the Sun). Solar radiation, ambient temperature, relative humidity, wind speed and direction, dust deposition, flies drops and other factors affect the output power of PV system. Due to the variability of solar radiation and environmental factors, the output power of PV system is a random process [Kim et. al. , 2009].

1.2 Problem statements

Many attempts had been done to predict the output of photovoltaic system due to the variation of climate. These attempts were classified as; empirical mathematical models, regression based models, statistical models and artificial intelligent neural network based models.

The fundamental downsides of the empirical mathematical models that they ordinarily relate the output power specifically to the meteorological factors with no thought of the other in the interim, the regression models and other time arrangement construct models are situated in classical statistics are surely knew and have moderately clear estimation process. Be that as it may, these models have a tendency to perform well just for very much carried on energy system with certain and stable performance [Wong et. al., 2010].

Finally, the artificial neural network based models represent a method to take into account the uncertainty of weather and the variation of climate (solar radiation G and ambient temperature T) which results in a non-linear relationship between the input and output variables of the system. the main advantage of ANN model that distinguishes it from other models is the self-learning capability. And so, these models were be the most suitable model in case of dealing with uncertain performance such as PV array output power of the PV system.

In this research, two cases were analyzed. The first case which talks about adding a fixed PVDG to the power system of 14 bus and observe the output power due to this case. The second one discusses the model which is implemented by ANN and inserted to the same power system. The output here is changes where as in the first case, the variation of solar radiation through the day is not considered and the absence the sun at night isn't also taken into account.

By using ANN the daily average measured data were employed for a grid connected PV (solar radiation and ambient temperature) to train and validate the time series model. However, solar radiation data were used for forecasting the daily output power. The proposed method was performed using MATLAB to generate a model from a function of ANN called Generalized Regression Neural Network (GRNN) .The proposed model (GRNN model) were based on Newton Raphson equations in matlab code. The results of the proposed models indicate that the models fit the intermediate period of the day which is from 6 am to 7 pm quite well but not for sunrise and sunset periods where the proposed system efficiency was almost zero.

In this research, we had experimental data for the PV systems installed in Sohar city in Oman. These data will be utilized in developing the proposed model. The performance of the system (output current and voltage) had been recorded every 2 seconds considering the uncertainty of the system's output current.

1.3 Objectives

The main objective of this work is to propose a novel online prediction model of the PV system output current and show its impact on electrical power system power flow. The novelty of the proposed model is presented in the ability of predicting system performance considering the uncertainty issue. In general the objectives of this thesis are,

1) To model an IEEE 14 bus system using matlab with several weak buses

2) To develop an accurate model of photovoltaic based distributed generation using generalized regression artificial neural network.

3) To study the impact of the developed model on the power follow of the adapted network

1.4 The significance of the research

1. GRNN model which deals with the uncertainty of climate .

2. A method for illustrating the differences between the fixed PV and the proposed model and then improving the performance of power system to reduce the power losses and improve the voltage level of IEEE 14 test bus system and reduce the peak power demand and so the PVDG contributes to generated power supplied to the grid and consequently increase the reliability.

1.5 Methodology

In this research, the methodology consists of number of work packages (WPs) and tasks as listed below:

WP.1 Data collection and literature review.

T1. Collect the data that are used to construct the GRNN model (solar radiation ,ambient temperature from 6:00 am to 7:00 pm every 1 sec)

WP.2 Implementing the GRNN model by using matlab.

WP.3 Modeling of IEEE 14 bus- power system.

T1.1 Develop a matlab code for IEEE 14 bus- power system

T1.2 Obtain a power flow analysis of IEEE 14 bus- power system in normal condition (without adding DG).

T1.3 Choosing the bus that PVDG will be added to it to reduce the power losses depending on minimum voltage bus.

WP.4 Adding a constant PVDG at bus 4 to reduce power losses as case 1.

WP.5 Analysis of the new power system in terms of power losses and voltage profile.

WP.5 Adding the PV model to the same bus as case 2.

WP.6 Analysis of the new power system in terms of power losses and voltage profile.

WP.7 Conduct a comparison between case 1 and case 2.

WP.8 Thesis writing.

Chapter Two
Literature Review

2.1 Distributed Generation

2.1.1 Definition of DG

Recently, there is a new term appeared in the map of electric power system, which is the Distributed Generation (DG). The power station has a new method for reducing the use of huge traditional centralized generation units which is sized from 100 MW to GW and far from consumers (near the resources). The alternative way is using generators sized from kW to MW at consumer sits near the place of consumption. This is known as distributed energy.

Power generation near the consumers eliminates the cost, complexity, and inefficiencies associated with transmission and distribution and increase the reliability of the system.

Distributed generation (DG) will become more important and sufficient in the future generation system.

By showing the contrasts between various sorts of distributed generation (DG) will help in choosing a reasonable kind of DG for conveyed age arranging in appropriation system for various load. The load might be, by and by, mechanical, commercial, and business.

The distributed generation assets, for example, sustainable power sources (renewable energies). Renewable energy source is vitality from common assets, for example, wind, daylight, tides, waves, geothermal warmth and biomass [Kann et. al. , 2014]. Table 2.1 [Singh, 2009] presents the common DG technologies that used and their typical module size.

Table 2.1. Typical available size per module for DG

Technology	**Typical available size per power module**
Consolidated Cycle Gas turbine	30-390 MW
Inner Combustion Engines	4.5 kW- 11 MW
Combustion Turbine	1-255 MW
Fuel cells , Phos.Acid	190 kW- 2.1 MW
Fuel cells, Molten Carbonate	255 kW- 6 MW
Fuel cells, Proton Exchange	1- 255 kW
Fuel cells, solid Oxide	255 kW – 6 MW
Battery Storage	510 kW – 6 MW
Small Hydro	1- 105 MW
Micro Hydro	24 kW – 1.1 MW
Wind turbine	210 W – 3 MW
Photovoltaic Arrays(PV Arrays)	18 W – 110 kW
Solar Thermal , Central Receiver	1-15 MW
Solar Thermal, Lutz System	11 MW – 85 MW
Biomass Gasification	100 kW – 22 MW
Geothermal	5.1 MW -110 MW
Ocean Energy	105 kW – 5.1 MW

The voltage drops below its specific operating limits along distribution feeders with the increase of loads because of huge demand of electricity in distribution systems. the distribution system ought to be moved up to take care of voltage drop issues [Bollen, 2003]. The incorporation of PVDG units in an appropriation system can upgrade the voltage profile as voltage drop across finished feeder segments is diminished because of diminished power move through the feeder. Be that as it may, if the power produced by PVDG is more than the local demand at the Point of connection (PCC) , the surplus power will return back to the network. Thus reverse power flow in the feeder to the generator ,these overabundance power from DG will deliver and make voltage ascend at the feeder [Changsong et. al., 2011]. A few examinations researched strategies for controlling voltage rise caused by PVDG association into distributed systems. System planning techniques were employed in the system design and planning stages whereas equipment control techniques were used to regulate the bus voltages along a feeder during real-time operation.

With high DG entrance at low voltage level, an infringement may happen in the upper voltage confine. Consequently, an answer is expected to diminish the overvoltage caused by DG. [Demirok et. al., 2010] addressed the overvoltage problem by applying distributed reactive power regulation and active power curtailment strategies at the DG inverters [Wong et. Al., 2010]. An approach for charging and discharging control of the storage system (lead-acid batteries) is applied to regulate the storage capacity effectively. An adaptive voltage control scheme which uses an on-load tap changer and automatic voltage control relay was proposed to increase the output capacity of DG without violating voltage limits [Yan et. al., 2012].

Group of distributed generations and the electrical loads are mainly called a micro grid. It can work parallel or “islanded” from existing utility power grid.

[Lasseter, 1999] in Distributed Energy Resource Micro grids, CERTS, has defined MG as The Consortium for Electric Reliability Technology Solutions (CERTS) Micro Grid idea accept an accumulation of burdens and miniaturized scale sources working as a solitary system giving both power and warmth. Most of the small scale sources must be power electronic based to give the expected adaptability to guarantee task as a solitary amassed system. This control adaptability permits the CERTS Micro Grid to introduce itself to the mass power system as a solitary controlled unit that addresses nearby issues for dependability and security [Willis et. al.,] state that DG incorporates utilization of little generators, regularly going in limit from 15 to 10,000 kW, scattered all through a power system, to give the electric power required by electrical consumers. As usually connected, the term DG incorporates all employments of little electric power generators, regardless of whether situated on the utility system, at the site of an utility client, or at a separated site not associated with the power grid [Zusa et. al. , 2008].

MG takes the form of shopping center but due to utility, it is an electrical load which is controlled in its magnitude.

Recently, the researchers had given their attention to DGs as important part of MG due to economic benefits that we get from using DGs in any grid . Also there is no need to build new transmission and distribution lines.

[Ramamoorthy and Ramachandran, 2016] reviewed the optimal placement of inserting DG in any power system to reduce the power losses for each mesh and radial grid, but their method is applied only at fixed DG size, this problem we will discuss in our research.

To talk about the great use of DG throughout the world, the United states has more than 12 million DGs units, in other word one- sixth of total power plant capacity.

Until 1968, Switzerland created 95.7 % of its completely delivered electrical vitality from hydro plants and the rest was secured with non-atomic warm plants. The power utilization of 22,437 GWh in 1968 expanded to 54,029 GWh in 2002; together with transmission misfortunes, pump stockpiling utilization and import/trade surpluses, this adds up to the aggregate electrical influence creation of 65,011 GWh in 2002, Hydro plants take an offer on that of 56.2 %, 39.5 % are delivered by atomic influence plants and 4.3 % by customary warm and inexhaustible, non-hydro influence plants [Beilfuss ,2010] .

India considered the sustainable power source, for example, wind and sun oriented vitality is a trade for requiring of future vitality , as on March 31, 2012 RES created around 24914 MW, i.e. around 12.1% of the aggregate introduced vitality limit. Promote Ministry of New and Renewable Energy (MNRE), Government of India is chosen to accomplish 20000 MW grid interactive power through sun oriented and 38500 MW from wind by 2022.[Sharique, 2012]

2.1.2 DG Resource Types

There are many types of distributed generation that are used to generate the power to the loads depending on the resources used. Distributed generation resources are have two types which are traditional resources and non-traditional resources such as renewable, non-renewable and storage techniques like batteries, capacitors and flywheels , figure 2.1 illustrate the various technologies[Haruna, 2015].

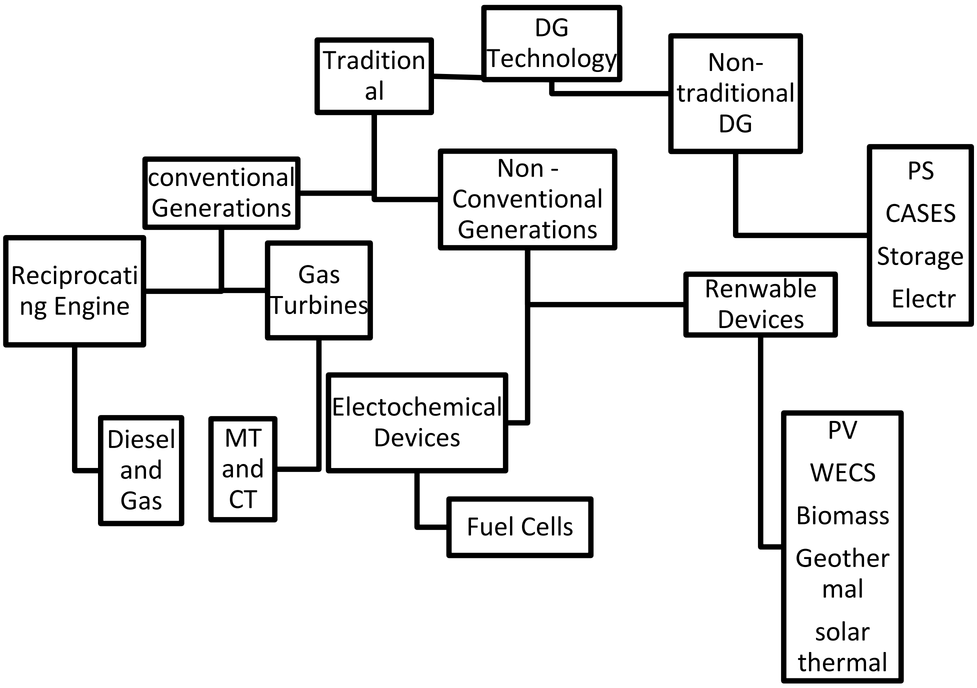

Figure 2.1: Distributed Generation Technologies

The traditional DGs are generators used widely although their small size. The principle of these DGs depend on the combustion of engines like gas turbine. But Non-traditional DGs are friendly sources that not pollute the environment through the energy production and didn't radiate emissions. In these resources DC-AC power electronic converters must be used to convert the output dc power before sending it to AC distributed network (grid) [Haruna , 2015].

