

POWER QUALITY ENHANCEMENT IN PV BASED AC MICROGRID USING ANN CONTROLLER

A Dissertation submitted in fulfillment of the requirements for the Degree

of

MASTER OF ENGINEERING

in

POWER SYSTEMS

Submitted by

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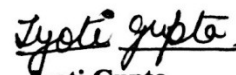
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DECLARATION

I hereby certify that the work which is being presented in the dissertation entitled, “**Power Quality Enhancement in PV Based AC Microgrid Using ANN Controller**” is the fulfilment of the requirement for the award of the Degree of **Master of Engineering in Power Systems**, submitted to **Electrical & Instrumentation Engineering Department of Thapar Institute of Engineering & Technology, Patiala**, is an authentic record of my own work carried under the supervision of **Mr. Jitender Kaushal and Dr. Prasenjit Basak**. It refers other researcher’s work which is duly listed in the reference section. The matter contained in this dissertation has not been submitted, neither in part nor in full to any other university except as reported in the text and references.

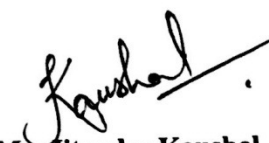
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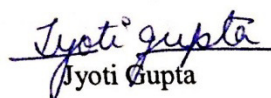

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LIST OF ABBREVIATION

PV	Photovoltaic
PI	Proportional Integral
IEEE	Institute of Electrical and Electronics Engineers
ANN	Artificial Neural Network
RESs	Renewable Energy Sources
MPP	Maximum Power Point
MPPT	Maximum Power Point Tracking
THD	Total Harmonic Distortion
PCC	Point of Common Coupling
EMI	Electromagnetic Interference
VSI	Voltage Source Inverter
APF	Active Power Filter
PCS	Power Conditioning System
UPS	Uninterrupted Power Supply
FPGA	Field Programmable Gate Array
DSP	Digital Signal Processing
IGBTs	Insulated Gate Bipolar Transistors
FPWNN	Fuzzy Probabilistic Wavelet Neural Network
LVRT	Low Voltage Ride Through
EMTP	Electromagnetic Transient Program
OLTC	On Load Tap Changer
PWM	Pulse Width Modulation
SPWM	Sinusoidal Pulse Width Modulation
P&O	Perturb and Observe
PLL	Phase Locked Loop
MSE	Mean Square Error
LM	Levenberg-Marquardt

ABSTRACT

Solar power is considered a very promising source for electric power generation. The increased penetration of PV based microgrid in distributed feeder system leads the power quality issues, especially under islanded condition. So there is need for efficient controlling scheme which can efficiently regulate the output of the system along with it improves the power quality. In this dissertation, artificial neural network is proposed as the inverter control system in PV based microgrid as an alternative to standard PI inverter control scheme. PV microgrid is connected at optimally position in 13 IEEE node feeder system. The controller model has nine numbers of input signals and generates twelve pulse output signals for inverter circuit. Artificial neural network is most suitable for nonlinear and complex system and its response is better than other controlling scheme. Due to this feature, ANN is proposed as inverter control scheme in system and it improves the performance and efficiency of the inverter and enhances the power quality. The proposed ANN trains feedforward network using Levenberg-Marquardt algorithm. The proposed system is verified through MATLAB simulink and the results are compared between the PI and neural network based controllers. The total harmonic distortion, voltage and phase angle variations are monitored and maintained within satisfactory range for the enhancement of microgrid power quality during grid-connected and islanded modes of operation.

CHAPTER 1

INTRODUCTION

1.1 Overview

The main source of energy is fulfilled directly or indirectly from fossil fuels which are exhausting day by day from the earth. With the rapid increase in power consumption around the world and increase in pollution, people have been switching towards renewable energy sources (RESs) for long term fulfilment of their basic energy demand. Nature has provided us various types of RES among which wind and solar energy are most popularly used. Microgrid can be explained as low voltage distribution system whose motive is to support small scale load demands. Due to advancement in inverter technologies, photovoltaic (PV) based microgrid are increasing tremendously. There are numerous benefits of PV based microgrid some are: environment friendly, improvement in manufacturing technique which in turn increased the efficiency of PV panels, as it can be installed near load demand thereby minimizing transportation losses, maintenance cost is minimum due to its static nature. Performance of photovoltaic array is mainly dependent upon two main factors temperature and irradiance. The power produce by photovoltaic system is maximum i.e. power at maximum power point (MPP), Maximum Power Point Tracking (MPPT) technology is executed on PV system.

Demand of power is increasing day by day due to which more and more microgrid are included in the power system. This has emerged various problems in grid like loss in power stability, increase in harmonics, reduction in power quality, increase in frequency and voltage deviation, etc. Harmonic reduction plays a very important part in grid connected PV system. IEEE Std. 519 was first introduced in 1981 and was revised in 1992 to give guidance on managing the harmonics induced by power electronics converters and nonlinear loads. According to IEEE Std. total harmonics distortion (THD) in the system voltage and current should not exceed more than 5% [1]. There could be an adverse effect on system if an oversize PV microgrid is attached to the grid. So as to improve the quality of the power in relation with the increase in production of PV output, various measures should be adopted some are: PV system should be placed at the optimum position in the grid, there are various algorithms like swam particle optimization, genetic algorithm, etc to calculate the point where PV microgrid could be connected effectively without effecting power quality, size of

the microgrid should be calculated appropriately before connecting to utility grid, as an oversized microgrid can cause adverse effect on power system, optimum selection of filter circuit as power electronic inverter circuit causes the injection of harmonic current and voltage into the utility grid so to reduce the harmonics in current the value of filter circuit should be calculated properly, fault-ride-through capability, etc.

1.2 Literature survey

The Infiltration of huge capacity and high voltage photovoltaic in power system has adverse effect on stability and protection of the utility grid. There are various type of adverse impact caused by the huge capacity PV microgrid on the distribution system, some are given as: reduction in power quality, distortion in the voltage and current, stability issues, utility grid failure, change in the codes and standard of the system or procedure for the grid and distribution system operation. Various research fields are developed in PV sector such as 1) designing of PV system by various methods, 2) analysis of the characteristics of the PV system when connected with distribution network or utility grid, 3) designing of different controller scheme for PV connected grid system, 4) regulation and formation of old and new codes and standards for the operation of the existing power system. Different capacity of PV system connected with utility grid and there controllers is designed and simulated in order to analyze PV array performance at different operating conditions [2]. A specific capacity of PV system is designed in Matlab-Simulink and connected with the distribution system. The PV array is modelled by considering the specific combination of series and parallel PV cell and observes the changes in its characteristics by change in the atmospheric factors. Whenever fault occurs in the system, there is fluctuation in the output voltage and current which can adversely affect the power electronic circuit. The output characteristics of the PV array are observed in all types of faults. According to observation, PV array generated least power during three phase fault and highest during single line to ground fault [3].

Basically, there are two types of operating modes of PV i.e. islanded operating mode and grid connected operating mode. The islanded operating mode and effect of fault condition on the output of the PV connected grid system when intentionally switch to islanded mode. An inverter connected with an off shore grid is modelled and the various faults are added to the system which mainly occur on the distribution network. It is concluded from the experiment results that under the specific codes and standard, the inverter took time to detect the islanded state and also took time to stop energizing under fault condition when intentionally switch to islanded mode. It is also concluded that the higher penetration of PV in the distribution network which has adverse effect on the protective device of the power system [4]. The feed

forward compensation scheme is presented to switch to islanded mode effectively. This scheme operates when there is switching of circuit breaker at the at the point of common coupling (PCC) due to increase in frequency, Total harmonic distortion (THD), voltage, current or impedance beyond threshold value. Any of the above element value could be used as feed forward signal. In these system two types of loads was considered i.e. RLC load and induction machine to study the PV system output characteristics under islanded condition [5].

A mathematical derivation is also included in order included in order to understand the behaviour easily. A single phase PV system connected to the utility grid is designed using eigenvalue algorithm to observe its transient and characteristics under nonlinear load. The system response is carefully examined under transient condition [6]. The PV connected grid is designed mathematically in order to study the stability characteristics accurately. The eigenvalue analysis is primarily introduced to outline region of attraction that verify the dynamics of the converter state. It is concluded that fluctuation occur more often in the system when operating at high loading state i.e. operating at maximum power point (MPP). The reason behind it is the small margin of the current presented to overcome any fault or disturbances. However, further research is required on determination of the stability margin and operating limits and development of the higher control methods to cope with the disturbances in the power system [7].

Further discussion about eigenvalue is presented in order to study the stability margin of the, multiple PV system connected with the utility grid. Impact of climatic conditions like reduction in irradiance level due to cloudy weather is observed on the multi PV system connected with grid. The experimental results shows that transient nature and stability limits of proposed model can be accurately determine by using eigenvalue scheme under various fault modes and operating conditions [8]. A novel control scheme using control loops is proposed. The current control scheme allows the regulation of the voltage across DC link. The inner control loop significantly synchronises the output of the PV system with the distribution network by regulating the dynamics of the distribution system. The outer voltage control loop regulates and manages the power produced by the PV array system. The model system is also operated in the digital time domain in order to justify the system effectiveness. Also various tests was perform on the PV system so as to estimate the dynamic characteristics, to observe robustic nature of the controller method, also observe outcome of photovoltaic system when operated in the grid connected mode [9].

The multi string PV model connected with the distribution system is designed using the DC bus model. The inner current control loop is used as control scheme in order to regulate

the voltage source inverter (VSI) as to synchronise the power output of photovoltaic array with the distribution network. The system response to the transient is observed when subjected to various disturbances like sudden change in climatic condition, all type of fault condition etc. [10]. The storage system is added in the PV model in order to regulate the increment in the DC link voltage. The storage system is mainly composed of capacitor bank of rated size. A multilevel controller is designed to regulate the excessive energy produced by the PV system under faulty condition and it has various advantages as compared to the standard two level inverter control system i.e. improved power quality with the reduction in THD, better shape of the output waveform, reduction in the electromagnetic induction (EMI). Pulse width modulation generates triangular carrier wave as gate pulse to trigger the multi level inverter. There is increase in the harmonics the power system with the increase in nonlinear load like power electronic converters, inverters and rectifier circuit [11].

The operation of the active filter reduces harmonics in the output power of the system. A highly efficient active power filter (APF) is proposed which include PV system with an active filter to reduce harmonics by designing a specific controller. A controller is designed in such a way that harmonic current which flows to the grid system through power conditioning system (PCS) is reduced to minimum extent. The grid current is not used by the controller as it has low margin to the fault and low electromagnetic induction with the grid current. The voltage source inverter controller scheme uses the extraction algorithm to reduce the voltage harmonics from PV generated output voltage by comparing the harmonic output voltage to the harmonic grid voltage [12]. A novel controller scheme is proposed and to justify its validity it is tested on the 400 kW PCS. In this scheme inverter circuit is forced to generate compensating current to diminish the distortion in the voltage at load side. The compensation gain could be improved within its range of inverter system by regulating PV cell output. The interconnection of PV system with the grid is formed using a special inductance network. The output power produced by the photovoltaic system is fed to the active filter before transferring it to the AC load with the purpose of reducing harmonics in output current and voltage [13].

PV system could be connected with the distribution system by two different configurations. First configuration is formed by comparing the voltages of both PV array and DC bar at MPP and output of the PV is fed across the filter before transferring into load. In second configuration, as power generated by PV is not at MPP due to disturbance so its power is boosted up using DC converter which is connected with the active filter [14]. Grid connected PV is connected with the power conditioning system with the purpose of maintaining the

uninterrupted electric supply across load. Power conditioning system not only regulates the PV output but also regulates the operation of active filter connected across PV. The harmonic output current is detected by using instantaneous reactive power theory and it also use for signal synthesis algorithm of reference current. There are two operating modes in the system grid connected mode and uninterruptible power service (UPS) connected mode which is regulated by the proposed control strategy. In order to switch modes with fast response, a dual loop control method is designed [15].

A four leg dual level inverter with the boost converter is presented. The proposed model permits the wide range of power and also balances the compensated unbalanced current across the load. The control scheme is regulated using the reference current generated by the PV. A 100 kV PV connected grid system is designed to justify the proposed controller of scheme that is combination of FPGA and DSP controller [16]. For power quality of the improvement of the PV connected system, neural network based controller scheme is proposed. In this PV connected grid model is designed with the three phase voltage source inverter made up of six IGBTs power electronics element, DC link and active filter circuit. The proposed neural network control scheme is based on calculating real and reactive components of the current of the grid side of all three phases in order to regulate between fixed range under all type of disturbances and unbalanced load [17].

A fuzzy probabilistic wavelet neural network (FPWNN) control scheme is projected for the grid connecting operating mode. The control scheme operates by regulating the output current component of the invert circuit by comparing the injected current to the load side. This controller scheme stabilizes the system under fault condition and at a time when PV produces low voltage due to external disturbances. It also synchronises PV output with the grid by regulating the voltage produce by the DC link. So as to regulate injection of reactive current in the system through a LVRT operation, range of current is set earlier as to avoid the over current situation. It is observed that the FPWNN controller is effective control scheme for operation of PV connected grid under numerous disturbances and fault condition [18]. There are various types of MPPT controlling scheme, Artificial Neural Network (ANN) based MPPT controller scheme is presented. It is operated in the real time domain with the aim of detecting maximum power point (MPP) of photovoltaic system and regulates it if the output of the PV is not obtained at MPP. The neural network generates controlling signal for the boost converter to regulate the output of PV system according to the requirement of load and assure the operation of PV array at MPP. The neural network provides the data to the PI controller for the efficient operation of VSI for the conversion of DC power to AC power in

synchronism with phase angle and power output of the distribution network. From the experimental results it is concluded that the artificial neural network proved to be an effective control scheme [19].