The traditional internal combustion engines (rotary machines) are synchronized generators and Wind turbines are connected directly to the grid. In some wind applications as well as some combustion engines such as micro-turbines, power inverters are used for the network interface because of the benefits associated with the interface justify the additional cost and complexity involved. Therefore, we must use synchronous Generators and fixed power transformers or induction generators to invert the energy generated from different DG sources and injected it into the grid. The nature of operation of these generators or invertors determines the types of DG that will be used to solve the flow of energy.

2.1.3 DG Resources and Conversion Devices Modeling

In general modeling, the representation of the system requires an athlete to give mathematical model and sufficient information about the actual systems that cover all the required system behavior within certain constraints. It is important that the appropriate model of the DG which can adequately represent the type of DG is to assess its impact on the network. The model should be represented in such a way that it would be easy to conduct an impact assessment approach to the network because of the presence of DG.

Types of DG were also classified depending on size, construction and output power [El-Khattam and Salama, 2004]. DGs have been classified into four major classes upon combined power transfer capability by an author mentioned them in [Hung et. al. , 2010].

1 The first one, DGs provide active power (P) only and inserted to the grid by employing power inverters such as the fuel cell, photovoltaic and wind turbine.

2 The second type of DGs that are providing active (P) and reactive (Q) power, and it depends on synchronous machines which available in gas turbine and cogeneration.

3 The third one which supply reactive power only such as the Synchronous compensators that we used in the grid to improve the power factor.

4 DGs can supply active power (P) and at the same moment consume reactive power (Q) such as the induction generators and the doubly fed induction generator (DFIG) systems.

2.1.4 DG technologies

2.1.4.1 Micro-hydro

Hydropower systems converts the energy that is taken from the water flow to electrical or mechanical energy [EPRI Technical Report, 2000]. Some portion of stream's water is changed over to channel or pressurized pipeline which conveys to the turbine. Water development will move the wheel or turbine, which turns a pole. The pole development can be utilized for mechanical procedures, for example, pumping water, or it can be utilized to run a generator and afterward produces the power. [EPRI Technical Report, 2000]

2.1.4.2 Wind turbine

The kinetic energy of the wind is transferred to the blades, which drive a shaft along with a generator that converts wind energy into electrical energy. [Ackermann et. al., 2000] The major parts of a wind turbine are: rotor, blades, shaft, gearbox ,electric generator and tower .[Ackermann et. al., 2000]

2.1.4.3 Photovoltaic panel

The photovoltaic term means light (photo) and electric (voltaic), the label came from Greece. A photovoltaic(PV) panel inverts the light come from the Sun directly to electric energy. The main components of a PV are the solar cells [Ackermann et. al., 2000] A solar cell contains at least two layers of semiconductor material, for example, Silicon. Each layer has a thickness in the vicinity of 0.001 and 0.2 mm at that point doped with compound components to shape "p" and "n" intersections. The sun sparkle unsettle the electrons when the silicon layer is presented to it, thus a little electric current will be delivered. These sells are utilized as a series arrangement and parallel association with deliver adequate current that can utilized for all intents and purposes. [Ackermann et. al., 2000].

The nature of the semiconductor material that used in manufacturing made a differences between the PV panels and so they divided to: mono crystalline, polycrystalline and amorphous [Ackermann et. al. ,2000].

electric current that flow is created in the vicinity of 36 and 72 sun oriented cells by Photovoltaic modules comprise of photovoltaic circuits fixed in a defensive cover condition. each panel contain at least one photovoltaic modules. A photovoltaic exhibit is the entire power creating unit having number of modules and photovoltaic panels. [Ackermann et. al., 2000] The output power of photovoltaic panels can be mathematically expressed as [Ackermann et. al., 2000]:

$$P = \eta . I . Sn \qquad (2.1)$$

where:

η - efficiency of the panel;

I – installation (the power produced per unit square meter of the panel);

Sn - number of panels.

The reliability of PV system can be defined as the ability of the system to supply the load demand all the time under all conditions. The uncertainty of output power of PV systems is the principle hindrance of these systems. Consequently the analysts must urged to give more spotlight on finding the answer for this issue either by proposing advancement strategies or joining hybrid energy sources. In U.S PV is currently the most renewable energy source available and growing [Kann et. al., 2014] because of more available, reasonable, and pervasive in the nation than any time in recent memory.

Demonstrating of PV module is in effect constantly refreshed to empower specialists to show signs of improvement comprehended their works and undertakings. contingent upon the kinds of programming analysts, for example, C-programming, excel, matlab, simulink or the tool stash the modules were created. A capacity in matlab condition has been produced to figure the current yield from information of voltage, sun oriented illumination and temperature in the investigation of [Walker, 2001] and [Gonzalez , 2005].

Different investigations cover California as the lead state in number of sun powered tasks introduced over past decade [Dubey et. al., 2015]. The PV incorporation confine, named facilitating limit, is ascertained as for bus over voltages, voltage deviations, and voltage unbalance utilizing California sunlight based measurements [Dubey et. al., 2015].

Another examination has used genuine field information of an example circuit from Southern California to accentuate the need of time-arrangement reproduction in seeing genuine effects of high entrance PVDG establishment into conveyance systems [Sadigh and Smedly, 2015]. Cohen and Callaway contemplated the impacts of PVDG on California's appropriation framework both from building and financial perspectives [Cohen and Callaway, 2016].

2.2 Modeling of Power System

Here an electric power system is to be defined as a group of electrical components which were constructed to supply, transfer, store, and use electric power, the components are shown in figure 2.2. An electrical grid power system can be broadly divided into the following parts:

a. Generators which supply the power.

b. Transmission system which carries the power from the generators to the load

c. Distribution

d. Loads

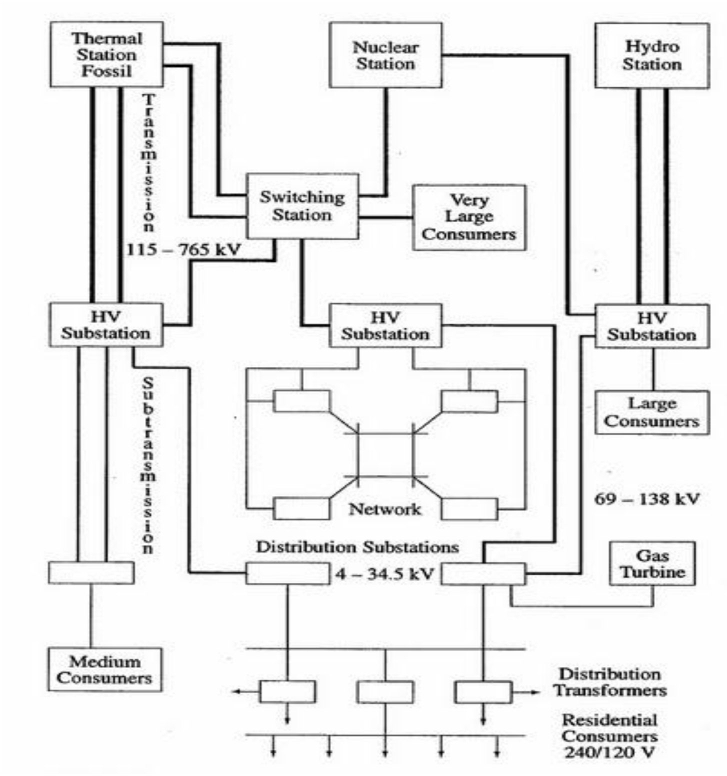

Figure 2.2: Basic components of power system

2.2.1 Generation

It is a synchronous generator (three phase) with two rotating field the first one is produced by the rotor and the second is produced in the stator windings through the three phase armature currents. Rotor dc current is provided by excitation systems. The generator excitation system maintains generator voltage and controls the reactive power flow.

The size of generators will vary from 50 MW to 1500 MW in the power system.

The source of input mechanical energy can be hydraulic turbines , steam turbines

that energy produced from the burning of coal , gas and nuclear.

In a power station, several generators are operated in parallel connection to increase the reliability of the system and provide the total power needed, if one generator is out of service the other will generate the power and remain the energy is supplied to the loads. They are connected in a common point called a bus.

2.2.2 Transformers

They are the major second part of the power system that transfers energy with

high efficiency from one level to another. The quantity of power transferred is the same before and after the transformer except if we are taking into account the core

and copper losses in the transformer .

Step up transformers are used in generation side to increase the voltage and

decrease the current so decrease the losses; on the other hand step down

transformers are used in the distributed area at the receiving end of the

transmission lines to reduce the voltage to suitable values for the customers.

2.2.3 Distribution

The distribution system is the part that connects the substation to loads and

consumers. Distribution lines are classified to primary distribution in the range of 4 to 34.5 KV.

And secondary distribution which services commercial and residential consumers

with 240 to 120 V levels. Distribution systems are both:

1. Overhead

2. Undergrounded

Each of them has its advantages and disadvantages.

2.2.4 Loads

Loads of power systems are divided into industrial , commercial and residential.

The real power of load is computed in kW or MW. The value of load varies throughout the day.

Chapter Three

Modeling of Photovoltaic Based Distributed Generation Unit and Active Distribution Network

3.1 Modeling of PV based distributed generation

Modeling of PVDG requires estimating the output of PV array with respect to weather changes (irradiance intensity and ambient temperature) as input variables. The output can be current, voltage, power or others.

In general, the variation of climate during the day makes the PV output power is the major obstacle of these systems. The proposed model that is introduced in this thesis will be the solution of the climate variations and the uncertainty of the output power from the PV. GRNN model is used to predict the output current of the PV module by introducing it to training and testing data. Thus, a developed GRNN model will predict accurately the output depending on the solar radiation and ambient temperature by taking into account the absence of sun in some hours day.

Last that the model was inserted to IEEE 14 bus grid as PVDG of the power system. This prediction of the output power of the photovoltaic will increase the reliability of the power system .

3.1.1 Empirical mathematical model

In fact, climate data such as temperature, solar radiation, humidity...etc, have important influence on the performance of the photovoltaic system.

Changing the sun based radiation influences the present yield delivered by the PV module/array relatively.

In any case, the average ambient temperature and the load line area at the designing level, the output voltage of the PV array does not change altogether through the day because the ambient temperature swings low through it. Additionally the variation of sun oriented radiation during that time day prompts change the output current of PV module array each day.

The energy generated from the PV systems essentially depends on the current generated from the PV Array. Many mathematical models have been introduced to describe the output current of a PV system. the It depends on the solar radiation and the ambient temperature. The following equation describes the output current of a PV array [Khatib and Elmenreich , 2014]

$$P_{out} = P_m \left(\frac{G_{t(t)}}{G_{reference}}\right) [1 + \propto T(T_{c(t)} - T_{reference})] \times \eta_{inv} \times \eta_{wire} \qquad (3.1)$$

Where

$G_t(t)$: the interconnected solar radiation in (W/m^2)

$G_{reference}$: the solar radiation at standard conditions in (W/m^2)

$\propto$T: the temperature coefficient of the PV module power and it is specified by the manufacturer.

$T_{reference}$: the cell temperature at standard conditions

η_{inv}: the efficiency of the inverter

η_{wire}: the efficiency of the wires.

Tc: the temperature of the cell which can calculate from the following equation:

$$T_{c(t)} = T_{amb(t)} + \left(\left(\frac{NOCT-20}{800}\right) \times G_{t(t)}\right) \quad (3.2)$$

Where

T_{amb}: the temperature of air ambient in °C

NOCT: the nominal operating cell temperature in ◦C and it depends on the construction of the module. The NOCT represents the temperature that measured at the cell when the cell is exposed to 800 W/m^2 and the ambient temperature 20°C while the terminal of the cell are open and wind speed is 1m/s.

The efficiency of the inverter is described in terms of the input power and the inverter rated power.

3.1.2 Proposed Generalized Regression Artificial Neural Network Model

Artificial neural networks, ANNs, are non-algorithmic but it is information parallel processing systems. It works by learning the relationship between input and output

when training data is entered to it and then testing data is performed. It usually consists of parallel units called neurons which are connected with huge number of weighted links that pass signals or information. The neuron collects the input and then produced the final results in a nonlinear process. The term ANN refers to the Multilayer Perception Network (MLB); there is numerous kinds of neural systems, including Probabilistic Neural Networks (PNNs), General Regression Neural Networks (GRNNs), Radial Basis Function (RBF) Networks, Cascade Correlation, Functional Link Networks, Kohonen systems, Gram Charlier systems, Learning Vector Quantization, Hebb systems, Adaline systems, Hetero cooperative systems, Re current Networks, and Hybrid Networks [EPRI Technical Report, 2000]

Statistical values are used to check the accuracy of the model .These statistics are mean absolute percentage error (MAPE), mean bias error (MBE), and root mean square error (RMSE). From the results of these statistics, Generalized Regression Neural Network (GRNN) beats the other models . It is also the most recommended type of ANN for solar radiation prediction according to [Khatib et al., 2012] .

Many calculations were done to find the suitable type of ANN to be used in the model construction.

GRNN is a probabilistic based network that makes classification where the target variable is definite, and GRNNs make regression where the specified variable is continuous.

GRNNs contain input, hidden layers (Pattern layer and summation layer), and output layers. The input layer owns one neuron for every predictor variable.

The input neurons standardize the range of values by subtracting the median and dividing by the inter quartile range. The input neurons at that point gave the quantities to every one of the neurons in the hidden layer. In the hidden layer, there is one neuron for each case in the preparation training data. The neuron stores the estimations of the predictor factors for each case, alongside the objective value. At the point when given a vector of input value from the information layer, a hidden neuron figures the Euclidean separation of the experiment from the neuron's inside point and afterward applies the RBF kernel function utilizing the sigma value The subsequent value is passed to the neurons in the pattern layer. Nonetheless, the pattern (summation) layer has two neurons: one is the denominator summation unit and the other is the numerator summation unit. The denominator summation unit gathers the weights of the values coming from all hidden neurons. The numerator summation unit also gathers the weights of the values multiplied by the target value for each hidden neuron.

The decision layer divides the value accumulated in the numerator summation unit by the value in the denominator summation unit and uses the result as the predicted target value [Khatib and Elmenreich, 2015].

GRNN illustrated in Figure 3.1 is proposed for current prediction. The input layer of the network has two inputs: mean daily solar radiation, temperature(ambient and PV temperature). Meanwhile, the output layer has one node which is the current (the power).

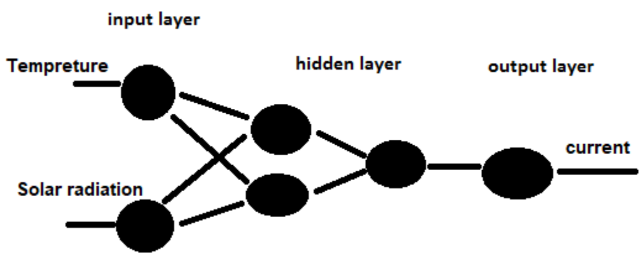

Figure 3.1: GRNN model

3.1.3 Model's Evaluation Criteria

As it is mentioned previously, the proposed GRNN model has to evaluate to many statistics errors which are: mean absolute percentage error (MAPE), root mean

square error (RMSE)and Mean Bias Error (MPE).The accuracy of ANN can be measured by MAPE, which is defined by the following formula:

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{Mi-Pi}{Mi}\right| \tag{3.3}$$

Where

M - the measured data

P - the predicted data.

On the other hand , MBE is a quantity that indicates the average deviation of the predicted values from measured data. A positive MBE shows an overestimation in the predicted values and vice versa. Also, information on the long haul execution of the neural network model is also assessed by MBE. MBE is calculated by:

$$MBE = \frac{1}{n}\sum_{i=1}^{n}(Pi - Mi) \tag{3.4}$$

RMSE shows the short haul execution of the models and is a measure of the variation of the predicted values around the measured values, it can also provide the efficiency of the developed network in the prediction the individual value in the future time. Large positive RMSE shows a large deviation in the predicted value from the measured value. RMSE can be calculated as follows:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Pi - Mi)^2} \tag{3.5}$$

3.1.4 Weather data utilized

The research was done for 1.4 KWp PV system with two years of experimental data. The data was recorded every 1 s to take into account the variation of climate and the uncertainty in the output current. These data are for a system installed at Sohar city in Oman

Table 3.1 shows the specifications of PV system modules used in this system. The PV array is fixed at a tilt angle of 27° facing the south in order to increase the average annual energy to maximum value. The output current was recorded every 1 second [Ameen et. al., 2015].

There are many devices that used to measure the variables of the model. “solar radiation transmitter of high-stability silicon photovoltaic detector unit WE300 with an accuracy of 61%, temperature sensor for the surface of the PV panel unit WE710 with an accuracy of 60.25°C, air temperature sensor model WE700 with the range of -50°C to + 50°C and accuracy of 60.1°C, and current transducer unit: CTH050 with an input range of 0–50A (DC) and output range of 4–20mA” [Ameen et. al., 2015].

Table 3.1 Specifications of the proposed system.

PV array (Kyocera KD140GH-2PU)	
PV module rated power	140 Wp
Maximum voltage	17.7 V
Maximum current	7.91 A
Open circuit voltage	22.1 V
Short circuit current	8.68 A
PV module efficiency	13.9 %
Temperature coefficient of Vo.c	- 0.36 % / K
Temperature coefficient of Is.c	0.06 % / K
Temperature coefficient of max. power	-0. 46 % / K
Inverter	1 kW
AC voltage	220-260 V
Inverter efficiency	94.1 %

In this research, 3500 records for the 1st of march 2013 were used as samples for normal and cloudy days of random solar radiation and ambient temperature records for testing the model. Meanwhile, 3500×6 records were used as training data for different days. It is worth to mention that the testing day was not used in the training process.

3.2 Contents of the Grid

In this research, IEEE 14-bus grid was considered to be the test grid . It represents a simple approximation of the American Electric Power system of February 1962 .It has 14 buses, 5generators, and 11 loads. one line diagram of the standard system extracted from IEEE site is shown in Figure 3.2. The grid consists of five synchronous machines with IEEE type-1 exciters. There is three synchronous compensators used only for reactive power support. There are 11 loads in the system totaling 259 MW and 81.3 MVAr. [IEEE org]

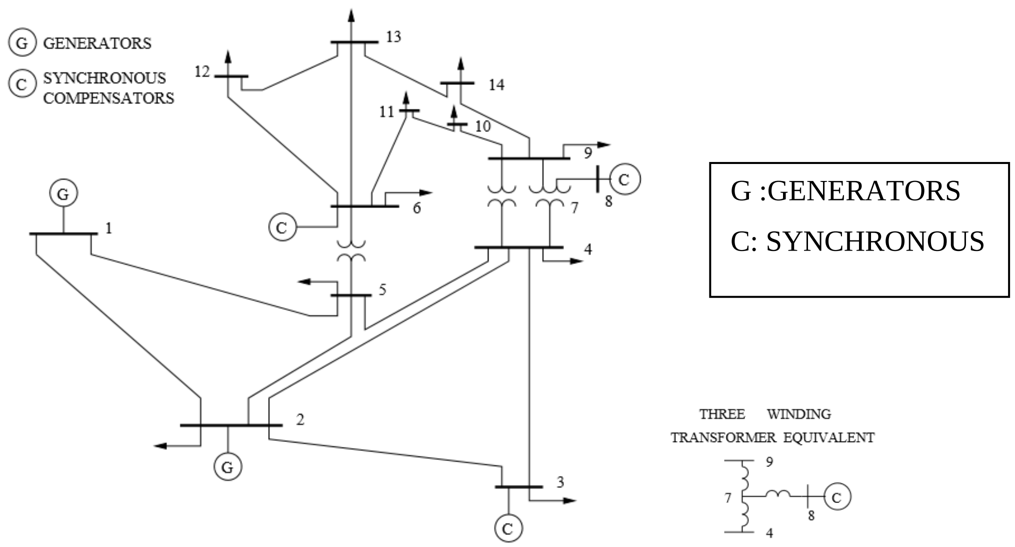

Figure 3.2: IEEE 14-bus test system.

3.3 Load flow analysis based on Newton – Raphson Method

Here load flow solution will be done to the tested grid to determine the magnitude of the load, bus voltages, reactive power generation, tap settings of a tap-changing transformer , and power factor at any point in the grid.

It can also give the phase angles , the injected bus power and the power flows through transmission lines. These investigations require number of load flow arrangements under both ordinary and abnormal conditions (blackout of transmission line or blackout of a some generators).

Load flow arrangement additionally gives the underlying state of the system when the transient behavior of the system is to be contemplated. Under steady state condition, the system conditions will be as basic arithmetical algebraic solution.

It likewise made to decide the best working strategy in case of the loss of at least one producing station or transmission lines. [Bhowmik et. al. ,2012]

3.3.1 Bus Classification

The buses in a power system are specified with four quantities which are: real power , reactive power, voltage magnitude of each bus and phase angle. In a load flow solution , two quantities of the four must be specified and the others are to be calculated through the solution of equations. The buses are arranged and classified into three types depending on the known and unknown quantities as follow:

- Load bus: Here the real power and the reactive power of the bus are specified but it is desired to calculate through load flow solution the voltage magnitude V and phase angle δ. The load bus voltage can be permitted to vary within a recommended range.

- Generator bus or voltage-controlled bus: the voltage magnitude V and the real power of the generator P are known but the reactive power Q and the phase angle δ are to be determined.

- Slack/Swing or reference bus: Here the voltage magnitude V and phase angle δ are known . Here, it should be taken into account the additional power generation required and the transmission line losses. The real and reactive power generations (PG, QG) at this bus will be calculated.

3.3.2 Newton-Raphson load flow (NRLF) Method

One of the significant power flow solution techniques is the Newton-Raphson method. The most important idea behind Newton-Raphson is to utilize consecutive linearization.

This technique needs to start with initial estimates for every one of the variables of the buses which are unknown (voltage magnitude and phase angle). After that a Taylor arrangement is utilized with higher request terms overlooked, for each power adjusted condition. Subsequently linearly equations are shown [Stevenson, 1982].

The current equation:

$$I_i = \sum_{j=1}^{n} Y\,ij\,Vj \quad = \sum_{j=1}^{n} |Y\,ij|\ |V\,j\,| < \theta\,ij + \delta j \qquad (3.6)$$

where:

I_i: current injected from bus i (pu)

$Y\,ij$: mutual admittance between bus i and j (pu).

$V\,j$: voltage of bus j (pu).

$\theta\,ij$: angle of mutual admittance between bus i and j (radian).

δj: voltage angle of bus j (radian).

Real and reactive power injection:

$$Pi - j\,Qi = \overline{Vi} \times Ii \qquad (3.7)$$

Pi: active power injected from bus i (pu).

Qi: reactive power injected from bus (pu).

V_i: voltage of bus i (pu).

I_i: current injected from bus i (pu)

Substituting for Ii yields

$$P_i - j\,Q_i = (|Vi\,| < -\delta i)\sum_{j=1}^{n}|Yij||Vj| < \theta ij + \delta j \qquad (3.8)$$

where

δi: voltage angle of bus i (radian).