1.3 Gap in research

From literature survey, it is concluded that different methods have been adopted for MPPT technology like fuzzy logic, FPWNN, neural network etc. to generate control signals for boost converter. It is observed that the grid is designed on the assumed data or by using onsite collected data. The PI controller scheme has been used for inverter circuit of PV connected utility grid. In most of the literatures, the microgrid connected to utility grid is considered based on the fictitious grid parameters as compared to the standard IEEE test system. In this dissertation, the 13 IEEE node feeder test system is considered as an utility grid. Hence, an artificial neural network is suggested as the inverter control scheme to the PV connected grid system.

1.4 Objective of dissertation

The major contribution of this dissertation is summarised as follows:

- To implement 13 IEEE node feeder system in Matlab-Simulink.
- To propose a PV system connected with 13 IEEE node feeder system at optimal location.
- To develop artificial neural network based controller using Levenberg-Marquardt feedforward network for improvement of power quality.

1.5 Organization of dissertation work

- Chapter 1: This chapter includes the research motivation in the field of PV connected grid system and improving power quality. Based on it, a literature survey has been performed to get a detailed analysis of various aspects of PV connected grid system. In the end, objective of dissertation is formulated.
- Chapter 2: This chapter include the detail discussion about characteristics and features of 13 IEEE node feeder system.
- Chapter 3: This chapter discuss about the components of PV connected grid system which include characteristics and modelling of PV array, inverter circuit, filter circuit and operating modes of system.
- Chapter 4: This chapter include the detail discussion about the various controlling scheme of described system which are MPPT technique, PI controller, and ANN controller.
- Chapter 5: Detail discussion and results about the proposed simulink model.
- Chapter 6: Conclusion and future scope is discussed.

CHAPTER 2

MODELLING OF 13 IEEE NODE FEEDER TEST SYSTEM

The grid system considered in this dissertation is 13 IEEE node test feeder system. 13 IEEE node test feeder system is standard distribution network is provided by IEEE which is used for testing purpose as shown in Figure 2.1 [20]. Important characterises are discussed below:

- 1) There are basically seven types of configuration each with characteristics as presented in Table 2.4 and Table 2.5.
- 2) It is relatively short network and its longest line is 2000 ft among the entire line segment which is between two nodes 650 to 632 and 632 to 671 as shown in Table 2.3.
- 3) There is one three-phase voltage regulated transformer with regulator data specified and there is another transformer which steps down voltage from 4.16kV to 0.48kV as given in Table 2.6 and Table 2.7.
- 4) There are two shunt capacitors, one three-phase connected at node 633 and other is single-phase connected at node 611 as shown in Table 2.8.
- 5) It is small system with one distributed load and eight spot loads as presented in Table 2.1 and Table 2.2.

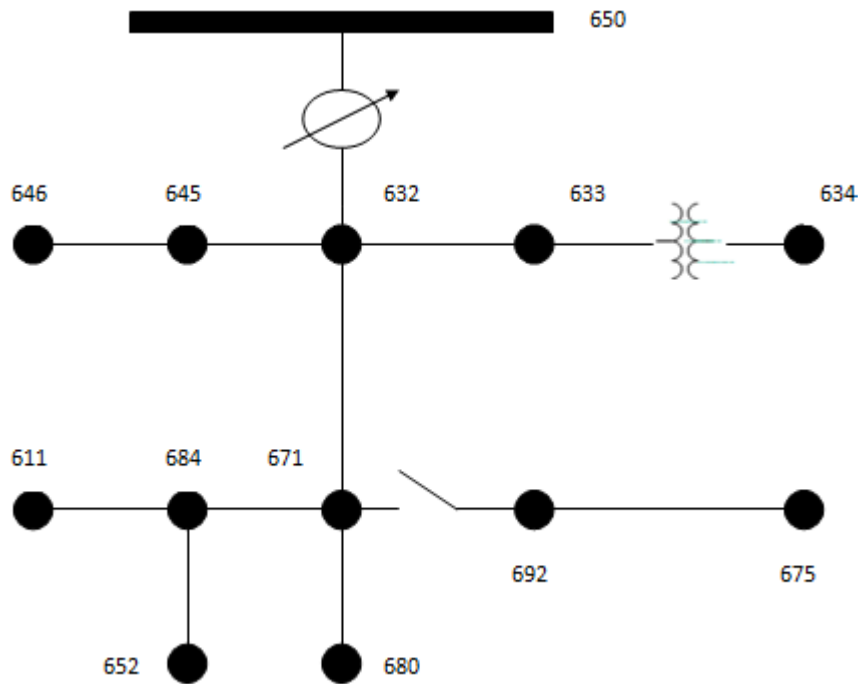


Figure 2.1 13 IEEE node feeder test system

2.1 Load model

The IEEE 13 node distribution feeder mainly comprises of single phase and three phase load either connected in constant I, PQ or Z load in delta or star configuration as given in the Table 2.1 and 2.2. The three-phase series load block (RLC) from simulink Power system library is used. In three-phase series load block (RLC) a series combination of resistance inductance and capacitance elements describe a three-phase balanced load. Elements of the three-phase series (RLC) load block are given below:

1. Nominal voltage phase to phase (V_n): The value of voltage is set at $4.16 / \sqrt{3}$ of three phase load.
2. Nominal frequency (f_n): The value of frequency is set at 50 defined in hertz.
3. PQ power for each phase: This is select block which specify where to define resistive active power, inductive reactive power and capacitive reactive power for each phase or single phase of the load.
4. Active Power P (W): The value of active power of three phase load.
5. Inductive reactive power Q_L (positive Var): The value of inductive reactive power Q_L , of three phase load.
6. Capacitive reactive power Q_C (negative Var): The value of capacitive reactive power Q_C , of three phase load.
7. Configuration: The connection of the three phases i.e. star (grounded), star (floating), star (neural), Delta can selected according to load data.
8. Load type: load type like PQ, I, Z can be used.

Table 2.1 Spot Load Data

Node	Load Model	Ph-1 (kW)	Ph-1 (kVAr)	Ph-2 (kW)	Ph-2 (kVAr)	Ph-3 (kW)	Ph-3 (kVAr)
634	Y-PQ	160	110	120	90	120	90
645	Y-PQ	0	0	170	125	0	0
646	D-Z	0	0	230	132	0	0
652	Y-Z	128	86	0	0	0	0
671	D-PQ	385	220	385	220	385	220
675	Y-PQ	485	190	68	60	290	212
692	D-I	0	0	0	0	170	151
611	Y-I	0	0	0	0	170	80
	TOTAL	1158	606	973	627	1135	753

Table 2.2 Distributed Load Data

Node A	Node B	Load Model	Ph-1 (kW)	Ph-1 (kVAr)	Ph-2 (kW)	Ph-2 (kVAr)	Ph-3 (kW)	Ph-3 (kVAr)
632	671	Y-PQ	17	10	66	38	117	68

2.2 Distribution feeder line model

Distributed line parameter model is used from simulink library. This model can be used for any type of phase and it also considers lumped losses in the system. The different types of phases for 13 IEEE node test system are given in the Table 2.4 and Table 2.5. Distribution feeder line block follows the Bergeron's travelling wave method used by the Electromagnetic Transient Program (EMTP) [21]. Single line diagram of distributed feeder line model is shown in Figure 2.2. In single line diagram of distributed feeder line model, Z is characteristic impedance, i_s is the current in the sending end and e_s potential at sending end. Similarly i_r is the current in the receiving end and e_r potential at receiving end. The impedance is calculated by formulate $Z_c = \sqrt{l/c}$

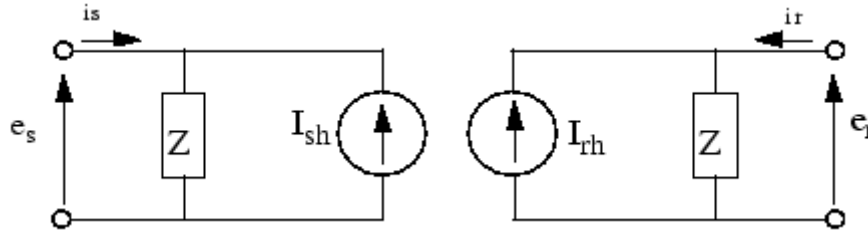


Figure 2.2 single line diagram of distributed feeder line model

There are various parameters in the distribution feeder line model. The line length data is shown in Table 2.3. The overhead line configuration data are given in Table 2.4 and the underground line configuration data is given in Table 2.5. The standard data is given in the form of impedance (Z) and value B , where B is the susceptance of the system and the value of R , L , C are calculated using formula given in Appendix I.

Table 2.3 Line Segment Data

Node A	Node B	Length(ft.)	Config.
632	645	500	603
632	633	500	602
633	634	0	XFM-1
645	646	300	603
650	632	2000	601
684	652	800	607
632	671	2000	601
671	684	300	604
671	680	1000	601
671	692	0	Switch
684	611	300	605
692	675	500	606

Table 2.4 Overhead Line Configuration Data

Config.	Phasing	Phase (ACSR)	Neutral (ACSR)	Spacing ID
601	B A C N	556,500 26/7	4/0 6/1	500
602	C A B N	4/0 6/1	4/0 6/1	500
603	C B N	1/0	1/0	505
604	A C N	1/0	1/0	505
605	C N	1/0	1/0	510

Table 2.5 Underground Line Configuration Data

Config.	Phasing	Cable	Neutral	Space ID
606	A B C N	250,000 AA, CN	None	515
607	A N	1/0 AA, TS	1/0 Cu	520

2.3 Voltage regulator

Voltage regulator is used to regulate the voltage of the system using autotransformer. There is a control system which regulates the output of voltage regulator according to specified data. Regulatory data is presented in Table 2.6. A standard step regulator mainly consists of switching mechanism which enable $\pm 10\%$ regulator, which relate to 5 to 8% change in

voltage. A usually used type of step voltage regulator is type-B as given in [22]. Some of the important features of OLTC transformer are:

1. The standard model presented in Simulink library consists of mainly 18 taps, but the IEEE 13 node test feeder distribution system requires 32 steps or ± 16 steps.
2. The 13 node distribution model is an unbalanced feeder, which requires an independent control for tap changing mechanism.
3. Per unit voltage change for one step change is 0.00625 per unit.
4. The transformer voltage level is step down from 115 kV for the primary and 4.16 kV for the secondary.

Table 2.6 Regulator data

Regulator ID:	1		
Line Segment:	650 – 632		
Location:	50		
Phases:	A - B –C		
Connection:	3-Ph,LG		
Monitoring Phase:	A-B-C		
Bandwidth:	2.0 volts		
PT Ratio:	20		
Primary CT Rating:	700		
Compensator Settings:	Ph-A	Ph-B	Ph-C
R - Setting:	3	3	3
X - Setting:	9	9	9
Voltage Level:	122	122	122

2.4 Transformer, circuit breaker and capacitor models

3-phase transformer and breaker models were used from Power System library in Simulink. The values of transformer power and voltage and per unit reactance and resistance was considered from the 13 IEEE node test feeder system data as shown in Table 2.7. Capacitor banks were modelled using a series RLC load branch from Power Systems library in simulink. The values of active power and inductance were kept to zero. The value voltage is set as standard phase to line voltage. Capacitors were connected in star or grounded configuration and the respective kVAr values were obtained from the IEEE 13-Node test system as shown in Table 2.8.

Table 2.7 Transformer Data

	kVA	kV-high	kV-low	R - %	X - %
Substation:	5,000	115 – D	4.16 Gr. Y	1	8
XFM -1	500	4.16 – Gr.W	0.48 – Gr.W	1.1	2

Table 2.8 Capacitor Data

Node	Ph-A (kVAr)	Ph-B (kVAr)	Ph-C (kVAr)
675	200	200	200
611			100
Total	200	200	300

CHAPTER 3

COMPONENTS OF PHOTOVOLTAIC SYSTEM

Various elements are required to develop a PV system as given in Figure 3.1. A Photovoltaic array is employed to absorb the direct sun light and converts it into DC power. The power produced by the photovoltaic array is stored temporarily in the massive capacitors before it is carried out for the power conversion i.e. DC to AC. Conversion is performed by the three-phase inverter which is connected across the capacitor. Inverter control circuit uses pulse width modulation (PWM) to provide trigger pulse to inverter circuit to shape the amplitude and phase angle of the output power. After power conversion, harmonics are eliminated from the power output using filter circuit.

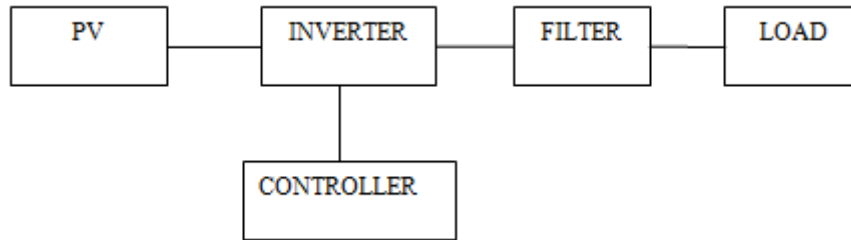


Figure 3.1 PV system

3.1 Basic equivalent circuit of PV cell and its characteristics

Simplified model of a photovoltaic cell is needed to define its actual behaviour. In [23], simplified model of single photovoltaic cell is discussed as given in Figure 3.2. Utilizing the physics, DC current system can be used for describing the photovoltaic cell with a diode connected across photovoltaic cell in parallel that reflects the generation of current because of diffusion and charge recombination of the ions in cell. Two resistances are incorporated in the system, R_{sh} and R_{se} , as the shunt resistances and the series resistance respectively. There are two methods to acquire the values of these two resistances i.e. either by calculating using standard formula or by using curve fitting method. The work done in [24] is a case of curve fitting method for estimating the value of R_{se} and R_{sh} .

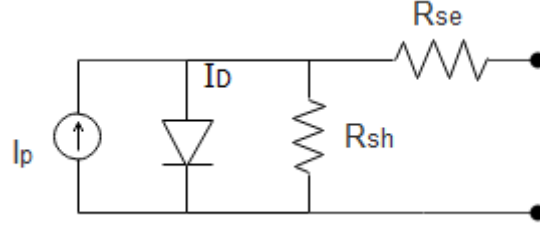


Figure 3.2 Simplified model of PV

Current produced by the photovoltaic cell and current across the diode can be calculated using these equations:

$$I = I_p - I_D - \frac{V + IR_{se}}{R_{sh}} \quad (3.1)$$

$$I_D = I_o \left[\exp \left(\frac{q(V + IR_{se})}{akT} \right) - 1 \right] \quad (3.2)$$

Where I_{ph} is the PV cell internal generated photocurrent, I_D is the currents passing through diode, a is the idealist factor of the diode, k is the Boltzmann constant whose value is $1.3806503 \times 10^{-23}$ J/K, T is the cell temperature in degrees Kelvin, q is the electron charge ($1.60217646 \times 10^{-19}$ C), I_o is the reverse saturation currents of the diode. Similar type of work has been discussed in [25], [26] and [27].

In this equation, diode current I_D is replaced by the equation (3.2) in equation (3.1) as given below in equation (3.3):

$$I = I_p - \left[I_o \left[\exp \left(\frac{q(V + IR_{se})}{akT} \right) - 1 \right] - \frac{V + IR_{se}}{R_{sh}} \right] \quad (3.3)$$

From above equations (3.1), (3.2) and (3.3), it is depicted that relation of the output current and voltage across system is not linear i.e. nonlinearity output is observed. The main reason behind the nonlinearity is presence of the semiconductor junction. Outcome of the voltage-current characteristics of the PV module are unique i.e. output current is consistent for a quite long range of voltage till it reaches a particular point where it started to drop exponentially. A voltage-current characteristic for a 200 W PV module is appeared in Figure 3.3. A PV module is the outcome of the interconnection of several PV cells. Characteristic has same shape except for changes in the magnitude of the open circuit voltage.

Another critical characteristic is the power-voltage characteristics of PV cell. The result of the product of the voltage element and the current element is assessed at every point in voltage-power graph. It is discovered that there is change in power output with the variation in voltage. Another critical characteristic is the voltage-power characteristics of PV cell. The result of the product of the voltage element and the current element is assessed at every point in voltage-power graph to discover that with change in power output with the variation in

voltage. The voltage-power characteristic of the PV module is given in Figure 3.4. At first, power begins to increase with increment in the voltage.

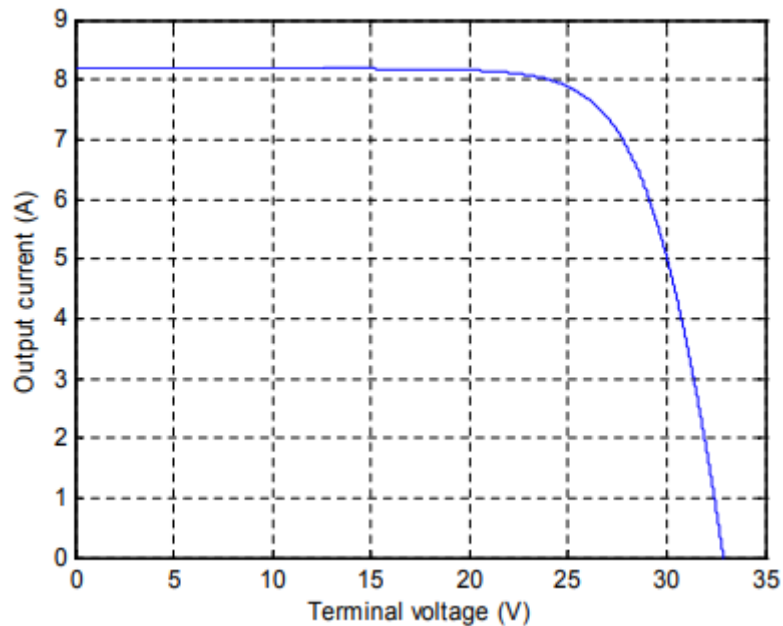


Figure 3.3 Voltage-current characteristic of a PV module

After some time curve reaches a specific point where maximum power output of the PV cell is achieved, that specific point in the curve is described as maximum power point (MPP). After MPP on curve, with the increment of voltage power began to drop exponentially until it become zero at open circuit voltage. The outcome of the photovoltaic cell is directly related with the value of the constant load connected across it, characterized by the division of the terminal voltage over the current in PV array, at the time when the load is constant. If maximum outcome of the PV system is not equivalent to the load connected across it, at that point we can utilize a boost DC converter to increase the power output produced by photovoltaic module so as to meet load demand. MPPT is method of regulating the terminal voltage of PV array with the intention of extracting maximum outcome for specific load. While designing a PV array characteristics of voltage-power and voltage-current should be taken in consideration.

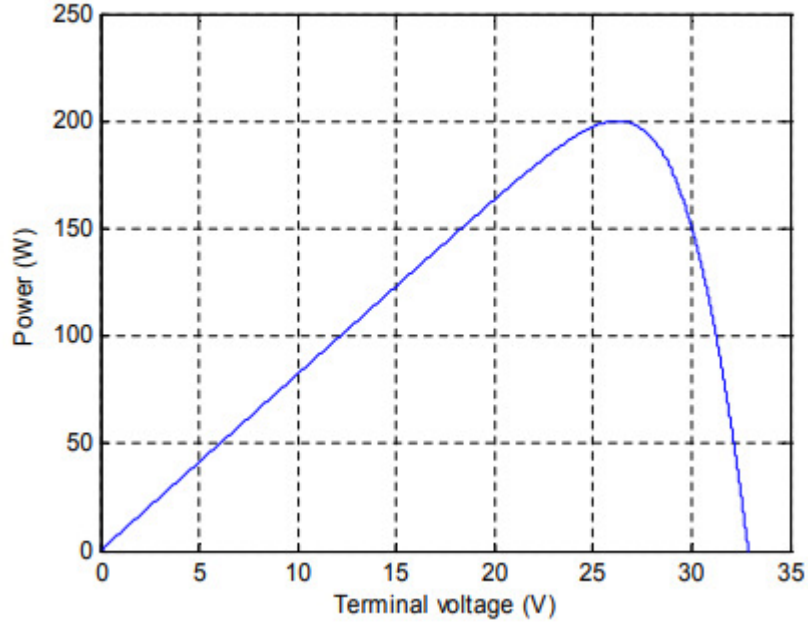


Figure 3.4 Voltage-power characteristics of a PV module

The PV module characteristics rely upon two outer components which includes surface temperature of PV and intensity of the solar irradiance. Impact of these components on PV system can be described by two equations (3.4) and (3.5). Equation (3.4) described the effect of external components on the current of the system i.e. it fluctuates with the change in temperature and irradiance:

$$I = (I_n + K_l \Delta T) \frac{G}{G_n} \quad (3.4)$$

Where I_n is the output current of the PV cell at standard condition, K_l is the current divided by temperature variation coefficient ($A/^{\circ}C$), ΔT is the variation from the nominal temperature ($25^{\circ}C$) and G_n is the nominal solar irradiance (1000 W/m^2). The value of K_l is quite small and that makes the cell output current proportionally dependent on solar radiation level more than temperature.

Temperature has a very strong effect on the reverse saturation current (I_o). This can be explained in Equation (3.5) [25]:

$$I_o = \frac{I_{sc,n} + K_l \Delta T}{\exp(q(V_{oc,n} + K_v \Delta T)/akT) - 1} \quad (3.5)$$

Where $I_{sc,n}$ the nominal short circuit is current of the PV cell, $V_{oc,n}$ is the nominal open circuit voltage, K_l is the current/temperature variation coefficient in $A/^{\circ}C$ and K_v voltage/temperature variation coefficient in $V/^{\circ}C$.

Impact of the atmospheric conditions on the outcome of the photovoltaic module is described in Figures 3.5, 3.6, 3.7 and 3.8. To research the impact of solar irradiation on the current and voltages of the module, temperature is held steady at standard value i.e. 25 °C and the subsequent voltage-current and voltage-power characteristics was plotted. Figure 3.5 demonstrates the voltage-current characteristics of the module at various irradiance levels i.e. 500, 800 and 1000 W/m². Power-voltage characteristics are appeared in Figure 3.6 for a similar irradiance levels specified. It is seen that the output current is directly proportional to changes in solar irradiation. Power drooped considerably after the reduction in the solar irradiation i.e. to 500 W/m². To discover impact of temperature on the module performance, solar irradiation level is accepted steady at 1000 W/m² while enabling temperature to differ between 25 and 80 °C. The outcome is appeared in Figures 3.7 and 3.8 for the voltage-current and voltage-power characteristics as temperature is set to 25, 60 and 80 °C respectively. The open circuit voltage of the module reduces considerably as surface temperature increments. Current increment marginally with increase in the surface temperature of PV array. With the increase in surface temperature there is decrease in the outcome power of the PV module.

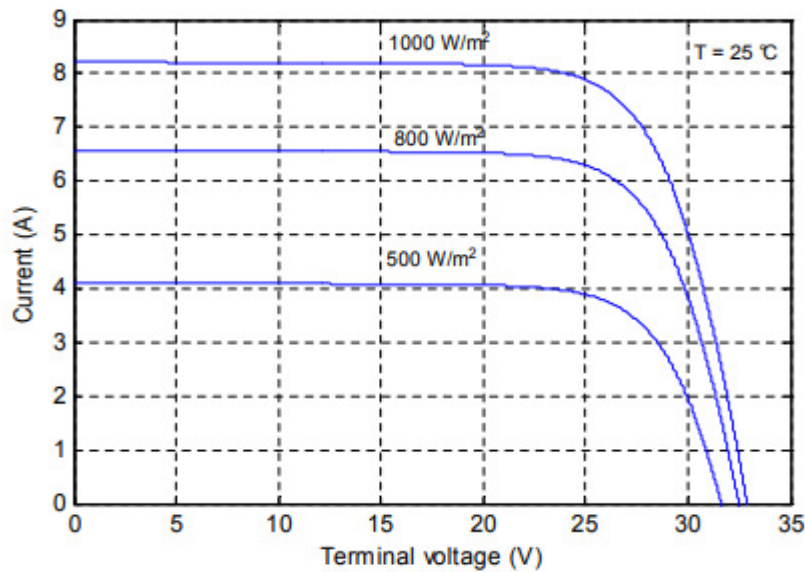


Figure 3.5 Voltage-current characteristics of a PV array under different solar irradiation level

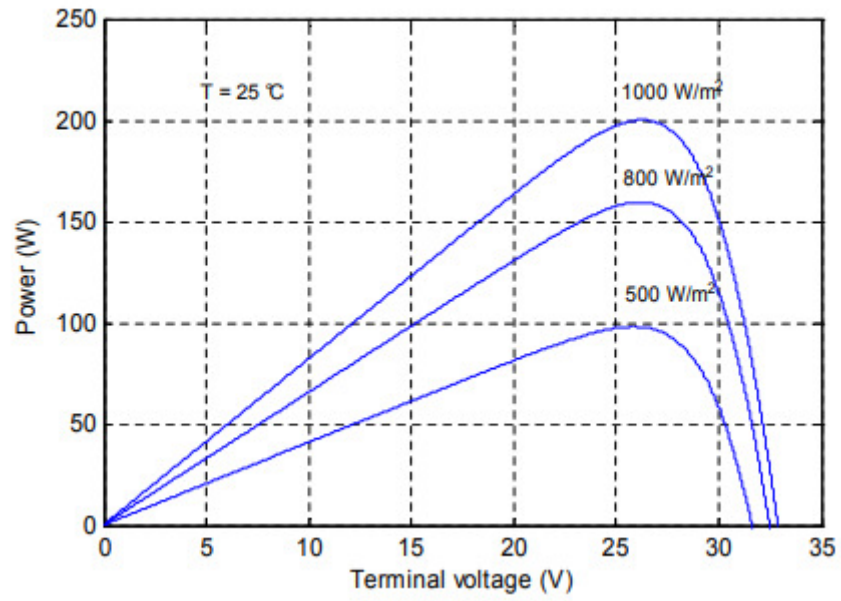


Figure 3.6 Voltage-power characteristics of a PV array under different solar irradiation level

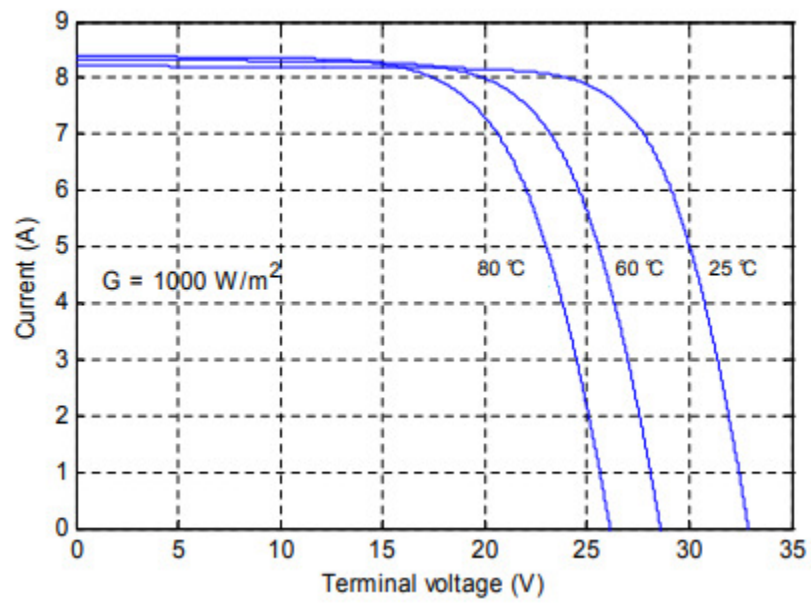


Figure 3.7 Voltage-current characteristics of a PV module at different surface temperature