Then real and reactive powers

$$P_i = \sum_{j=1}^{n}|Vi|\;|Vj|\;|Yij|\;\cos(\theta ij - \delta i + \delta j) \qquad (3.9)$$

$$Q_i = -\sum_{j=1}^{n}|Vi|\;|Vj|\;|Yij|\;\sin\,(\theta ij - \delta i + \delta j) \qquad (3.10)$$

Cast power equations into iterative form

$$P_i^{[k]} = \sum_{j=1}^{n}\left|V_i^{[k]}\right|\left|V_j^{[k]}\right|\left|Y_{ij}\right|\cos\left(\theta_{ij} - \delta_i^{[k]} + \delta_j^{[k]}\right) \qquad (3.11)$$

$$Q_i^{[k]} = -\sum_{j=1}^{n}\left|V_i^{[k]}\right|\left|V_j^{[k]}\right|\left|Y_{ij}\right|\sin\left(\theta_{ij} - \delta_i^{[k]} + \delta_j^{[k]}\right) \qquad (3.12)$$

where:

$P_i^{[k]}$: active power injected from bus i at iteration k (pu).

$Q_i^{[k]}$: reactive power injected from bus i at iteration k (pu).

$\left|V_i^{[k]}\right|$: voltage magnitude of bus i at iteration k (pu).

$\left|V_j^{[k]}\right|$: voltage magnitude of bus j at iteration k (pu).

$\left|Y_{ij}\right|$: mutual admittance magnitude between bus i and j (pu).

θ_{ij}: angle of mutual admittance between bus i and j.

$\delta_i^{[k]}$: phase angle of bus i at iteration k (radian).

$\delta_j^{[k]}$: phase angle of bus j at iteration k (radian).

Matrix form of the system of equations

$$C = \begin{bmatrix} P_{inj}^{sch} \\ Q_{inj}^{sch} \end{bmatrix} \tag{3.13}$$

$$x^{[k]} = \begin{bmatrix} \delta^{[k]} \\ V^{[k]} \end{bmatrix} \tag{3.14}$$

where

P_{inj}^{sch}: scheduled injected active power (pu).

Q_{inj}^{sch}: scheduled injected reactive power (pu)

$\delta^{[k]}$: the unknown phase angle.

$V^{[k]}$: the unknown voltage magnitude.

$$f\,(x^{[k]}) = \begin{bmatrix} P_{inj}(x^{[k]}) \\ Q_{inj}(x^{[k]}) \end{bmatrix} \tag{3.15}$$

General form of the equation to find a solution

$$C = f\,(x_{solution}) \tag{3.16}$$

$$x^{[0]} = \text{initial estimate of } x_{solution} \tag{3.17}$$

The iterative equation

$$x^{[k+1]} = x^{[k]} + \frac{C - f\,(x^{[k]}\,)}{df(\,x^{[k]})\Big/_{dx}} \tag{3.18}$$

The Jacobian - the first derivative of a set of functions

$$df(\,x^{[k]})\Big/_{dx} \tag{3.19}$$

a matrix of all combinatorial pairs

The Jacobian Matrix

$$df(\,x)\Big/_{dx} \qquad \text{yield} \qquad \begin{bmatrix} \Delta\, P \\ \Delta\, Q \end{bmatrix} = \begin{bmatrix} \partial P\big/_{\partial\delta} & \partial P\big/_{\partial|V|} \\ \partial Q\big/_{\partial\delta} & \partial Q\big/_{\partial|V|} \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta|V| \end{bmatrix} \tag{3.20}$$

$$\begin{bmatrix} \Delta P_1 \\ \Delta P_{N-1} \\ \vdots \\ \Delta Q_1 \\ \Delta Q_{N-M} \end{bmatrix} = \begin{bmatrix} \frac{\partial P_1}{\partial\delta_1} & \cdots & \frac{\partial P_1}{\partial\delta_{N-1}} & \frac{\partial P_1}{\partial|V_1|} & \cdots & \frac{\partial P_1}{\partial|V_{N-M}|} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ \frac{\partial P_{n-1}}{\partial\delta_1} & \cdots & \frac{\partial P_{N-1}}{\partial\delta_{N-1}} & \frac{\partial P_{N-1}}{\partial|V_1|} & \cdots & \frac{\partial P_{N-1}}{\partial|V_{N-M}|} \\ \frac{\partial Q_1}{\partial\delta_1} & \cdots & \frac{\partial Q_1}{\partial\delta_{N-1}} & \frac{\partial Q_1}{\partial|V_1|} & \cdots & \frac{\partial Q_1}{\partial|V_{N-M}|} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ \frac{\partial Q_{N-M}}{\partial\delta_1} & \cdots & \frac{\partial Q_{N-M}}{\partial\delta_{N-1}} & \frac{\partial Q_{N-M}}{\partial|V_1|} & \cdots & \frac{\partial Q_{N-M}}{\partial|V_{N-M}|} \end{bmatrix} \begin{bmatrix} \Delta\delta_1 \\ \vdots \\ \Delta\delta_{n-1} \\ \Delta|V_1| \\ \vdots \\ \Delta|V_{n-m}| \end{bmatrix} \tag{3.21}$$

Where M : no of voltage bus (swing)

Real power w.r.t the voltage angle

$$\frac{\partial P_i}{\partial\delta_i} = \sum_{j\neq i}|V_i||V_j||Y_{ij}|\sin(\theta_{ij} - \delta_i + \delta_j) \tag{3.22}$$

$$\frac{\partial P_i}{\partial \delta_j} = - |V_i||V_j||Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j) \quad i \neq j \tag{3.23}$$

Real power w.r.t the voltage magnitude

$$\frac{\partial P_i}{\partial |V_i|} = 2\,|V_i||Y_{ii}| \cos\theta_{ii} + \sum_{i\neq j}|V_j||Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) \tag{3.24}$$

$$\frac{\partial P_i}{\partial |V_j|} = |V_i||Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) \quad i \neq j \tag{3.25}$$

Reactive power w.r.t. the voltage angle

$$\frac{\partial Q_i}{\partial \delta_i} = \sum_{j\neq i}|V_i||V_j||Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) \tag{3.26}$$

$$\frac{\partial Q_i}{\partial \delta_j} = - |V_i||V_j||Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) \quad i \neq j \tag{3.27}$$

Reactive power w.r.t. the voltage magnitude

$$\frac{\partial Q_i}{\partial |V_i|} = - 2\,|V_i||Y_{ii}| \sin\,\theta_{ii} + \sum_{i\neq j}|V_j||Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j) \tag{3.28}$$

$$\frac{\partial Q_i}{\partial |V_j|} = - |V_i||Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j) \quad i \neq j \tag{3.29}$$

Power mismatch or power residuals (difference in schedule to calculated power)

$$\Delta P_i^{[k]} = P_i^{sch} - P_i^{[k]} \tag{3.30}$$

$$\Delta Q_i^{[k]} = Q_i^{sch} - Q_i^{[k]} \tag{3.31}$$

where:

$\Delta P_i^{[k]}$: changes in active power at iteration k.

P_i^{sch}: scheduled active power at bus i.

$P_i^{[k]}$: calculated injected active power from bus i at iteratioin k.

$$\Delta Q_i^{[k]} = Q_i^{sch} - Q_i^{[k]} \tag{3.32}$$

$\Delta Q_i^{[k]}$: changes in reactive power at iteration k.

Q_i^{sch}: scheduled reactive power at bus i.

$Q_i^{[k]}$: calculated injected reactive power from bus i at itteratioin k.

New estimates for the voltages and angles After solving equation (21),

$$\delta_i^{[K+1]} = \delta_i^{[k]} + \Delta\delta_i^{[k]} \tag{3.33}$$

$$\left|V_i^{[k+1]}\right| = \left|V_i^{[k]}\right| + \Delta \left|V_i^{[k]}\right| \tag{3.34}$$

Solution Steps :

1- Set the voltage and angle for load buses as slack bus or $1 < 0^{\circ}$ (initial values) and set the angle for generator bus usually 0° .

2- Calculate P and Q injected to load bus using the given values and estimated values . For generator bus calcuate P injection . After that find ΔP and ΔQ .

3- Form Jacobian matrix using the partial derevitives w.r.t voltage magnitude and angle.

4- Solve jacobian matrix using one of the two methods :

- inverse the Jacobian matrix and multiply by the mismatch power matrix .

- using Gaussian elemination for the jacobian matrix .

Find $\Delta\delta$ and $\Delta|V|$.

5- Find new estimated values for voltage magnitude and angle .

6- Stopping criteria is when

$$\left|\Delta\delta_i^{[k]}\right| \leq \epsilon$$

$$\left|\Delta V_i^{[k]}\right| \leq \epsilon$$

Results are dependent upon the initial guess.

Chapter Four
Results and Discussion

4.1 Introduction

The output power generated from PV module is not accurate because it doesn’t take into account the uncertainty of weather and climate variations, therefore the relationship between the input and output is nonlinear. Thus, the prediction of PV output must be effective to overcome this problem , to improve the reliability of all power system and increase the power quality.

Here, big efforts have been done to illustrate the differences between using the empirical model, measured model and artificial neural network (ANN) model as PVDG in our grid.

The ANN has the capability of self learning which made it very important in the designed module. The information processing system of it is like a human thinking technique in learning the relationship between the input and output variables by studying previous data that are recorded in specific time.

At the beginning, a model is constructed by using GRNN method.

Many statistics were made to decide that Generalized Regression Neural Network (GRNN) is the best one specially in current prediction. Matlab code was constructed as a model of GRNN which will be entered to a 14 bus IEEE Grid to study the impact of adding PVDG model at a specific bus in the system.

The load flow of the power system will be shown by using Newton Raphson method.

Two cases were deal with to clear the main objectives. The differences of real power, reactive power and voltage profile in the normal case before adding any PV and then a constant PVDG were added at the bus 4 which detected according to some calculations of voltages and losses to all buses. Finally inserting GRNN model to the same bus and had the load flow study.

The results show that GRNN model is the best case which simulates the truth and considers the obscene of sun tonight because there is no solar radiation through this time and so it is impossible to add constant PV and consider the value is fixed.

4.2 Results of GRNN based model

A proposed model by using GRNN method was constructed depending on a data that was recorded in sohar Oman for two years of experiments for 1.4 kWp PV system in series connection . The data was the solar radiation , ambient temperature and PV temperature. It was recorded every 1sec in 1 and 2 march, 2013.

The data was measured and established for normal and cloudy day to get an accurate prediction of output current.

And it used to train the GRNN model by using matlab code by dividing it to testing data and training data. The data that are used in the proposed model contain the inputs (the ambient temperature and the solar radiation). The GRNN consists of four layers: an input layer, a pattern layer, a summation layer and an output layer. The first layer is connected to the second, pattern layer, where each unit represents a training pattern and its output is a measure of the distance of the input from the stored patterns. Here we have 2 hidden layer in the developed model with 3 neurons as the rule ($2 \times number\ of\ inputs - 1$) = 3 neurons.

The first layer has two neurons and the second layer has one neurons.