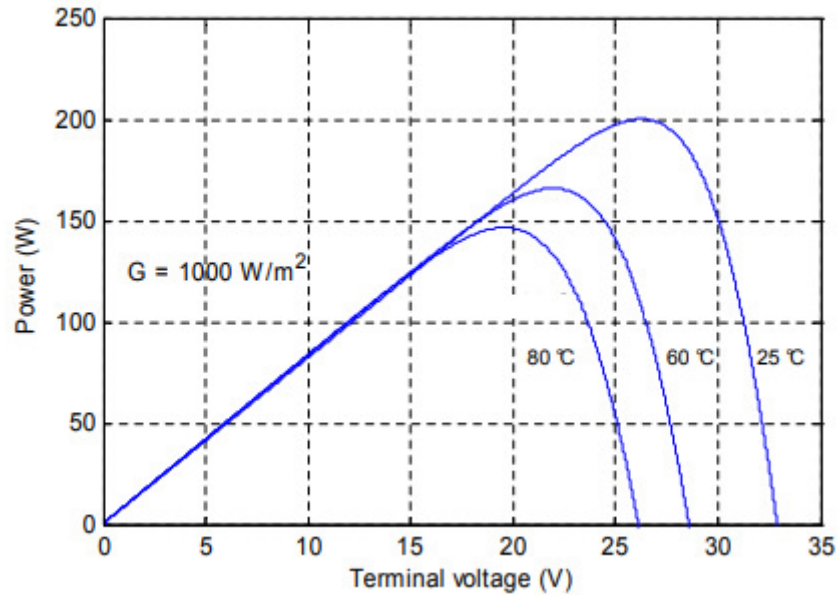


Figure 3.8 Voltage-power characteristics of a PV module at different surface temperature

3.2 Design scheme of inverter

The one main objective of the three phase inverter is to convert a consistent input DC power into output AC power. Figure 3.9 describes a basic diagram of three phase three level VSI. Voltage source inverter (VSI) is made out of twelve GTO switches and the diode is connected in parallel across each switch. Each four horizontal switches in each phase are utilized to build one “inverter leg”. The output of the each phase is associated with centre of every inverter leg. The output AC voltage is received by regulating the power electronic switches of the inverter circuit by turning ON and OFF. Pulse width modulation (PWM) methods are broadly used to perform this assignment. In the easiest form, three reference signals are related with a high frequency carrier waveform. The aftereffect of that comparison in every leg is utilized to regulate the switches ON or OFF. This method is known as Sinusoidal Pulse Width Modulation (SPWM). It is noticeable that the switches in every leg ought to be worked conversely all together as to avoid a short circuit of DC supply. Various power electronic elements can be utilized as switches such as IGBTs, GTO and power MOSFET etc. Each element has its specific characteristics and limitations; depending upon the application we can choose the specific devices like IGBTs device are most suitable for the application that requires medium power and switching frequency [28].

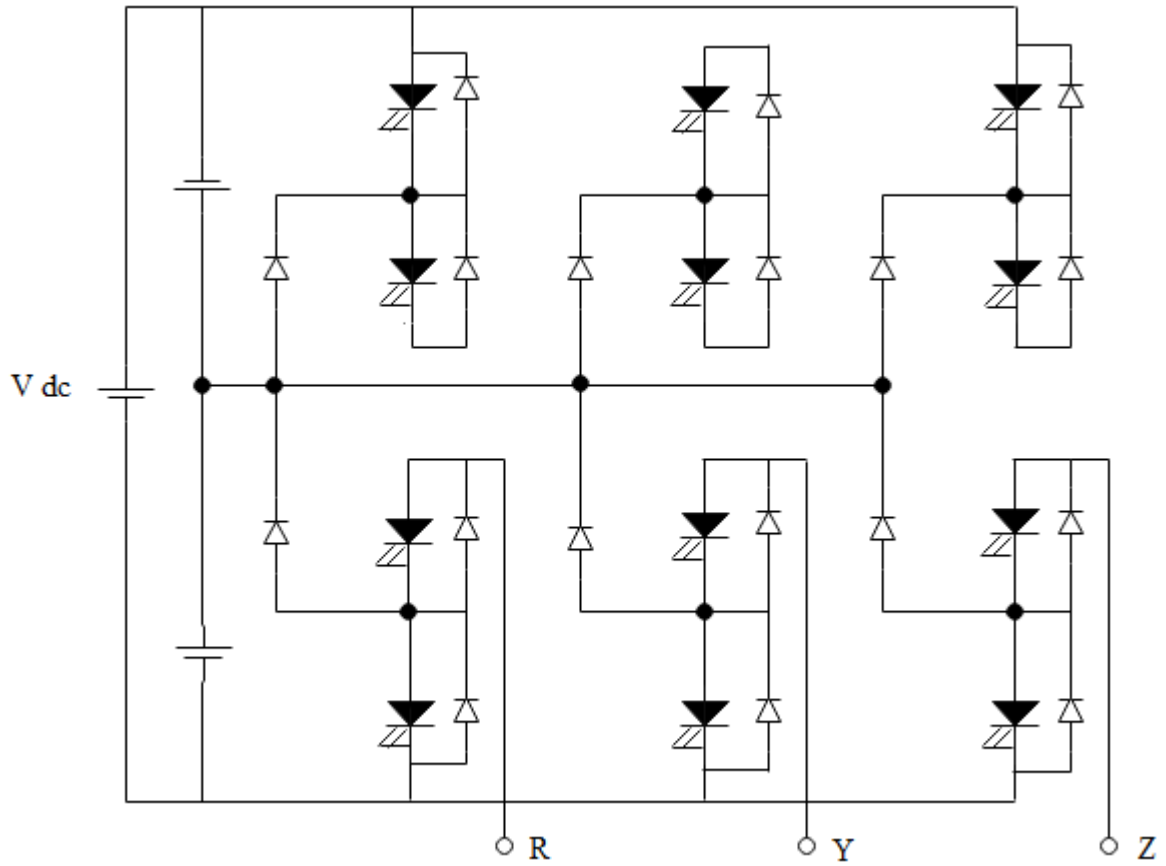


Figure 3.9 Three phase voltage source inverter

3.3 RL filter design

The output power generated by the inverter using PWM contains unwanted harmonics in it. According to the IEEE Standard, Total Harmonic Distortion (THD) cannot exceed more than 5% in the output current [1]. Therefore an RL filter plays a very critical role in the modelling of the PV system. The RL filter circuit is connected after the inverter circuit output in order to minimize the undesirable harmonics from sinusoidal output current so as THD is less than 5 %. The RL filter is designed according to the equation (3.6) i.e. the cut-off frequency (f_c) must be greater than the standard grid frequency (50 hertz) and less than the inverter switching frequency.

$$f_c = R/2\pi L \quad (3.6)$$

3.4 Operating modes of PV system

PV system basic structure includes only a PV module and load if required to support the water pump motor, which only needs to work when there is sunlight. But for electricity supply for the whole house, the PV system includes the converters and battery backup. As operate 24 hours as it necessary to met both AC and DC load demand of the house.

According to the PV system configuration, we can classify them in two basic categories: islanded mode system, grid connected mode system. The fundamental of the PV system remains same in all modes. System can be adjusted to meet specific demands by changing the type and amount of the fundamental components. A particular system configuration permits simple changes, when there is change in demand [29].

3.4.1 Islanded mode system

In islanded mode, PV system relies on only solar power. This system mainly includes the PV modules and a load, if only dc load is to be fed and they may incorporate batteries backup for inconsistent power supply. They also require inverter circuit and its regulator for ac load demand. Regulators are needed while including battery backup and also regulate the switching mode i.e. switch off or on the PV module when batteries are fully charged or discharged respectively and turn off the load when batteries is discharged below a fixed limit. The batteries must be selected according to the required load demand and maximum energy produced by PV system during daylight so that the stored energy is sufficient to be used at night and during periods of cloudy weather.

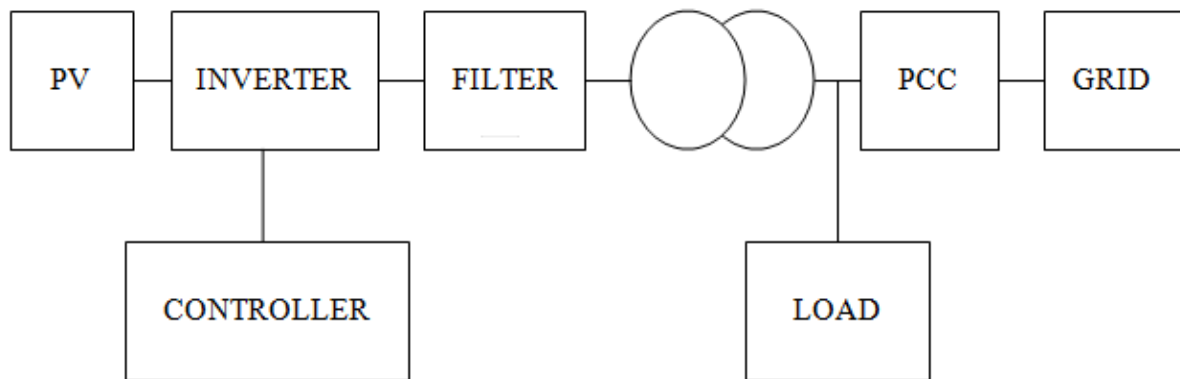


Figure 3.11 Grid connected system

3.4.2 Grid-connected mode system

Grid-connected PV system has turned out to be progressively well known for building integrated applications. As described in Figure 3.11, PV system is connected across the utility grid using inverter circuit. The systems with the small output which are planted in the building in this the inverter system is attached across the power distribution circuit. From inverter system the outcome produced by PV system can either be transferred into appliances in home or the electricity grid. This type of system does not need any backup support as they are directly attached to the utility grid. Utility grid acts as a support system at the time of

insufficient PV power generation to the household appliances and excessive photovoltaic generation is transported to the grid using two way switch.

3.5 Advantages and disadvantages of PV systems

Advantages of PV system are discussed below [30]:

1. As they generate power directly using sunlight without using any dynamic part so they are also referred as static power generators. PV system is easy to install as they come in packaged form, ready to be placed at building roof. Due to its static nature it eliminates the maintenance demands.
2. They are available in various scopes of sizes and output power worthy for every application. They are light in weight, allows safe and easy transportation.
3. PV systems output can be easily increase or decrease by adding or removing modules of PV either in parallel or series depend upon load demand .
4. Various tests are performed on PV systems during manufacturing process to withstand the most extreme environmental conditions like damp heat testing, static mechanical load test, hailing test, freezing test etc.
5. Systems can also be designed with battery backup in order to provide consistent, at cloudy days or at night.
6. PV systems are environmental friendly i.e. it creates no pollution.

Photovoltaic system also has some disadvantages. As discussed below:

1. Initial capital cost of PV system is very high.
2. Problem of tracking maximum.
3. Regular cleanliness of PV array is needed for maximum efficiency.
4. Significantly efficiency is quite low.

CHAPTER 4

CONTROLLING SCHEME OF GRID CONNECTED PV SYSTEM

This section covers the control scheme design to regulate a PV connected grid system. Architecture and the control elements of the control system are also presented. At every point, the function of each element is inspected in detail. A detail discussion is presented about Maximum Power Point Tracking (MPPT) and its objective. An outline about open and closed loops, dq transformation and sinusoidal PWM procedure are exhibited as standard PI inverter control scheme. A detail process of ANN technique is discussed as a more efficient inverter control scheme. The control system is accepted depending upon the quality of power injected into utility grid system and the speed of the MPPT control system in tracking MPP under climatic change. The THD level in the output current and voltage should be less than 5% as specified by the IEEE Std. 929-2000.

4.1 Model description

Block diagram of PV connected IEEE 13 node feeder system is presented in Figure 4.1 and its components are discussed below:

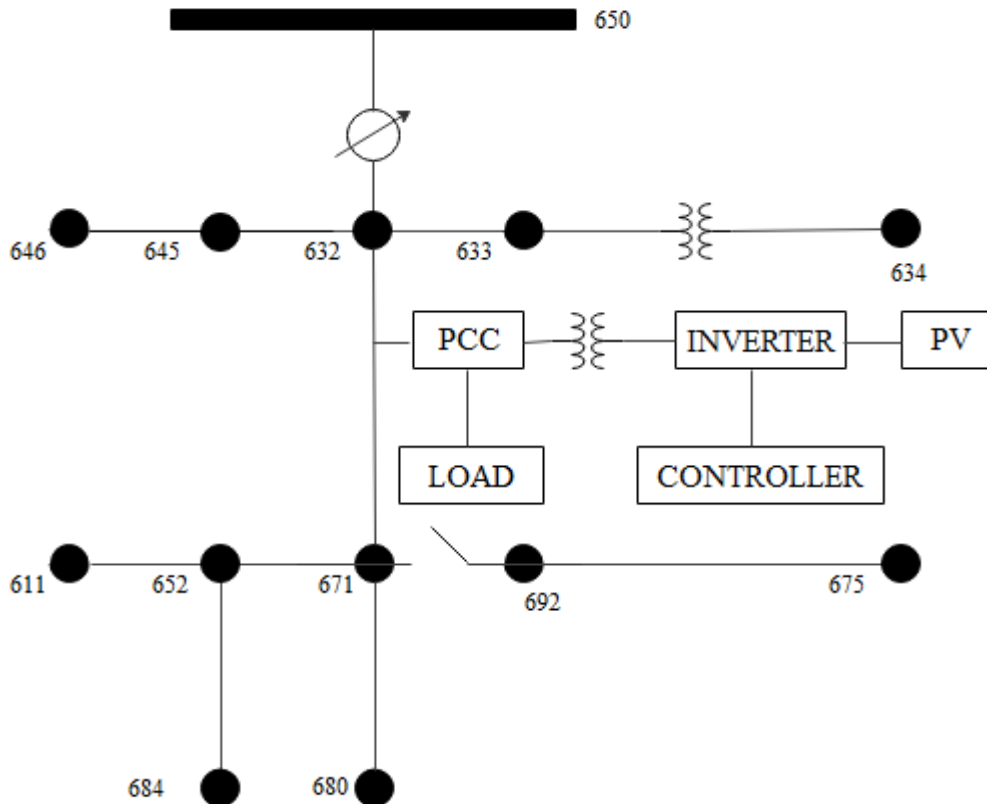


Figure 4.1 Block diagram of PV connected IEEE 13 node feeder system

4.1.1 Photovoltaic module

The photovoltaic module is simulated in simulink Matlab using photovoltaic array. In order to generate power of 341.65 kW, Sun Power SPR-445NX-WHT-D model is used, selected from the module block in the PV array block. Also there are 8 series connected module per string and 96 parallel connected per string. The module parameters and data are shown in the Table 4.1. These values are calculated are standard temperature and irradiance i.e. 25 degree Celsius and 1000 W/m^2 irradiance.

Table 4.1 Model parameters of PV array

Name of the parameters	Number/Rating
Maximum power (watt)	444.86
Cell per module	128
Light generated current I_p (A)	6.2167
Diode saturation current I_d (A)	1.3552e-11
Shunt resistance R_{sh} (ohm)	508.2463
Series resistance R_{se} (ohm)	0.54861

4.1.2. DC link capacitor and inverter circuit

Three phase inverter circuit is connected across the dc link. DC link capacitors are used to stabilize the DC link voltage of grid-connected inverter. As due to temperature and irradiance variation to the total resistance within PV cells leading to non linear output efficiency, capacitance is needed to allow electronic control methods to maintain maximum output power. The three phase inverter converts the dc output voltage i.e. 590 volt from microgrid into ac output i.e. 240 volt. Three phase inverter is basically the combination of six power electronic device connected as to form three single phase inverter. The power electronic device used as inverter is GTO with diode connected with snubber circuit in parallel. Snubber circuit suppresses the voltage spikes caused by switching mechanism of the power electronic devices. The value of snubber resistance is always kept high.

4.1.3. RL filter, transformer and load

RL filter is connected at the three phase inverter circuit output, to reduce the total harmonics distortion in current. They prevent over current condition in system. A three phase coupling transformer is between microgrid system and grid. Three phase coupling

transformer, star to delta connected step up the voltage i.e. 240 volts to 4160 volts at 50 hertz frequency and winding resistance of 0.01 per unit. Load is the distributed load of 13 IEEE node feeder system. It is the minimum load of the system which is distribution load of 13 IEEE node feeder system.

4.1.4. Point of common coupling and grid

Point of common coupling is described by using circuit breakers between PV system and grid system, it plays a very important role in the proposed system by isolating the PV system from grid system i.e. in the islanded mode at the time of grid blackout or when grid is under maintenance and to supply power to particular load in case of deficit energy produce by microgrid. Grid is standard 13 IEEE node test feeder system.

4.2 Maximum power point tracking techniques

Maximum power point tracking regulates the output of boost converter with the aim of obtaining maximum output from the photovoltaic system at given irradiance level and temperature. Boost converters regulate the working of photovoltaic system continuously near its MPP even if varying load is attached across it. There are basically two types of MPPT techniques that are conventional method and artificial intelligence methods as given below:

Conventional methods: There are various types of conventional method but the perturb and observe (P&O) is most commonly used algorithm, incremental conductance algorithm is extended form of P&O method [31], [32], the fractional open circuit voltage method [33], [34] is based on the value of open circuit voltage of PV array and the fractional short circuit current method [35], [36] is based on the value of short circuit current of PV array and is the least used method.

Artificial intelligence methods: There are mainly two types of artificial intelligence methods, fuzzy logic based MPPT [37] and neural network based MPPT [38].

4.2.1 Perturb and Observe (P&O) algorithm

Perturb and observe is referred as "slope climbing" algorithm. It depends on controlling the duty cycle (d) of a DC to DC converter by regulating the output terminal voltage at MPP [39] i.e. in this algorithm an annoyance is given to the output voltage of the operating PV module. This change in voltage will also affect the power output of the PV system i.e. an increment in voltage is directly proportional to raise in the power output. If the operating point is at a lower voltage than the MPP and consequently further voltage annoyance towards higher voltages is needed to reach to the MPP.

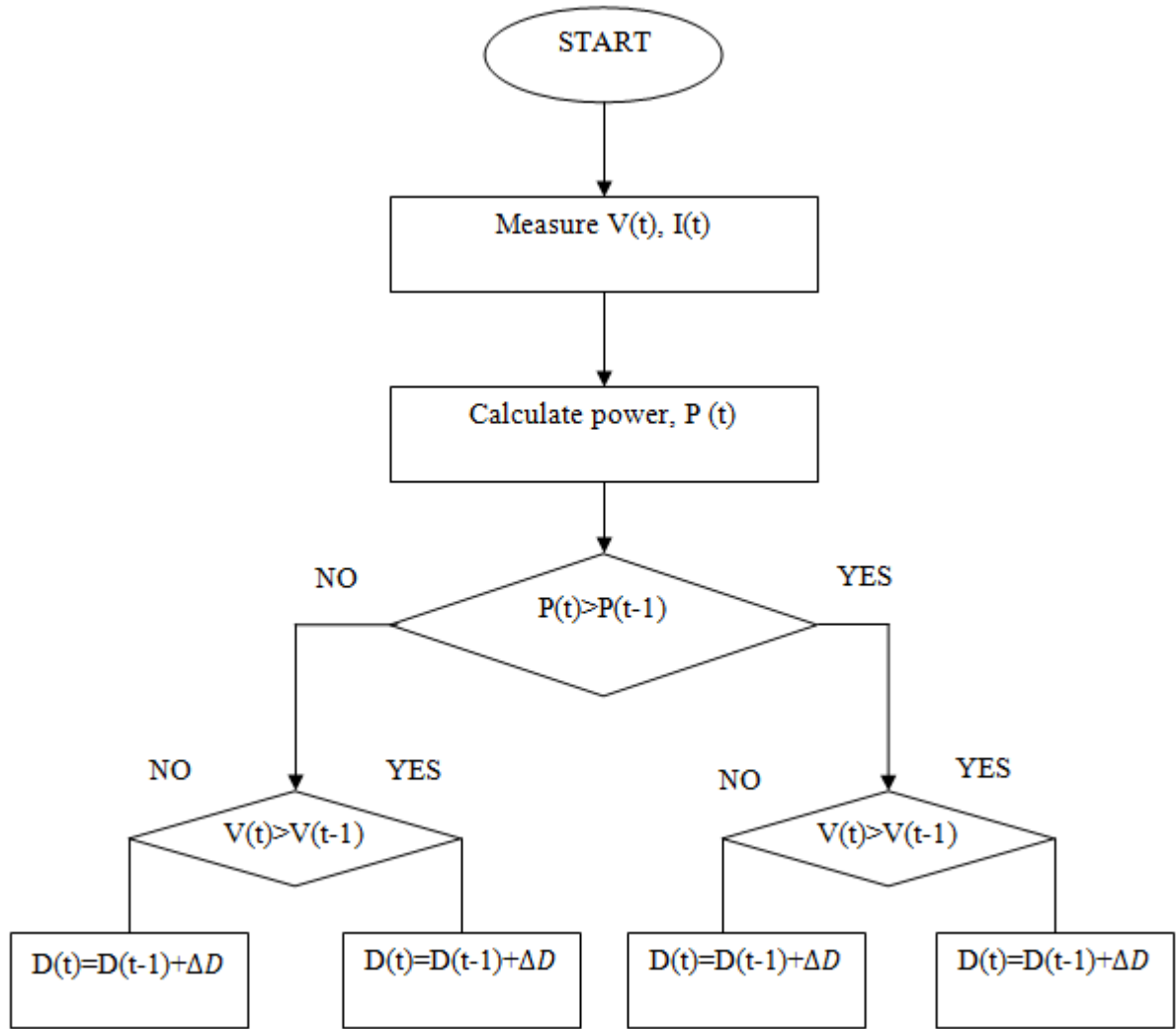


Figure 4.2 Flow chart of P&O

However, if there is any rise in a voltage, there will be drop in the output power. Further annoyance directed towards lower voltage is needed in order to reach the MPP. Thus, the algorithm will merge towards the MPP in few annoyances. The flow chart of P&O is presented in Figure 4.2. The disadvantage with this algorithm is that the operating point is never consistent at the MPP yet wandering around the MPP. Moreover, the P&O algorithm battles from quickly changing illuminations. For instance, if the irradiance changes in the middle of two testing moments in the process of convergence, then the algorithm surely collapse in its convergence efforts. In the most recent bother, the algorithm has established that the MPP lies at point A which is at higher voltage than of point B, and thus the following stage is an annoyance to reduce towards the MPP as needs. If the irradiance is stable, it would end up at point C and the algorithm would have concluded that the MPP is at still higher voltage, which is correct.

In any case, if irradiance changes quickly before the following bother, the following annoyance moves the operating point to C' rather to C, such that

$$P_{C'} < P_B \quad (4.1)$$

The slow speed of convergence is one of the main disadvantage of this MPPT technique. In this way, extreme changes in climate conditions seriously influence the effectiveness of the P&O algorithm.

4.3 PI inverter control system

4.3.1 Structure of inverter controller scheme

Inverter circuit control scheme is one of most significant part of the PV system. The inverter control system performs various functions like synchronization of distribution network with PV system, management of power flow in system and modulation of the trigger pulse of the inverter circuit. The proposed control system is designed in the synchronous reference frame. [40].

- **Control Loops**

Control system of inverter system is in charge of dealing with the power infusion into the grid. Generally, two cascaded loop forms the structure of the controller in this system i.e. outer voltage control loop and an inner current control loop. Various integration of cascaded loop can be utilized for this purpose, which incorporates outer voltage and internal power loop [42] and external power and inner current loop [41]. Yet, the most broadly utilized methodology as said in [40] which utilizes both voltage controller loop as outer loop and current controller loop as inner loop.

Outer voltage loop performs a specific function of maintaining the steady flow of power of system. The outer control loop is also utilized to regulate the voltage of DC-link at a steady level. At this point due to change in the climatic condition there is change in the power outcome produced by PV system, the voltage across DC link would likewise vary the power received by the system in so to synchronise the power at the distribution side [43]. The structure of voltage controller is presented in Figure 4.3. Main objective of this control loop is to synchronism the power components of PV system with power component of grid by regulating voltage across dc link.

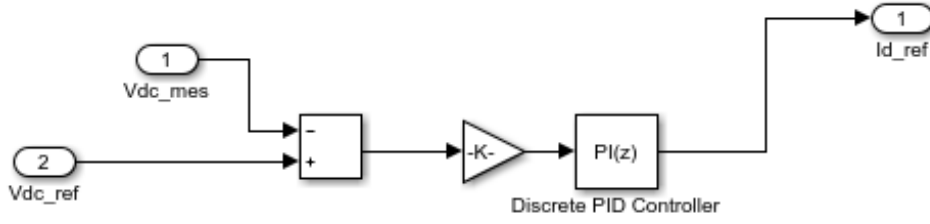


Figure 4.3 Structure of voltage controller

Inner control loop or current control loop control the current elements with the aim of providing needed voltage reference signals. The inner current loop works on regulating of quality of power and reduction in the total harmonics distortion (THD) in the output, in order to infuse better output voltage and current in distribution network. Equations (4.2) and (4.3) are utilized as a part of outlining the inner control loop [44]. Figure 4.4 demonstrates the structure of current circle controller.

$$V_{d-conv} = V_{d_mes} - \omega L i_q + \left(K_p + \frac{K_l}{s} \right) (i_{d(ref)} - i_d) \quad (4.2)$$

$$V_{q-conv} = V_{q_mes} - \omega L i_d + \left(K_p + \frac{K_l}{s} \right) (i_{q(ref)} - i_q) \quad (4.3)$$

Where,

V_{d_conv} and V_{q_conv} are d-axis and q-axis converted voltage references.

V_{d_mes} and V_{q_mes} are d-axis and q-axis measured voltages.

i_d and i_q are d-axis and q-axis measured currents.

$i_{d(ref)}$ is the reference current obtained from voltage control loop.

- Phase locked loop (PLL)

PLL function is to give the direct voltage components, quadrature voltage components and rotational frequency at the circuit breaker by transforming the voltage abc components of the utility grid. Various regulating sub system of the PV array depends upon phase locked loop output signal to adjust their command output signals. As expressed before, phase locked loop register the rotation frequency of the grid voltage vector by first converting it to the dq frame, and afterwards drive the quadrature component of the voltage towards zero to reduce cross coupling in the active and reactive power terms [43].