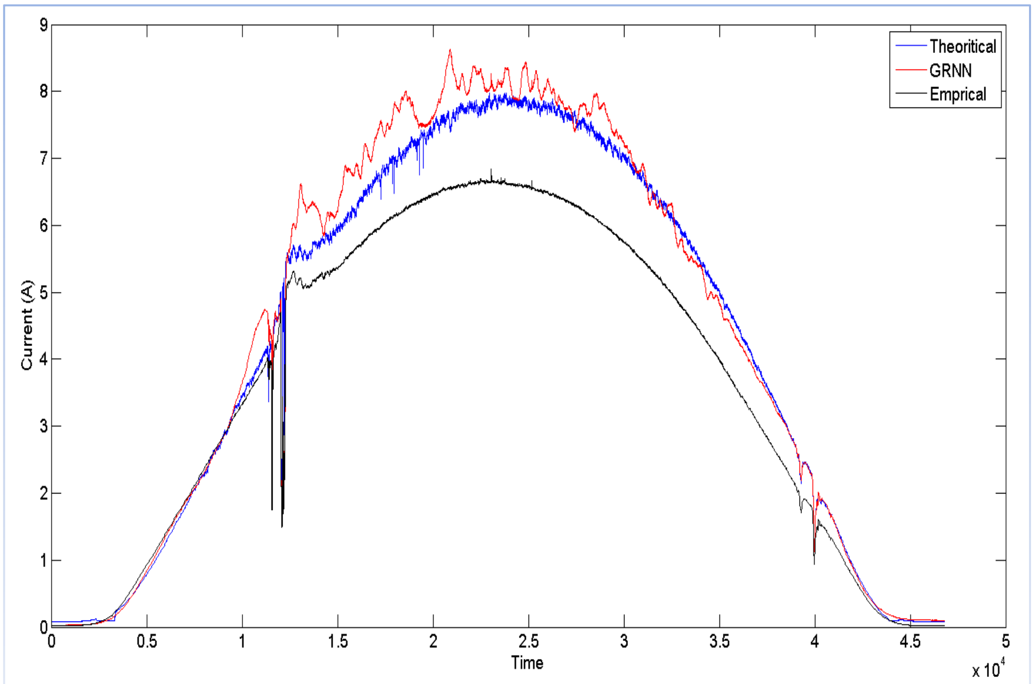

Figure 4.1: proposed model of GRNN

Figure 4.1 shows that the predicted model is more similar and closed to the measured model. But the statistical and empirical models seem to be under estimated compared to the measured data and so it may cause large problems in the system output.

The results explain the difficulty of statistical model to predict the output current of the PV system as much as GRNN model .

Here, Statistical values were calculated to decide the type of ANN system that used in the model construction . table 4.1. shows that the proposed model beats the other in the prediction the output with the climate variation although it has some under estimation but less than the others which make it generally ideal.

Table 4.1 Results of Statistics error for GRNN

Method Type	MAPE(%)	RMSE (A)	MBE (A)
Generalized regression neural network (GRNN)	0.0363	0.6470	-0.0051

4.3 Power Flow Analysis of IEEE 14 Bus System Without DG:

The electrical network that used to add the DG with fixed value and GRNN model

is shown in figure 4.2 which illustrates the one line diagram of IEEE 14 bus system

consists of 14 buses with five synchronous machines , IEEE type-1exciters,

three of which are synchronous compensators used only for reactive power support.

There are 11 loads in the system totaling 259 MW and 73.5 MVAr.

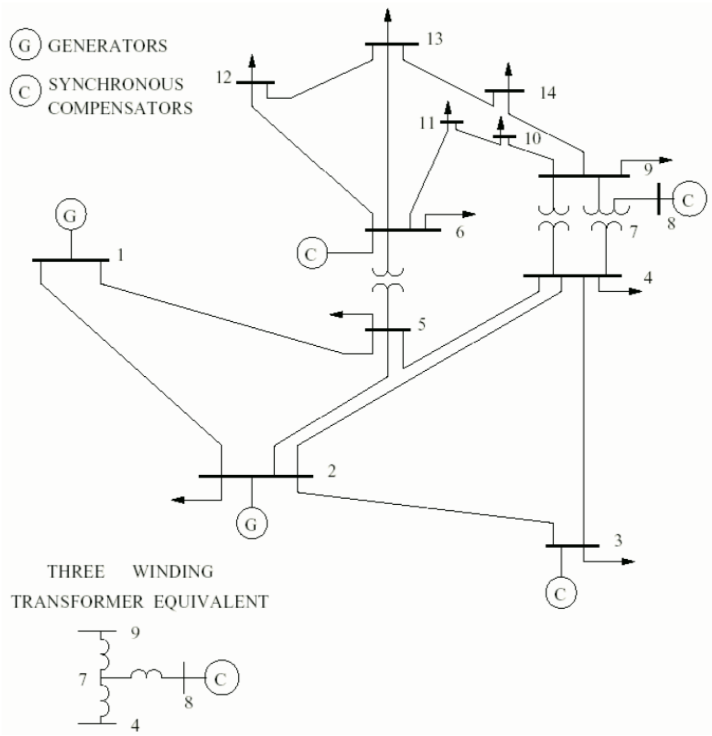

Figure 4.2: One line diagram of IEEE 14 bus system

The adapted testing system is studied in terms of active and reactive power losses and voltage magnitudes before any modifications using power flow analysis. The solution of the load flow is done mathematically by Newton-Raphson method. Voltages of all buses are relatively high and within 1 pu range. And so there is some modifications on real and reactive power will be done to make the grid more suitable for our analysis.

Load flow analysis of IEEE grid is shown in table 4.2 before making modifications at any bus.

Table 4.2 Newton Raphson Load flow Analysis in normal condition without modifications.

Bus no	**V (pu)**	**Angle (Degree)**	**Injection**		**Generation**		**Load**	
			MW	**MVAr**	**MW**	**MVAr**	**MW**	**MVAr**
1	1.06	0.0	232.593	-15.233	232.593	-15.233	0.0	0.0
2	1.045	-4. 9991	18.300	35.228	40	47.928	21.700	12.700
3	1.0100	-12.7492	-94.200	8.758	-0.000	27.758	94.200	19.000
4	1.0130	-10.2420	-47.800	3.900	0.000	-0.000	47.8	-3.900
5	1.0166	-8.7601	-7.600	-1.600	-0.000	0.000	7.600	1.600
6	1.0700	-14.4469	-11.200	15.526	0.000	23.026	11.200	7.500
7	1.0457	-13.2368	-0.000	0.000	-0.000	0.000	0.000	0.000
8	1.0800	-13.2368	-0.000	21.030	-0.000	21.030	0.000	0.000
9	1.0305	-14.8201	-29.500	-16.600	0.000	0.000	29.500	16.600
10	1.0299	-15.036	-9.000	-5.800	0.000	0.000	9.000	5.800
11	1.0461	-14.8581	-3.500	-1.800	0.000	0.000	3.500	1.800
12	1.0533	-15.2973	-6.100	-1.600	-0.000	0.000	6.100	1.600
13	1.0466	-15.3313	-13.500	-5.800	0.000	0.000	13.5	5.800
14	1.0193	-16.0717	14.900	-5.000	0.000	0.000	14.900	5.000
Total			**13.593**	**31.009**	**272.593**	**104.509**	**259.000**	**73.500**

Adding DG at any grid must be suitable for DG sizing and location, and so the next step is to decide the optimum placement of the PV model in the grid.

To choose the suitable bus that may be a PVDG bus , some power calculations were made .

Table 4.3 shows the real power losses of all buses that are far from generation sides after adding a constant PV .To detect the bus used as DG, 15 % of load power was injected to each bus and then power flow analysis was shown.

The table shows that real power losses after adding the DG at bus 4 became the least value. So The choice of bus 4 is excellent.

Table 4.3 Real Power Losses after adding PV to specified buses.

No of bus	**Total P_{losses} and Q_{losses} before adding PV**		**Injected power to each bus (MW)**	**Real power losses after adding PV (MW)**
4	13.573 MW	56.838 MVAr	7.143	12.789
5	13.573 MW	56.838 MVAr	1.14	13.465
9	13.573 MW	56.838 MVAr	4.35	13.05
10	13.573 MW	56.838 MVAr	1.35	13.417
11	13.573 MW	56.838 MVAr	0.525	13.515
12	13.573 MW	56.838 MVAr	0.915	13.469
13	13.573 MW	56.838 MVAr	2.025	13.333
14	13.573 MW	56.838 MVAr	2.235	13.266

The adapted grid is studied in terms of active power, reactive power, losses, voltage magnitudes and phase angles before adding a DG using power flow analysis. The mathematical solution of the load flow is done by Newton-Raphson method.

As a result, the total generation of the network is 272.593MW and 104.509 MVAr. And the total loads of the network are 259 MW and 73 MVAr distributed over 11 load buses, and the total real power and reactive power losses are shown in Table 4.4 that illustrate the line flow and losses of transmission line of IEEE 14 bus system.

Figure 4.3 shows the results of the load flow analysis in terms of voltage magnitudes before any modifications. From the figure, the buses that located away from the generation side have low voltage magnitude as compared to the buses that are located near generation source. But we can see that all voltages have reasonable values that makes no need for inserting a PVDG to any bus and so we made some changes to the grid to achieve the objective .

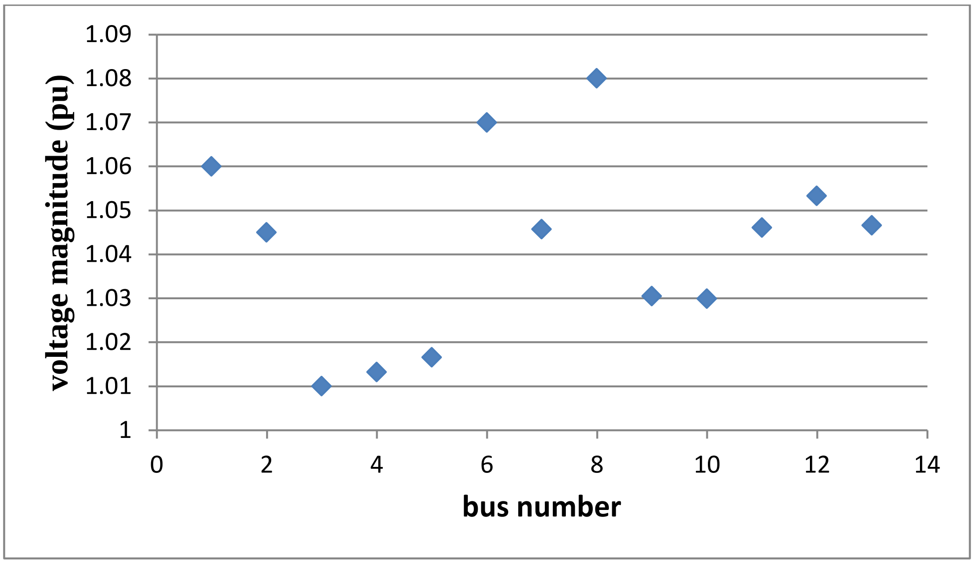

Figure 4.3: voltage magnitude for each bus before modification.

Table 4.4 Line Flow and Losses of transmission line of the power system before adding PV

From Bus	To Bus	P MW	Q MVAr	From Bus	To Bus	P MW	Q MVAr	Line Loss	
								MW	MVAr
1	2	156.946	-17.453	2	1	-152.645	30.585	4.301	13.132
1	5	75.447	7.977	5	1	-72.679	3.449	2.768	11.426
2	3	73.366	5.939	3	2	-71.035	3.883	2.331	9.822
2	4	55.884	2.931	4	2	-54.217	2.125	1.666	5.056
2	5	41.695	4.734	5	2	-40.777	-1.930	0.918	2.804
3	4	-23.165	7.746	4	3	23.557	-6.746	0.392	1.000
4	5	-59.496	11.563	5	4	59.974	-10.056	0.478	1.507
4	7	27.070	-15.388	7	4	-27.070	17.320	-0.00	1.932
4	9	15.466	-2.637	9	4	-15.466	3.929	0.00	1.292
5	6	45.882	-20.835	6	5	-45.882	26.606	0.00	5.771
6	11	8.283	8.896	11	6	-8.161	-8.639	0.123	0.257
6	12	8.064	3.176	12	6	-7.983	-3.008	0.081	0.168
6	13	18.335	9.980	13	6	-18.083	-9.484	0.252	0.496
7	8	0.00	-20.354	8	7	-0.00	21.022	0.00	0.667
7	9	27.070	14.797	9	7	-27.070	-13.84	0.000	0.957
9	10	4.397	-0.903	10	9	-4.391	0.919	0.006	0.016
9	14	8.639	0.322	14	9	-8.550	-0.132	0.089	0.190
10	11	-4.609	-6.719	11	10	4.661	6.839	0.051	0.120
12	13	1.883	1.408	13	12	-1.872	-1.398	0.011	0.010
13	14	6.455	5.082	14	13	-6.350	-4.868	0.105	0.214
Total Losses								**13.573**	**56.838**

IEEE 14 bus will have some modifications to make the improvement effective, so the buses voltages were reduced by increasing the real load power and reactive load power of bus 4 by 350% w.r.t normal value, and 400% for bus 13 ,because these buses have the minimum value of voltages . Buses voltages will decrease below 1 pu to allow for adding PVDG at the suitable bus.