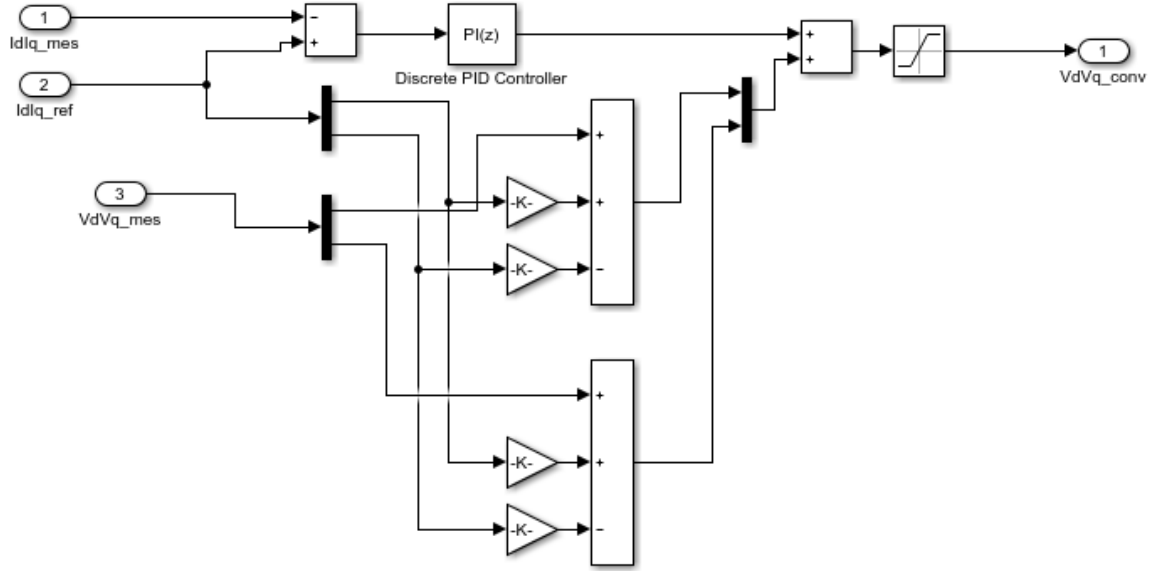


Figure 4.4 Structure of current loop controller

The three phase system values like voltage and current are converted to dq transformation from the (abc) frame using three fixed components when the system output is at stable. The formula that administers the conversion as discussed below:

$$\begin{bmatrix} x_d \\ x_q \\ x_o \end{bmatrix} = T \times \begin{bmatrix} x_a \\ x_b \\ x_c \end{bmatrix} \quad (4.4)$$

$$T = \sqrt{\frac{2}{3}} \times \begin{bmatrix} \cos(\omega t) & \cos(\omega t - \frac{2\pi}{3}) & \cos(\omega t + \frac{2\pi}{3}) \\ \sin(\omega t) & -\sin(\omega t - \frac{2\pi}{3}) & -\sin(\omega t + \frac{2\pi}{3}) \\ 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \end{bmatrix} \quad (4.5)$$

Where x is considered as a set of three phase current or voltage that is to be converted. [43]. The relationship between the abc and dq reference frame is presented in Figure 4.5 Outcome of this conversion is the three constant rotating components: quadrature (q), the direct and zero components. In balanced three phase systems, the zero components could be avoided since

$$x_a + x_b + x_c = 0 \quad (4.6)$$

The inverse transformation from the dq frame to the abc frame can be obtained by applying

$$\begin{bmatrix} x_a \\ x_b \\ x_c \end{bmatrix} = T^{-1} \times \begin{bmatrix} x_d \\ x_q \\ x_o \end{bmatrix} \quad (4.7)$$

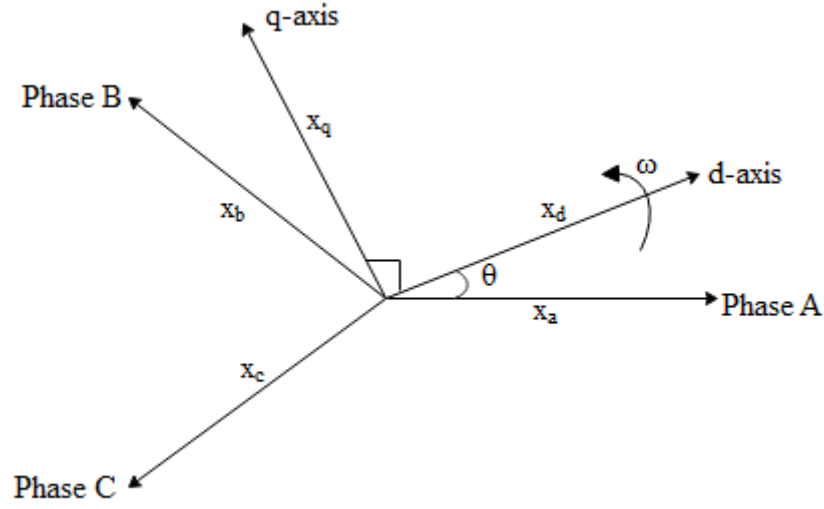


Figure 4.5 Phasor diagram of relationship between the abc and dq reference frame

This transformation is useful as it helps in forming the control system of inverter circuit of PV system under current control to adjust the output of the PV system. Powers obtain i.e. active and reactive can be calculated using the given relationships

$$P = V_d I_{d,inj} + V_q I_{q,inj} \quad (4.8)$$

$$Q = -V_d I_{q,inj} + V_q I_{d,inj} \quad (4.9)$$

Where V_d , V_q are the voltage in dq frame at PCC at the secondary side of the transformer $I_{d,inj}$ and $I_{q,inj}$ are current elements infused in dq frame at utility grid side. At the time of the formation of the reactive power Q it is observed a cross coupling between the components of voltage and current i.e. direct and quadrature components. PLL is used to rectify this problem as regulate the frequency of grid in a particular way that quadrature element of the voltage at forced to zero at the time of PV connection with the grid. Equation (4.9) and (4.10) simplifies to

$$P = V_d I_{d,inj} \quad (4.10)$$

$$Q = -V_d I_{q,inj} \quad (4.11)$$

This implies that the output power from PV array is regulated by inverter current components i.e. direct and quadrature component, as they are related to the injected currents. Assumption is considered that the voltage is relatively kept constant at the circuit breaker or

at PCC. At that time of current practice, utility system keeps voltage within specified limits using regulation mechanisms system.

- Pulse width modulation (PWM)

The desired voltage reference signals of d axis and q axis are V_{d_des} and V_{q_des} respectively, received from inner control loop are utilized to produce signal for three branches of GTO/Diode circuit connected in series in order to convert DC into AC power with the help of three level pulse width modulation circuit. PWM produce signals by comparing the input with standard triangular waveform. Before the production of the signal, V_{d_des} and V_{q_des} are converted to its original frame. Figure 4.6 shows structure of transformation to natural frame.

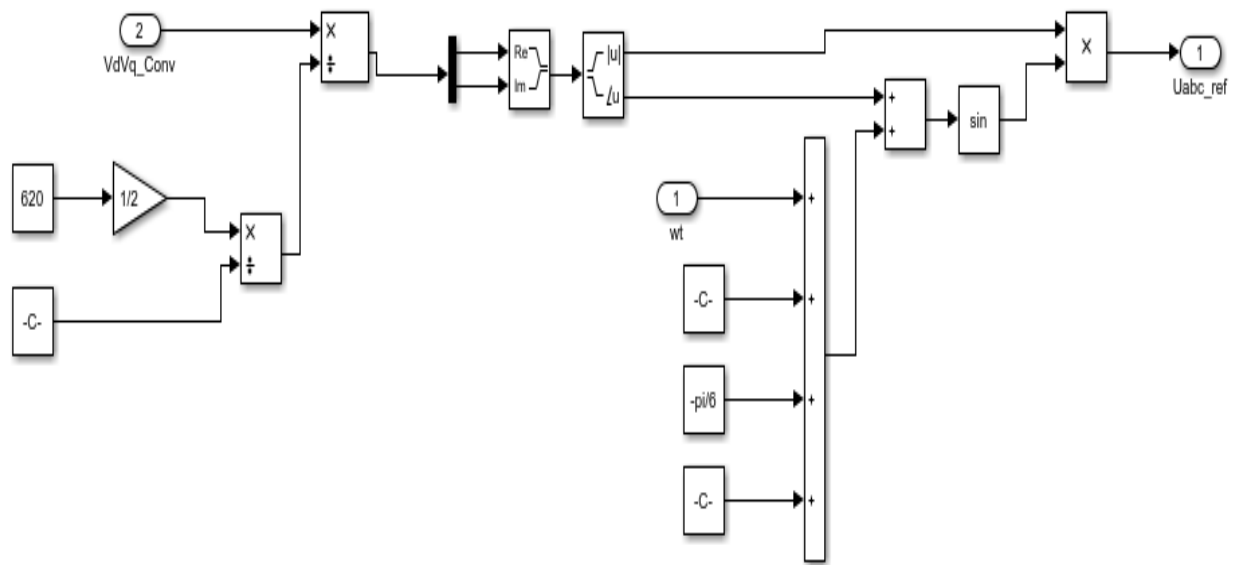


Figure 4.6 Structure of transformation to natural frame

4.4 Artificial Neural Network (ANN) control system

Artificial Neural Network (ANN) is physically cellular system as they can access, save and apply the knowledge acquired from the experiment [44]. Neural network operating procedure is related to the processing of the human brain and nervous system. They can into existence in 1943 as described [45]. They consist of neurons which are interconnected to each other and work together to solve a particular problem. ANN is self adaptive and self organised in nature. Supervised learning, unsupervised learning and reinforcement learning are the three main methods of learning.

A basic NN structure consists of three elements an input layer, hidden layers and an output layer. More than one hidden layer can implied for highly complex systems but mainly one hidden layer with adequate number of neurons is usually more than enough. Each layer

consists of neurons which take data from one or more inputs and compute an output. The output is computed an activation function. The general structure of neuron is shown in Figure 4.7.

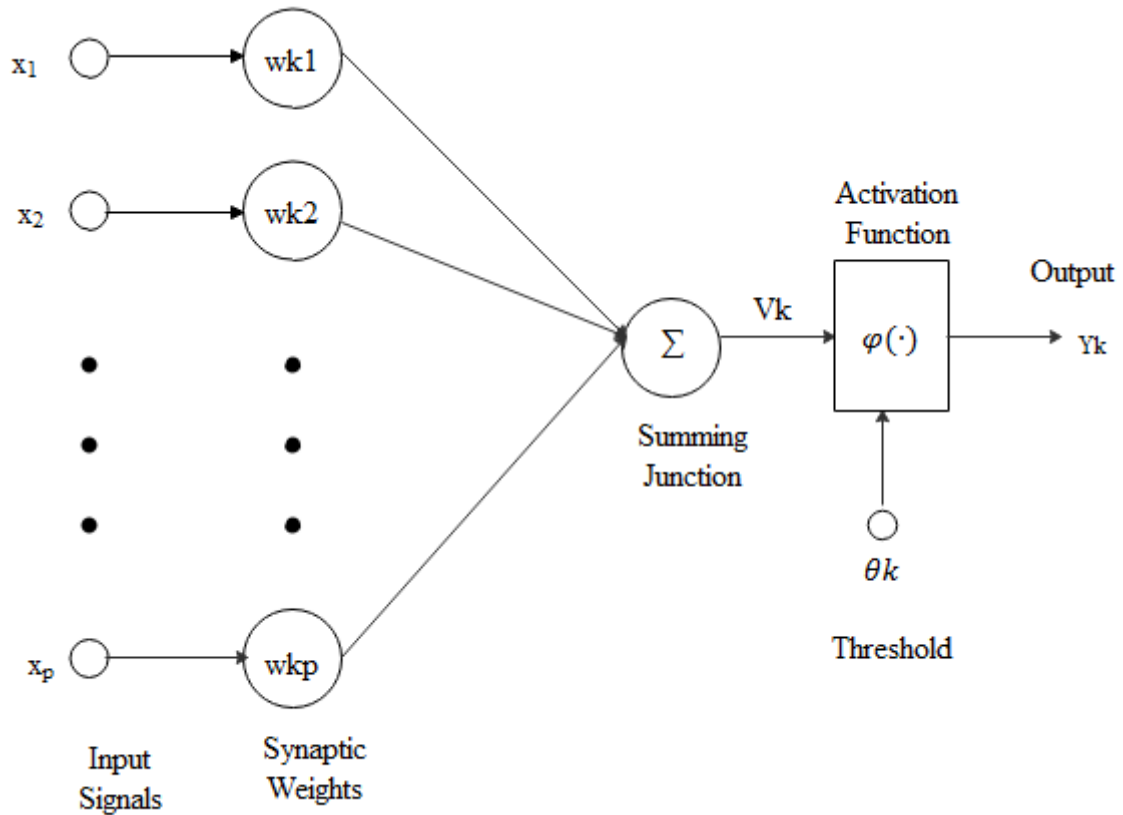


Figure 4.7 General structure of neuron

While calculating the output of the neural network [46], the activation function is considered in the form of a threshold function, in which the output of the neuron is +1 if a threshold level is reached or else 0. The various activation functions like squashing, hyperbolic tangent, sigmoid etc. can be used. In mathematical terms, a neuron k by writing the pair of equations:

$$u_k = \sum_{j=1}^m w_{kj} x_j \quad (4.13)$$

$$y_k = \varphi(u_k + b_k) \quad (4.14)$$

Where $x_1, x_2, \dots, x_m$ are the input signal; $w_{k1}, w_{k2}, \dots, w_{km}$ are the synaptic weights of neuron k ; u_k is the linear combiner output due to the input signals; b_k is the bias; $\varphi(\cdot)$ is the activation function; and y_k is the output signal of the neuron.

$$v_k = u_k + b_k \quad (4.15)$$

4.4.1 Collection of input and target data

The most important and major step of designing of Artificial Neural Network (ANN) controller is collecting input and target data of the system whose controller is to be designed.

For dissertation model, the array of solar voltage, current, dc output voltage and grid voltage and current are referred as input data to neural network. The array of PWM signals is obtained and is called target in neural network which are required to in order to train the network.

4.4.2 Designing of network structure

Neural network mainly consist of four elements i.e. input, hidden layer, output layer and output. The input data is provided to system as discussed above. The hidden layer is connected to the input data through weights, number of the hidden neuron is specified i.e. it is set on 10 neurons and weights and biases are remain constant. Hidden layer is very essential part of the system as controls the performance of the system. There is no specific method of deciding the no of hidden layers and neurons. It is calculated by hit and trial method.

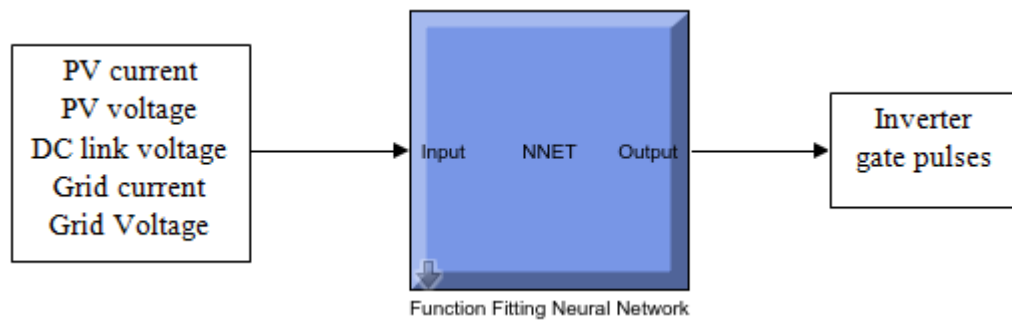


Figure 4.8 Architecture of ANN

In this dissertation, ANN model designed has 9 input data and 10 hidden neurons and 6 output layer with the PWM output pulse. Architecture of the ANN is shown in Figure 4.8

4.4.3 Training and deployment of simulink model

4.4.3.1 Multilayer feedforward network

At the point when the network weights and biases are defined, the network is prepared for training. The multilayer feedforward network could be train using pattern recognition or function approximation (nonlinear regression). The training procedure requires a set of data of appropriate network behavior i.e. inputs p and target output t .

The training of ANN includes regulating the estimations of biases and selection of the optimum algorithm to optimizes the algorithm execution, characterized by performance of the network function. The mean square error (MSE) and the regression plot is the outcome of the feedforward system after training of the system. According to its name it can be clear that the MSE is average squared error between the target output t and network output o . It is characterized by:

$$MSE = \frac{1}{N} \sum_{k=1}^N (e_i)^2 = \frac{1}{N} \sum_{k=1}^N (t_k - o_k)^2 \quad (4.16)$$

Incremental and batch mode are the two distinctive manners by which training of the system can be executed. Weights are upgraded after every input data applied to the ANN and gradient is computed after every iteration in incremental mode. All the input data is send together before there is upgradation in weights for training in batch mode. In this theses batch mode is used.

4.4.3.2 Levenberg-Marquardt algorithm

For training of the multilayer feedforward networks various numerical optimization algorithms, but there are very less optimization algorithms which have given the brilliant outcome after ANN training. For the respective model, Levenberg-Marquardt algorithm (LM) is used as training algorithm. LM is agreed as a standard technique. LM exhibits adaptive behavior according to the distance of solution so that it can be guaranteed the solution in many cases (Marquardt, 1963). When back propagation is gradient descent, the algorithm is far from the solution and it is quite slow (Hagan and Menhaj, 1994) [46]. Conversely, in the case that back propagation is Gauss-Newton, the algorithm is close to correct one. In LM, computation of the approximate Hessian given in (4.16) is done slightly, and the gradient is computed in the manner given in (4.17).

$$H = J^T J \quad (4.17)$$

$$g = J^T e \quad (4.18)$$

Where J indicate the jacobian matrix and e represents a vector of network errors. This algorithm typically requires less time and is robotic in nature. Training stops automatically when the improvement in the generalization is saturated improving, as described by an increase in the mean square error of the validation samples.

4.4.3.3 Model description ANN

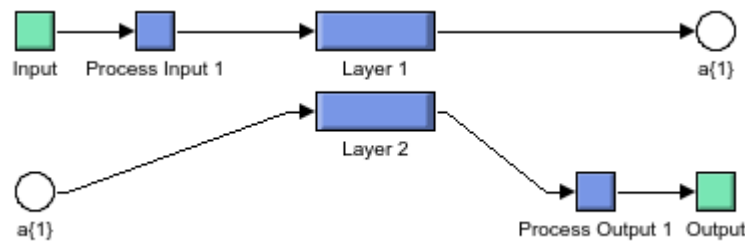


Figure 4.9 Internal model of neural network

After training the neural model is extracted as shown in Figure 4.9. It contains a single input, process layers and output. Weights and biases for layer are set at fixed value. When input is given to the neural network it is first multiplied by the fixed weights then at layer1

they are added with the biases and process using sigmoid activation function. Output obtain by this process is $a\{1\}$. Output $a\{1\}$ acts as input for layer 2. Again this input regulated using weights and biases and processed using linear activation function. After processing of input the desired output is obtained.

4.4.4 Advantages and disadvantages of ANN controller

Advantages are:

1. ANN can be used for performing specific function which cannot be performed by linear system.
2. If any part of data is distorted then also it continues to run without any problem due to its parallel nature.
3. Ones neural network is programmed it can be train again and again without reprogramming.
4. It is useful application for various controlling system.

Disadvantages are:

1. The architectural design of ANN is complex for intricate controllers.
2. It may require long time for training of the large data input.

CHAPTER 5

RESULTS AND DISCUSSION

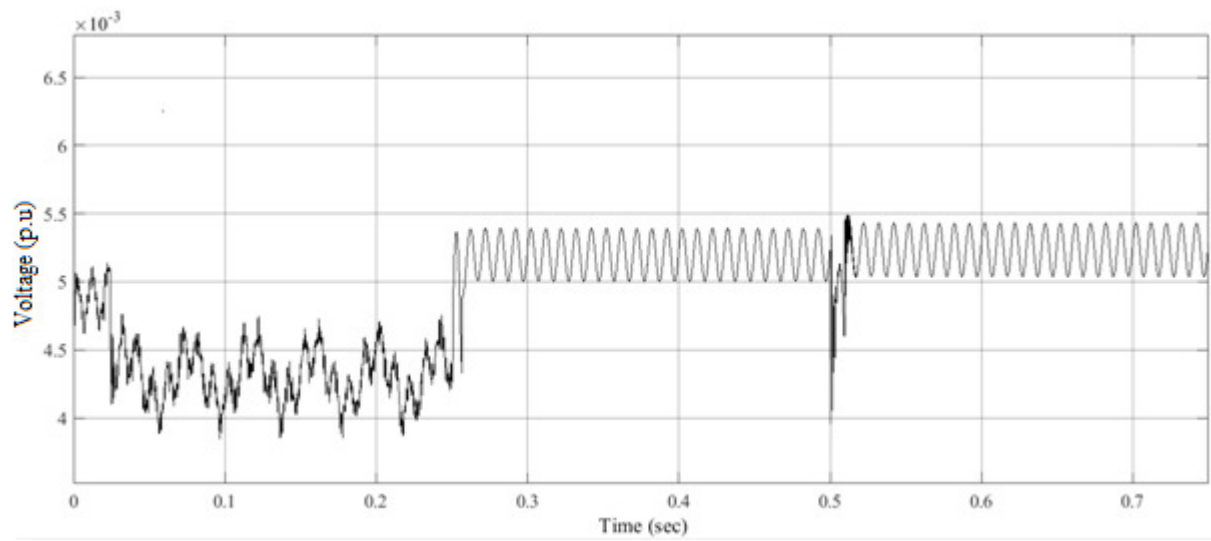
The system is simulated in simulink Matlab for 0.75 sec with following parameters: frequency at 50 hertz, standard irradiance and temperature and PV at 590 volt. The simulink model of PV connected grid is given in appendix II. The allocation of PV system between the load node 632 and 631 in 13 IEEE node feeder system is decided by the calculation the central position in the grid using table line segment data.

The inverter circuit is controlled by using standard PI controller and neural network. The power quality results using both the controller are compared. The power quality results include voltage and current at grid and PV side respectively, power output, voltage deviation, total harmonic distortion and phase angle deviation are observed using different controller. When PI controller is used, there is distortion in the voltage and current especially when load is feed by PV system. This distortion also affects the grid system voltage and current. ANN controller is very effective for non linear system. As there is an improvement in voltage and current on grid and PV side using NN controller as compared to PI controller i.e. reduced fluctuations in voltage and current as shown in the Figure (5.1) and Figure (5.2). Power output is improved at common point of coupling at is improved power quality using NN controller as shown in Figure (5.3). There is visible positive change in voltage and phase angle at different buses using NN controller as shown in Figure (5.4). There is reduction in the THD in the output power as shown in Figure (5.5) using NN controller.

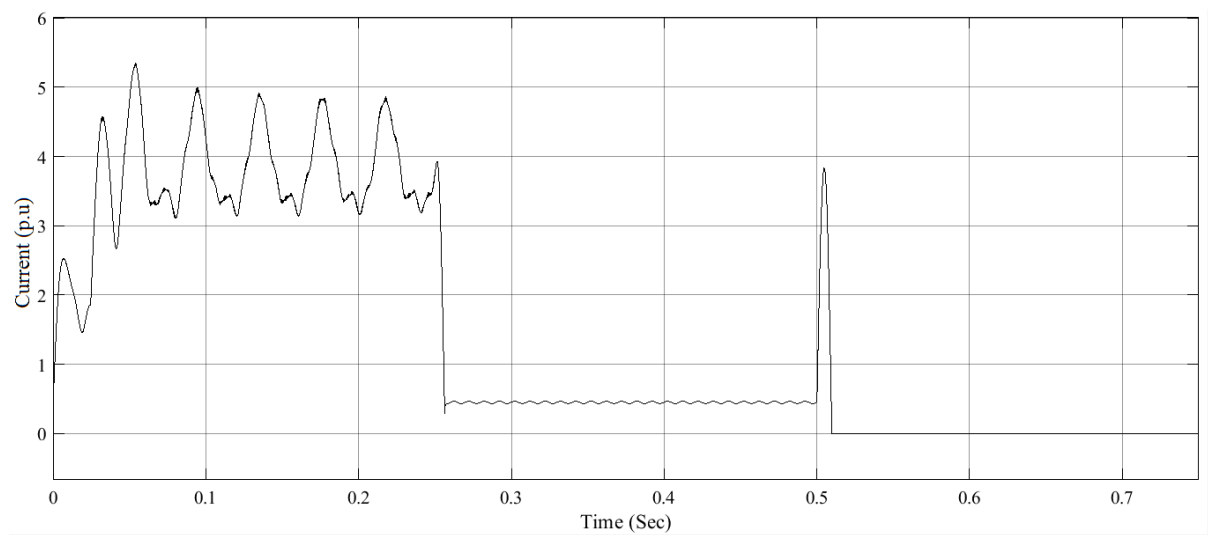
The output graphs of the power quality are divided into three half. This regulated using circuit breaker system at common point of coupling:

- 1) First part is from 0 sec to 0.25 sec, at this time system load is met by both PV system and grid i.e. system is operated at PV connected grid mode. At this time it is assumed that power produced by PV system is not sufficient to satisfy load demand due to varying atmospheric conditions like low irradiance level so load is feed by both PV and grid system.
- 2) Second part is from 0.25 sec to 0.5 sec, at this time system load is met by only grid. At this we have assumed that PV output is almost zero as it is no sun light due to cloudy weather conditions or it's a night. So load is only supported by grid.
- 3) Third part is from 0.5 sec to 0.75 sec, at this time system load is met by only PV system i.e. PV output is sufficient to satisfy load and system is operated at islanded mode as PV is

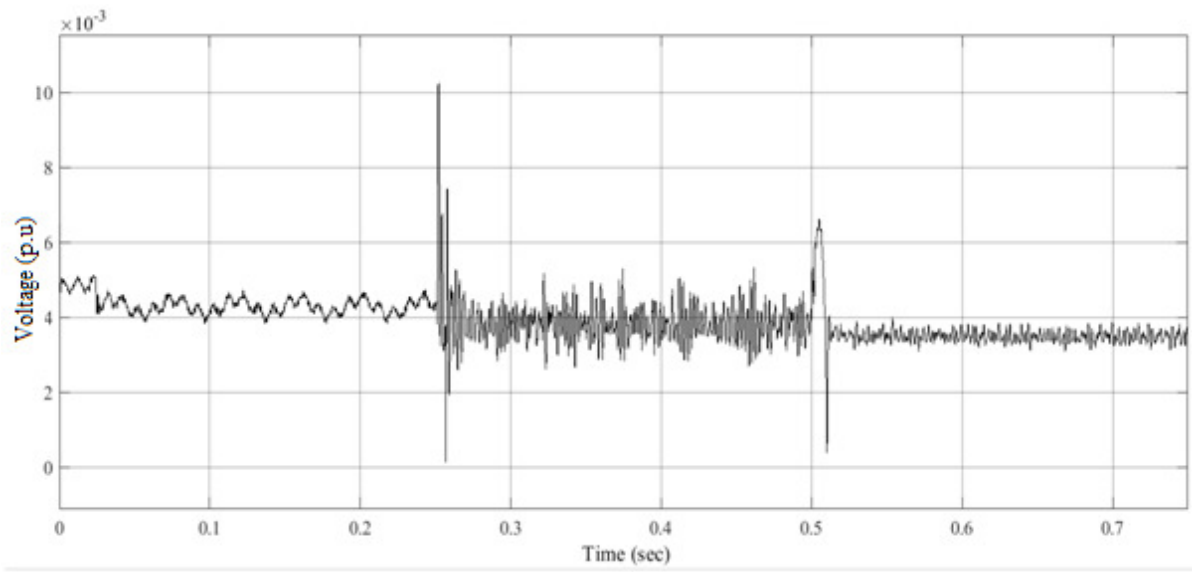
operated at maximum power point due to optimum weather condition i.e. on bright sunny day and excessive power is supplied to grid.