Figure 4.4 shows the voltage magnitude of each bus after making the modifications. The voltages now have lower value than the normal case.

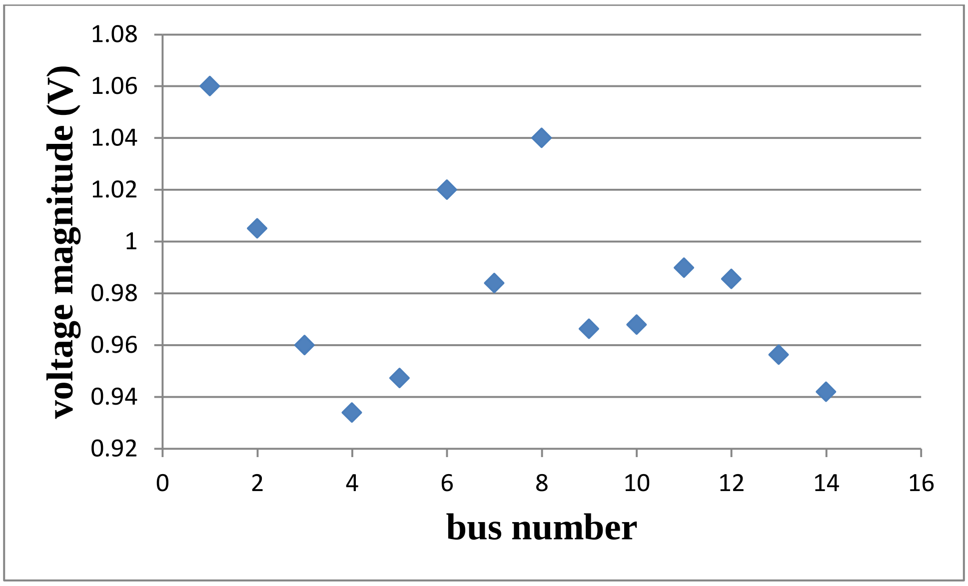

Figure 4.4: voltage magnitude for each bus after modification

Table 4.5 shows the load flow analysis of the modified power system, the voltage at bus 4 is about 0.93 pu and the load real power for bus 4 is 166.34 Mw and reactive load power is 9.75 MVAr. The voltage profile of the power system buses shows in table 4.5 after the modifications also.

The real power losses and reactive power losses became 44.704 MW , 176.116 MVAr respectively.

Constant PVDG now will add to the optimum placement of the power system to have the load flow analysis again and compare the results with the proposed model results.

Table 4.5 Newton Raphson Load flow Analysis after modifications

Bus no	V (pu)	Angle (Degree)	Injection		Generation		Load	
			MW	MVAr	MW	MVAr	MW	MVAr
1	1.06	0.0	422.665	59.943	422.665	59.943	0.0	0.0
2	1.005	-8.7908	18.300	44.347	40	57.047	21.700	12.700
3	0.9600	-20.4265	-94.200	22.352	-0.000	41.352	94.200	19.000
4	0.9339	-19.9892	-166.34	-9.750	0.000	-0.000	166.34	9.750
5	0.9472	-16.6966	-7.600	-1.600	-0.000	0.000	7.600	1.600
6	1.0200	-27.5927	-11.200	55.650	0.000	63.150	11.200	7.500
7	0.9839	-24.3544	-0.000	0.000	-0.000	0.000	0.000	0.000
8	1.0400	-24.3544	-0.000	33.145	-0.000	33.145	0.000	0.000
9	0.9662	-26.6225	-29.500	-16.600	0.000	0.000	29.500	16.600
10	0.9678	-27.1110	-9.000	-5.800	0.000	0.000	9.000	5.800
11	0.9899	-27.4733	-3.500	-1.800	0.000	0.000	3.500	1.800
12	0.9855	-29.4420	-6.100	-1.600	-0.000	0.000	6.100	1.600
13	0.9563	-30.0240	-54.000	-23.200	0.000	0.000	54.000	23.200
14	0.9419	29.3003	14.900	5.000	0.000	0.000	14.900	5.000
Total			**44.623**	**150.086**	**462.665**	**254.636**	**418.042**	**104.550**

Table 4.6 The voltage Profile of the buses before adding PV

Bus	Type	Vsp	PGi	QGi	PLi	QLi
1	1	1.06	0	0	0	0
2	2	1.045	40	42.4	21.7	12.7
3	2	1.010	0	23.4	94.2	19.0
4	3	1.0	0	0	166.67	9.4
5	3	1.0	0	0	7.6	1.6
6	2	1.0700	0	12.2	11.2	7.5
7	3	1.0	0	0	0	0
8	2	1.0900	0	17.4	0	0
9	3	1.0	0	0	29.5	16.6
10	3	1.0	0	0	9.0	5.8
11	3	1.0	0	0	3.5	1.8
12	3	1.0	0	0	6.1	1.6
13	3	1.0	0	0	54	23.2
14	3	1.0	0	0	14.9	5.0

4.4 Power Flow Analysis of IEEE 14 Bus System with fixed DG:

In our power system we are looking for improving the voltages of the buses and reduce the power losses by adding a photovoltaic (PV) to all load buses which their voltages are below 1 pu voltage, and they are far away from generating buses (near the loads).

the injection fixed power to bus 4 is about 30 MW, and so the new real power for bus 4 became 136.67 MW.

P_{losses} after adding the constant PV is about 37.288 And reactive power losses 148.97 MVAr , these results are shown in table 4.7.

From previous results, It can be noticed that when PV was added to bus 4 , the real power losses and reactive power losses decrease with reasonable values that give a good impression on the improvement of the power system .

Otherwise, this improvement is not taking into account the weather variations and the absence of sun tonight and so, it doesn't accurate.

A model of GRNN was inserted to achieve accurate output , the value of PV that inserted to bus 4 is entered to the system with different values of solar radiations depending on the time .

Table 4.7 Comparisons between two cases before and after adding PV

Bus num	**Before adding PV**			**After adding PV**		
	Voltage pu	**P_{Losses} MW**	**Q_{Losses} MVAr**	**Voltage pu**	**P_{Losses} MW**	**Q_{Losses} MVAr**
4	0.934	44.704	176.116	0.95	37.288	148.97

4.5 Power Flow Analysis of IEEE 14 Bus System with PV model based on GRNN

The output of PV system is not constant , it depends on the solar radiation and ambient temperature through the day, here the proposed model is entered to the IEEE 14 bus system as DG to obtain the load flow study by using Newton Raphson method in matlab code.

Adding the proposed model is done by following steps which are shown in table 4.8:

1. The average solar radiation is calculated every 1 hour as shown in table 4.9.

2. the output power of the PV is calculated every 30 minute from 6 am to 7 pm and then entered to bus 4.

3. The total power of the load bus after adding the DG is calculated also.

4. Load flow is performed every 30 minute to obtain the total real power and

reactive power losses.

5. The average of these losses is calculated every 1 hour to have total energy of the GRNN model from 6 am to 7 pm.

If the total real power and reactive power losses is calculated, an improvement in the voltage profile and power losses is clear in the addition of GRNN model.

This improvement is not as the previous results when 30 MW is entered to bus4 , this differences are shown in table 4.10 which illustrates that there is an imaginary improvement is cleared from the addition of constant PV to bus 4 caused by neglecting the absence of sun evening.

Table 4.8: The average real and reactive power every 1 hour.

Time (from 6 am to 7pm)	Average Power injected to bus 4 (MW) From excel file	Total Power at bus 4 after adding DG	Total Losses		Average Losses (through 1 hour)
			P (MW)	Q (MVAr)	
6 – 6:30	0.325555326	166.3444447	44.624	175.833	44.6065 MW 175.77 MVAr
6:30 – 7	0,466632519	166.2033675	44.589	175.707	
7 – 7:30	2.303865156	164.366	44.140	174.120	43.745 MW 172.721 MVAr
7:30 – 8	5.5741159	161.1	43.350	171.322	
8 – 8:30	9.243297785	157.4267	42.473	168.22	41.986 MW 166.333 MVAr
8:30 -9	13.24084084	153.43	41.499	164.446	
9-9.30	17.15704869	149.513	40.595	161.247	40.2035 MW 159.2315 MVAr
9.30-10	22.18212661	144.488	39.457	157.219	
10-10.30	23.74101896	142.93	38.655	153.796	38.3695 MW 152.789 MVAr
10.30-11	26.33250028	140.3375	38.084	151.782	
11-11.30	28.22662977	138.4434	37.672	150.324	37.505 MW 149.735 MVAr
11.30-12	29.76805792	136.902	37.338	149.146	
12-12.30	30.57557953	136.094	37.164	148.532	37.137 MW 148.4355 MVAr
12.30-1	30.82998725	135.84	37.110	148.339	
1-1.30	30.42036529	136.25	37.198	148.650	37.302 MW 149.018 MVAr
1.30-2	29.45366338	137.2164	37.406	149.386	
2-2.30	27.78930089	138.881	37.767	150.660	38.0105 MW 151.52 MVAr
2.30-3	25.56017611	141.11	38.254	152.380	
3-3.30	22.72403557	143.946	39.336	156.790	39.714MW 158.1285 MVAr
3.30-4	19.36530441	147.3047	40.092	159.467	
4-4.30	15.47221471	151.198	40.982	162.617	41.4905 MW 164.579 MVAr
4.30-5	11.25515887	155.4148	41.999	166.541	
5-5.30	7.025480081	159.6445	43.001	170.087	43.4815Mw 171.7885 MVAr
5.30-6	3.0346377	163.635	43.962	173.490	
6-6.30	0.554103745	166.1159	44.568	175.634	44.5955 MW 175.7325 MVAr
6.30-7	0.328076028	166.3419	44.623	175.831	

Table 4.9 Average solar radiation every 1 hour

Time	Average Solar radiation (w /m^2)
6-7	8.9
7-8	140.9
8-9	359.23
9-10	576.6
10-11	721.175
11-12	810
12-1	**837.18**
1-2	801.68
2-3	703.95
3-4	544
4-5	338.7
5-6	129.7

Table 4.10 Differences between normal case, constant PV and GRNN total power losses

Normal case (with modifications)		Adding constant PV		Adding GRNN model	
P_{Losses} (MW)	Q_{Losses} (MVAr)	P_{Losses} (MW)	Q_{Losses} (MVAr)	P_{Losses} (MW)	Q_{Losses} (MVAr)
44.704	176.116	37.288	148.97	40.29	160

From previous results in table 4.10, the second GRNN method gave a much more accurate planning that simulate the truth and away from the simplistic exaggeration.

Figure 4.5 , 4.6 and 4.7 illustrate the variation of solar radiation and power losses during a day, it is obvious that solar radiation is maximum value in the mid day, otherwise the losses are minimum value at the same hour.

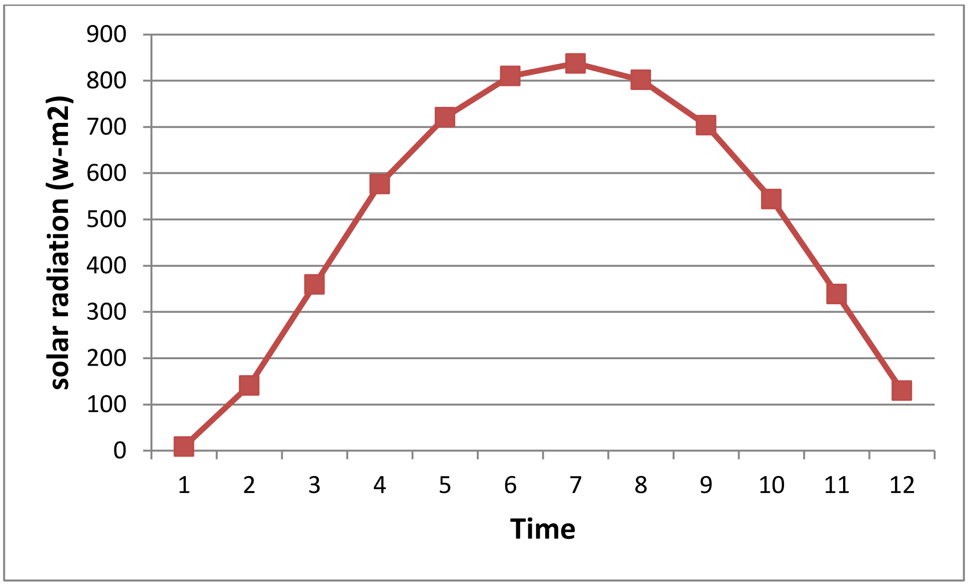

Figure 4.5: Variation of solar radiation during a day after Adding GRNN model

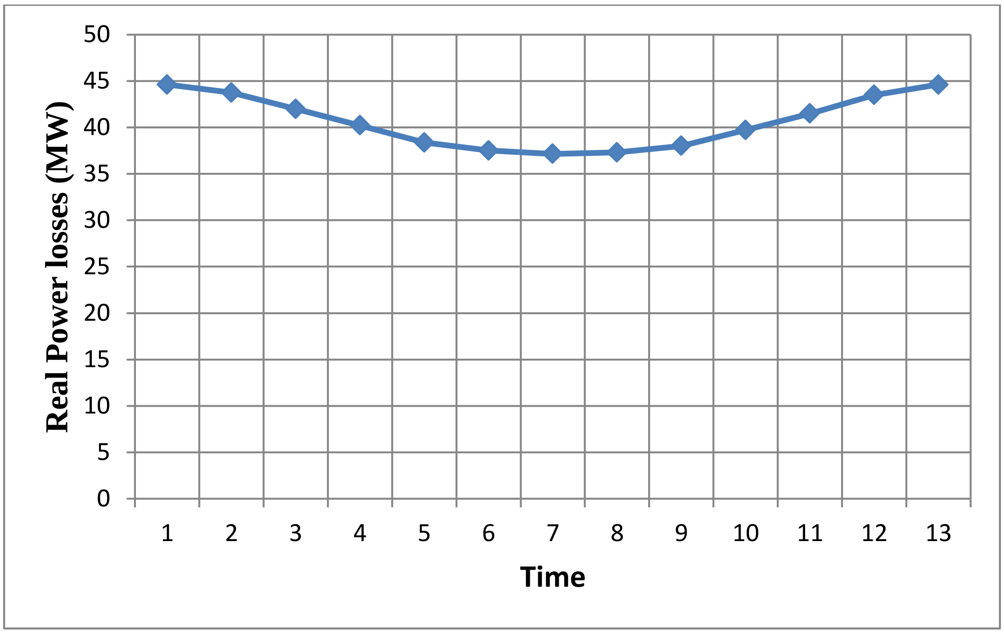

Figure 4.6: Variation of power losses during a day after Adding GRNN model

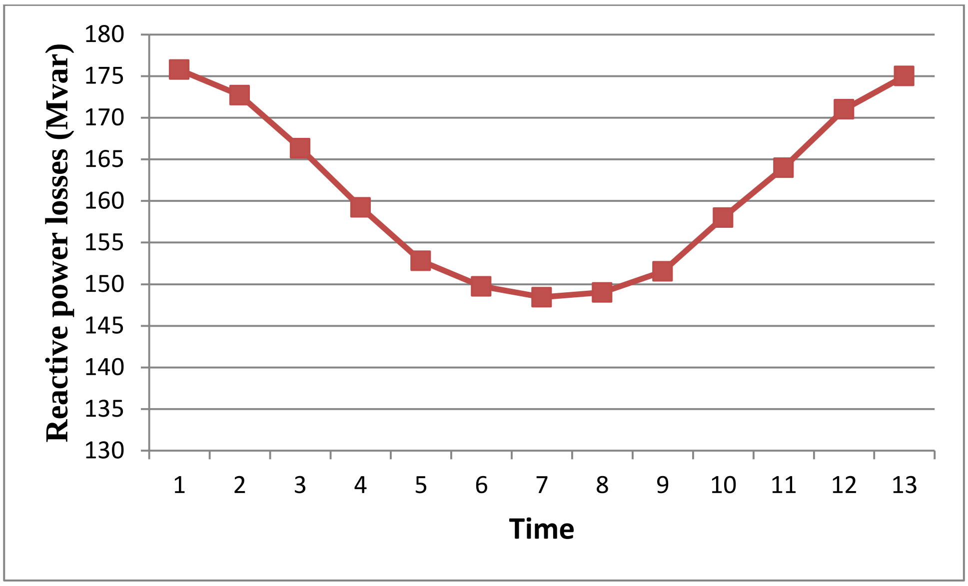

Figure 4.7: the relationship between reactive power losses and time after adding GRNN model

Chapter 5
Conclusion and future work

5.1 Conclusion

GRNN based model was introduced in this thesis , it was the most recommended in the prediction the output current of PV system although the variation of climate , this model was chosen after three statistical errors calculations (MAPE, RMSE and MBE) . Ambient temperature and solar radiation was used as an inputs to the model and the current was used as the output . The proposed model was implemented by matlab code that show the proposed GRNN model , measured model and regression model . The output of the matlab file explain that the proposed model seem more accurate from statistical and regression models from the measured value . and so it will be generally ideal in prediction the output current. GRNN model was used as PVDG at IEEE- 14 bus grid to improve the voltage profile and decrease the losses . The total generation of the network is 272.593MW , 104.509 MVAr, and the total loads of the network are 259 MW and 73 MVAr distributed over 11 load buses.

The buses that located away from the generation have low voltage magnitude in comparison with the buses that are located near generation source, so adding PV has been done on specific bus with low voltage. The target was bus 4 in order to minimize the power losses and enhance the voltage profile . Here fixed PVDG was introduced to test the features of the proposed GRNN model . The fixed power injected to bus 4 is about 30 MW, and so the new real power became 136.67 MW.

P_{losses} after adding the constant PV is about 37.288 but the reactive power losses was 148.97 MVAr .

Integrating of GRNN model during the day will make the real power losses 40.28 MW and reactive power 160 MVAr .

By comparing the two results there is about 3 Mw of imaginary improvement from the first traditional way of constant PV in comparison with the second scenario. The second scenario gives much more accurate results that simulate the truth.

5.2 Future work

The proposed GRNN model introduced an important and real contribution for improving the characteristic of the power system and the distributed generation (DG) is used to solve distribution networks problems such as voltage drop, power losses, harmonics and power quality. but there is many recommendations may show below :

1- To study other types of ANN methods .

2- To use other grids and may be real one.

3- To test the approach for other cases with different data.

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Appendixes

Appendix A

GRNN PV model

```
clc
%datasource
fileName = 'Source 1.xls';
sheetName = '1-3-2013';
sheetName2='2-3-2013';
%-------------------------

%Inputdata
Ta=xlsread(fileName, sheetName , 'C2:C3500');  %Input
G=xlsread(fileName, sheetName , 'D2:D3500');   %input
Ipv=xlsread(fileName, sheetName , 'F2:F3500');  %target
Ta_test=xlsread(fileName, sheetName2 , 'C2:C3500');  %testing input
G_test=xlsread(fileName, sheetName2 , 'D2:D3500');  %testing input
I_test=xlsread(fileName, sheetName2 , 'F2:F3500');  %testing output
%------------
inputs = [Ta,G];
I=inputs';
targets= Ipv;
T=targets';
%-------ann Model development
net = newgrnn(I,T);
%------------testing the developed model--------
test=[Ta_test,G_test];
Test1=test';
I_pr=sim(net,Test1);
I_P= I_pr';
%---------------------------------------------
%Emprical model
IE=(G_test./1000)*7.91;
%--------------------
plot(I_test)
hold on
plot (I_P, 'red')
hold on
plot (IE,'k')
%------------------
MAPE_i=[];
for i=1:length(I_test);
MAPE_ii= abs((I_test(i)-I_P(i))/ I_test(i));
MAPE_i=[MAPE_ii;MAPE_i];
end
MAPE_i;
MAPE=sum(MAPE_i)/length(I_test)

I_avg=sum(I_test)/length(I_test);
MBE_i=[];
for i=1:length(I_test);
MBE_ii= I_P(i)-I_test(i);
MBE_i=[MBE_ii;MBE_i];
end
MBE_i;
MBE=sum(MBE_i)/length(I_test)
```

```
MBE_percentage= MBE/I_avg


RMSE_i=[];
for i=1:length(I_test);
RMSE_ii= squareform(I_P(i)-I_test(i));
RMSE_i=[RMSE_ii;RMSE_i];
end
RMSE_i;
RMSE=sqrt(sum(RMSE_i)/length(I_test))
RMSE_percentage= RMSE/I_avg
```

Appendix B

IEEE 14 bus Network in normal case before modifications

```
% Returns Initial Bus datas of the system...

function busdt = busdatas(num)

% Type....
% 1 - Slack Bus..
% 2 - PV Bus..
% 3 - PQ Bus..

%          |Bus | Type | Vsp | theta | PGi | QGi | PLi | QLi |  Qmin |
Qmax |
busdat14 = [1      1    1.060    0       0     0     0     0       0
0;
             2      2    1.045    0      40   42.4  21.7  12.7    -40
50;
             3      2    1.010    0       0   23.4  94.2  19.0     0
40;
             4      3    1.0      0       0     0   47.8  -3.9     0
0;
             5      3    1.0      0       0     0    7.6   1.6     0
0;
             6      2    1.070    0       0   12.2  11.2   7.5     -6
24;
             7      3    1.0      0       0     0    0.0   0.0     0
0;
             8      2    1.090    0       0   17.4   0.0   0.0     -6
24;
             9      3    1.0      0       0     0   29.5  16.6     0
0;
             10     3    1.0      0       0     0    9.0   5.8     0
0;
             11     3    1.0      0       0     0    3.5   1.8     0
0;
             12     3    1.0      0       0     0    6.1   1.6     0
0;
             13     3    1.0      0       0     0   13.5   5.8     0
0;
             14     3    1.0      0       0     0   14.9   5.0     0
0;];

switch num
    case 14
        busdt = busdat14;

end
```

Appendix C

IEEE 14 bus Network in normal case after modifications

```
% Returns Initial Bus datas of the system...

function busdt = busdatas(num)

% Type....
% 1 - Slack Bus..
% 2 - PV Bus..
% 3 - PQ Bus..

%          |Bus | Type | Vsp | theta | PGi | QGi | PLi | QLi |  Qmin |
Qmax |
busdat14 = [1      1     1.060    0        0      0      0      0        0
0;
            2      2     1.045    0       40    42.4   21.7    12.7     -40
50;
            3      2     1.010    0        0    23.4   94.2    19.0      0
40;
            4      3     1.0      0        0      0  166.67    9.75      0
0;
            5      3     1.0      0        0      0     7.6     1.6      0
0;
            6      2     1.070    0        0    12.2   16.8    11.25     -6
24;
            7      3     1.0      0        0      0     0.0     0.0      0
0;
            8      2     1.090    0        0    17.4    0.0     0.0     -6
24;
            9      3     1.0      0        0      0    29.5    16.6      0
0;
            10     3     1.0      0        0      0     9.0     5.8      0
0;
            11     3     1.0      0        0      0     3.5     1.8      0
0;
            12     3     1.0      0        0      0     6.1     1.6      0
0;
            13     3     1.0      0        0      0    20.25    8.7      0
0;
            14     3     1.0      0        0      0    14.9     5.0      0
0;];

switch num
    case 14
        busdt = busdat14;

end
```

Appendix D

IEEE 14 bus Network with fixed DG

```
% Returns Initial Bus datas of the system...

function busdt = busdatas(num)

% Type....
% 1 - Slack Bus..
% 2 - PV Bus..
% 3 - PQ Bus..

%           |Bus | Type | Vsp | theta | PGi | QGi | PLi | QLi |  Qmin |
Qmax |
busdat14 = [1      1     1.060    0        0      0      0      0        0
0;
            2      2     1.045    0       40    42.4   21.7    12.7     -40
50;
            3      2     1.010    0        0    23.4   94.2    19.0      0
40;
            4      3     1.0      0        0      0  136.67   9.75      0
0;
            5      3     1.0      0        0      0     7.6    1.6      0
0;
            6      2     1.070    0        0    12.2   11.2     7.5     -6
24;
            7      3     1.0      0        0      0     0.0    0.0      0
0;
            8      2     1.090    0        0    17.4    0.0    0.0     -6
24;
            9      3     1.0      0        0      0    29.5   16.6      0
0;
            10     3     1.0      0        0      0     9.0    5.8      0
0;
            11     3     1.0      0        0      0     3.5    1.8      0
0;
            12     3     1.0      0        0      0     6.1    1.6      0
0;
            13     3     1.0      0        0      0      54    23.2      0
0;
            14     3     1.0      0        0      0    14.9    5.0      0
0;];

switch num
    case 14
        busdt = busdat14;
end
```

```
% Program for Newton-Raphson Load Flow Analysis..

nbus = 14;                  % IEEE-14, IEEE-30, IEEE-57..
Y = ybusppg(nbus);          % Calling ybusppg.m to get Y-Bus Matrix..
busd = busdatas(nbus);      % Calling busdatas..
BMva = 100;                 % Base MVA..
bus = busd(:,1);            % Bus Number..
type = busd(:,2);           % Type of Bus 1-Slack, 2-PV, 3-PQ..
V = busd(:,3);              % Specified Voltage..
del = busd(:,4);            % Voltage Angle..
Pg = busd(:,5)/BMva;        % PGi..
Qg = busd(:,6)/BMva;        % QGi..
Pl = busd(:,7)/BMva;        % PLi..
Ql = busd(:,8)/BMva;        % QLi..
Qmin = busd(:,9)/BMva;      % Minimum Reactive Power Limit..
Qmax = busd(:,10)/BMva;     % Maximum Reactive Power Limit..
P = Pg - Pl;                % Pi = PGi - PLi..
Q = Qg - Ql;                % Qi = QGi - QLi..
Psp = P;                    % P Specified..
Qsp = Q;                    % Q Specified..
G = real(Y);                % Conductance matrix..
B = imag(Y);                % Susceptance matrix..

pv = find(type == 2 | type == 1);   % PV Buses..
pq = find(type == 3);               % PQ Buses..
npv = length(pv);                   % No. of PV buses..
npq = length(pq);                   % No. of PQ buses..

Tol = 1;
Iter = 1;
while (Tol > 1e-5)   % Iteration starting..

    P = zeros(nbus,1);
    Q = zeros(nbus,1);
    % Calculate P and Q
    for i = 1:nbus
        for k = 1:nbus
            P(i) = P(i) + V(i)* V(k)*(G(i,k)*cos(del(i)-del(k)) +
B(i,k)*sin(del(i)-del(k)));
            Q(i) = Q(i) + V(i)* V(k)*(G(i,k)*sin(del(i)-del(k)) -
B(i,k)*cos(del(i)-del(k)));
        end
    end

    % Checking Q-limit violations..
    if Iter <= 7 && Iter > 2    % Only checked up to 7th iterations..
        for n = 2:nbus
            if type(n) == 2
                QG = Q(n)+Ql(n);
                if QG < Qmin(n)
                    V(n) = V(n) + 0.01;
                elseif QG > Qmax(n)
                    V(n) = V(n) - 0.01;
                end
            end
         end
    end

    % Calculate change from specified value
    dPa = Psp-P;
```

```
    dQa = Qsp-Q;
    k = 1;
    dQ = zeros(npq,1);
    for i = 1:nbus
        if type(i) == 3
            dQ(k,1) = dQa(i);
            k = k+1;
        end
    end
    dP = dPa(2:nbus);
    M = [dP; dQ];       % Mismatch Vector

    % Jacobian
    % J1 - Derivative of Real Power Injections with Angles..
    J1 = zeros(nbus-1,nbus-1);
    for i = 1:(nbus-1)
        m = i+1;
        for k = 1:(nbus-1)
            n = k+1;
            if n == m
                for n = 1:nbus
                    J1(i,k) = J1(i,k) + V(m)* V(n)*(-
G(m,n)*sin(del(m)-del(n)) + B(m,n)*cos(del(m)-del(n)));
                end
                J1(i,k) = J1(i,k) - V(m)^2*B(m,m);
            else
                J1(i,k) = V(m)* V(n)*(G(m,n)*sin(del(m)-del(n)) -
B(m,n)*cos(del(m)-del(n)));
            end
        end
    end

    % J2 - Derivative of Real Power Injections with V..
    J2 = zeros(nbus-1,npq);
    for i = 1:(nbus-1)
        m = i+1;
        for k = 1:npq
            n = pq(k);
            if n == m
                for n = 1:nbus
                    J2(i,k) = J2(i,k) + V(n)*(G(m,n)*cos(del(m)-
del(n)) + B(m,n)*sin(del(m)-del(n)));
                end
                J2(i,k) = J2(i,k) + V(m)*G(m,m);
            else
                J2(i,k) = V(m)*(G(m,n)*cos(del(m)-del(n)) +
B(m,n)*sin(del(m)-del(n)));
            end
        end
    end

    % J3 - Derivative of Reactive Power Injections with Angles..
    J3 = zeros(npq,nbus-1);
    for i = 1:npq
        m = pq(i);
        for k = 1:(nbus-1)
            n = k+1;
            if n == m
                for n = 1:nbus
```

```
                    J3(i,k) = J3(i,k) + V(m)* V(n)*(G(m,n)*cos(del(m)-
del(n)) + B(m,n)*sin(del(m)-del(n)));
                end
                J3(i,k) = J3(i,k) - V(m)^2*G(m,m);
            else
                J3(i,k) = V(m)* V(n)*(-G(m,n)*cos(del(m)-del(n)) -
B(m,n)*sin(del(m)-del(n)));
            end
        end
    end

    % J4 - Derivative of Reactive Power Injections with V..
    J4 = zeros(npq,npq);
    for i = 1:npq
        m = pq(i);
        for k = 1:npq
            n = pq(k);
            if n == m
                for n = 1:nbus
                    J4(i,k) = J4(i,k) + V(n)*(G(m,n)*sin(del(m)-
del(n)) - B(m,n)*cos(del(m)-del(n)));
                end
                J4(i,k) = J4(i,k) - V(m)*B(m,m);
            else
                J4(i,k) = V(m)*(G(m,n)*sin(del(m)-del(n)) -
B(m,n)*cos(del(m)-del(n)));
            end
        end
    end

    J = [J1 J2; J3 J4];      % Jacobian Matrix..

    X = inv(J)*M;            % Correction Vector
    dTh = X(1:nbus-1);       % Change in Voltage Angle..
    dV = X(nbus:end);        % Change in Voltage Magnitude..

    % Updating State Vectors..
    del(2:nbus) = dTh + del(2:nbus);    % Voltage Angle..
    k = 1;
    for i = 2:nbus
        if type(i) == 3
            V(i) = dV(k) + V(i);        % Voltage Magnitude..
            k = k+1;
        end
    end

    Iter = Iter + 1;
    Tol = max(abs(M));                  % Tolerance..

end
loadflow(nbus,V,del,BMva);              % Calling Loadflow.m..
```

جامعة النجاح الوطنية

كلية الدراسات العليا

تأثير نموذج التوليد الموزع على معاملات انسياب الأحمال في نظام القوى الكهربائي: حالة دراسية عن أنظمة الخلايا الكهروضوئية كوحدات للتوليد الموزع

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إشراف

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قدمت هذه الاطروحة استكمالاً لمتطلبات الحصول على درجة الماجستير في هندسة القوى الكهربائية، بكلية الدراسات العليا، في جامعة النجاح الوطنية، نابلس– فلسطين.

2018

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الملخص

لقد قمنا في هذا العمل ببناء نموذج للتنبؤ بمخرجات الخلايا الكهروضوئية باستخدام نظام الشبكة العصبية الاصطناعية وهي طريقة للتنبؤ بالاعتماد على بيانات سابقة يتم ادخالها على النموذج ثم تدريبه وفحصه عن طريقها لإعطاء نتائج دقيقة و قريبة من الواقع، لقد قمنا باختيار الانحدار المعمم للشبكة العصبية كنوع من انواع الشبكات العصبية الاصطناعية بناءً على قيم احصائية تم حسابها والتعامل معها رياضياً.

السبب الذي دفعنا لاختيار هذا النموذج من الخلايا العصبية هو التغيرات المناخية والتقلبات الجوية وغياب الشمس ليلاً وبالتالي لا يمكننا ان نعتبر ان الطاقة الشمسية الخارجة من الخلايا الكهروضوئية هي قيمة ثابتة طوال اليوم .

النموذج المقترح الذي قمنا بتصميمه باستخدام برنامج الماتلاب له مدخلين هما الإشعاع الشمسي ودرجة الحرارة المحيطة ودرجة حرارة الخلايا الشمسية بينما الناتج هو التيار، تم التعامل معه بدايةً من خلال بيانات التدريب والاختبار المستخدمة لتدريب الشبكات العصبية الاصطناعية لإعطاء مخرجات دقيقة.

أظهرت النتائج في هذه الدراسة الفروق بين النموذج المقترح والنماذج التجريبية والإحصائية الأخرى.

بعد تصميم النموذج المقترح قمنا بإدخاله على شبكة كهربائية كوحدة توزيع كهربائي بالقرب من الاحمال والمستهلكين لتقليل الضياعات الناتجة عن انتقال التيار الكهربائي في الشبكة الي الاحمال البعيدة وزيادة الاعتمادية على النظام وتحسين مستوى الجهود الكهربائية .

الشبكة الكهربائية المستخدمة هي شبكة IEEE-14 تحتوي على5 مولدات كهربائية و11 حمل كهربائي موزعين على نقاط التحميل، ويبلغ اجمالي الأحمال 259 MW و73.5 MVAr .

لكن هذه الشبكة تحتوي على جهود عالية بحدود من 1pu على جميع buses وبالتالي هي بحاجة لبعض التعديلات لإدخال وحدة توزيع جديدة.

للقيام بهذا العمل يلزم تحديد مكان و قيمة وحدة التوزيع المستخدمة وبناء على ذلك لقد قمنا باختيار bus 4 لإضافة الخلايا الكهروضوئية عليها لأنها كانت اقل جهد وقلت الخسائر عن الاضافة عليها لأقل ما يمكن وهي بعيدة عن مناطق التوليد.

تم إدخال الخلايا الكهروضوئية الثابتة كحالة دراسة أولى لإظهار الاختلافات بين مخرجاتها ومخرجات النموذج العصبي الاصطناعي المقترح. بلغت القدرة الثابتة المحقونة في bus4 حوالي MW30، وهكذا أصبحت الطاقة الحقيقة الجديدةعلى هذه bus 136.67 MW.

الخسائر الكهربائية قبل اضافة اي نوع من وحدات التوزيع هي (45.96 MW, 182.551 MVAr)

بينما أصبحت الخسائر بعد إضافة قدرة ثابتة خارجة من الخلايا الكهروضوئية حوالي (37.288 MW ,148.97 MVAr) وبمقارنتها مع نتائج نموذج الخلايا العصبية الاصطناعية (GRNN) فقد كانت الخسائر الكهربائية حوالي (40.3 MW, 160 MVAr).

عند المقارنة بين النتائج التي حصلنا عليها من اضافة قدرة ثابتة واضافة نموذج GRNN هناك حوالي 3 MW من التحسين الخيالي من الطريقة التقليدية الأولى التي تتحدث عن قدرة ثابت بدلا من الطريقة الثانية لتكون أكثر دقة. الطريقة الثانية أعطت تخطيطاً أكثر دقة يحاكي الحقيقة وبعيداً عن المبالغة المبسطة بينما كانت الطريقة الاولى تعطي تحسين وهمي بمقدار الخسائر.