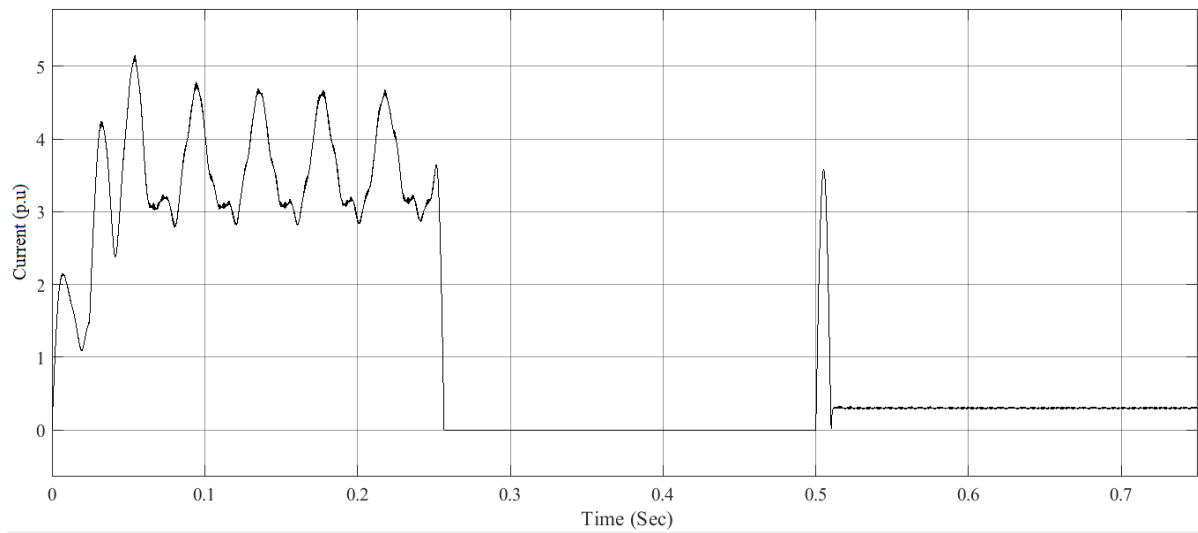
(a)



(b)

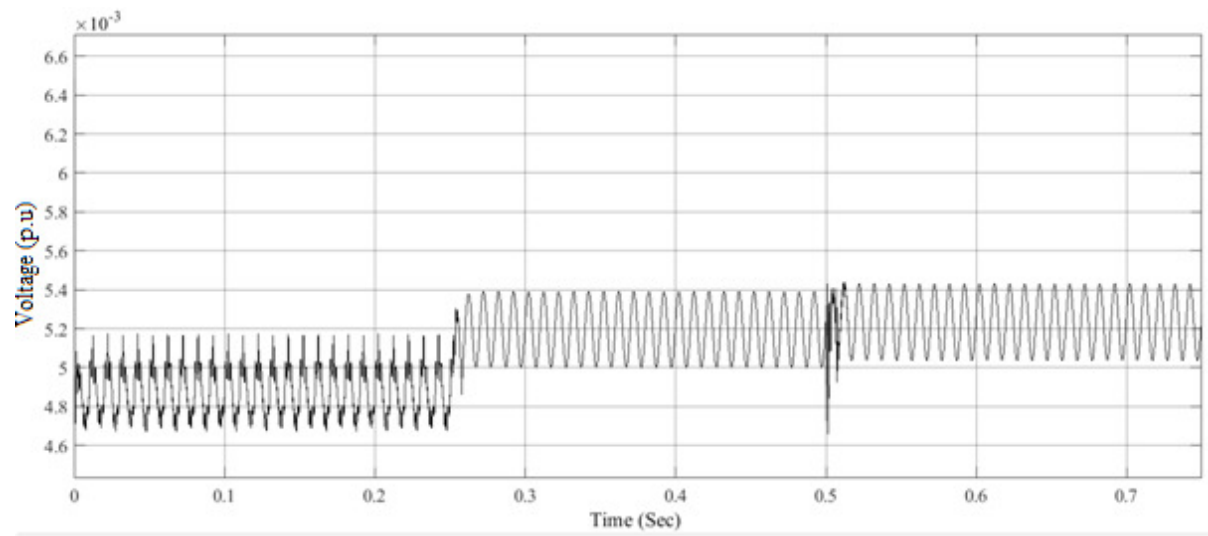


(c)

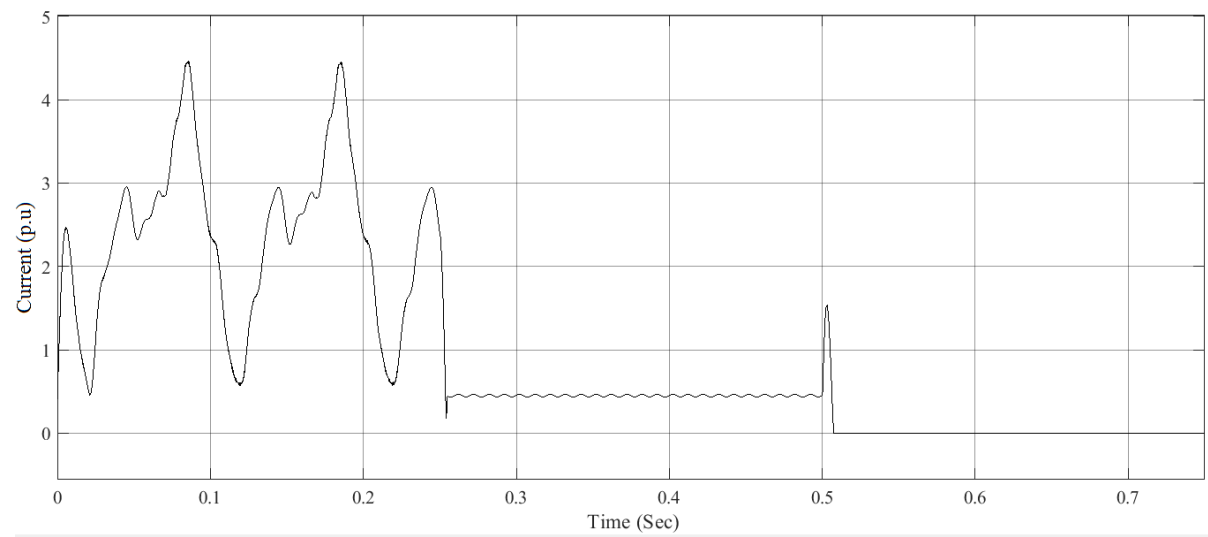


(d)

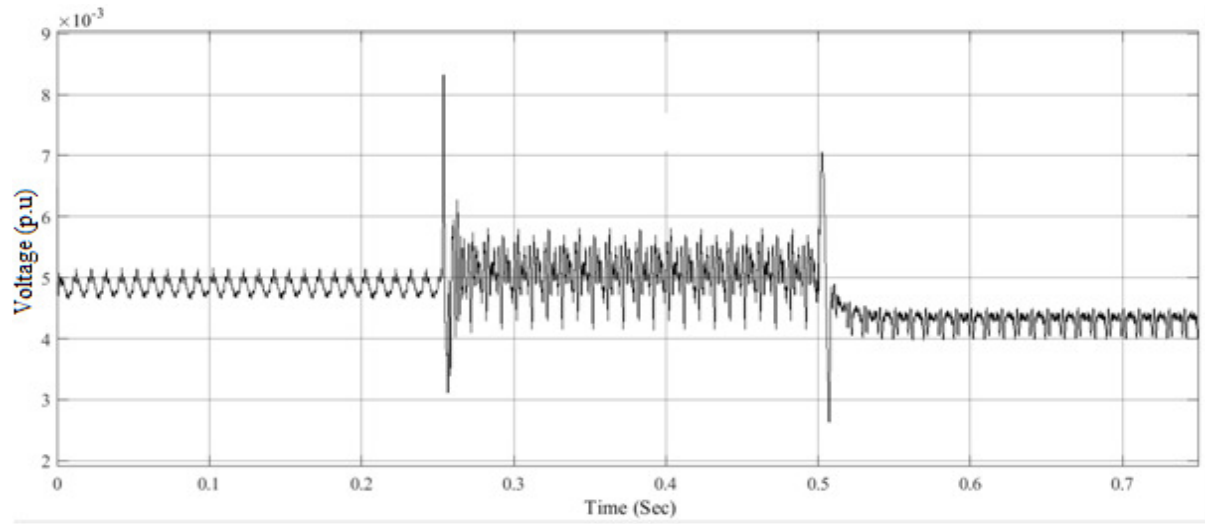
Figure 5.1 (a) voltage at grid, (b) current at grid, (c) voltage at PV, (d) current at PV using PI controller



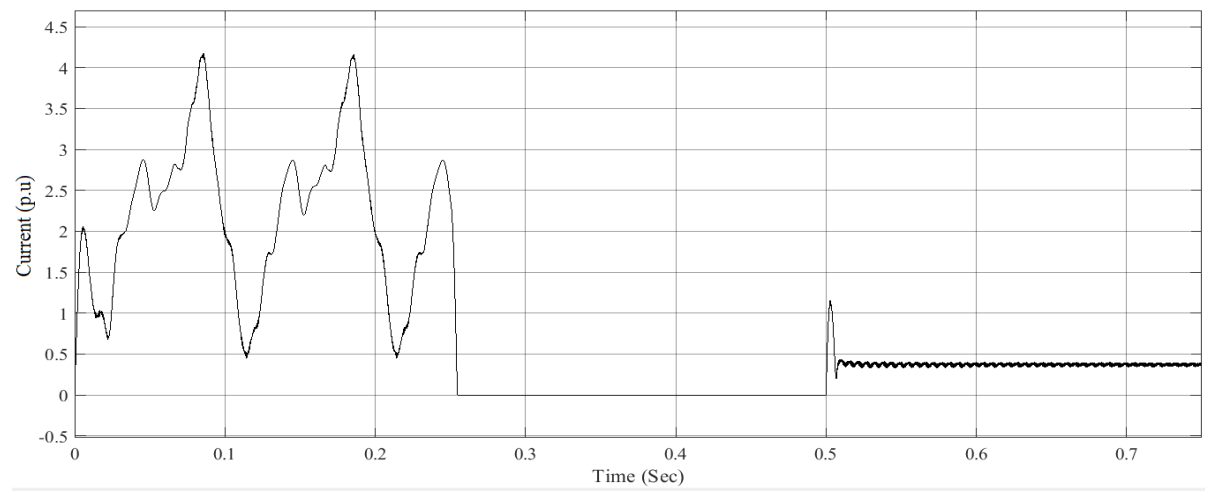
(a)



(b)



(c)



(d)

Figure 5.2 (a) voltage at grid, (b) current at grid, (c) voltage at PV, (d) current at PV using NN controller

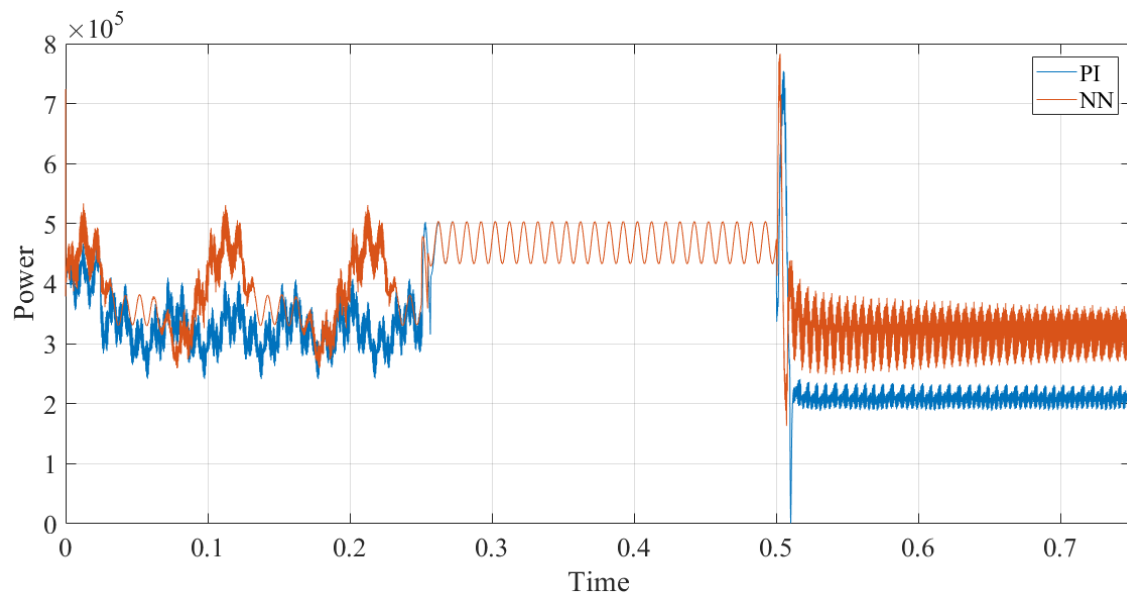
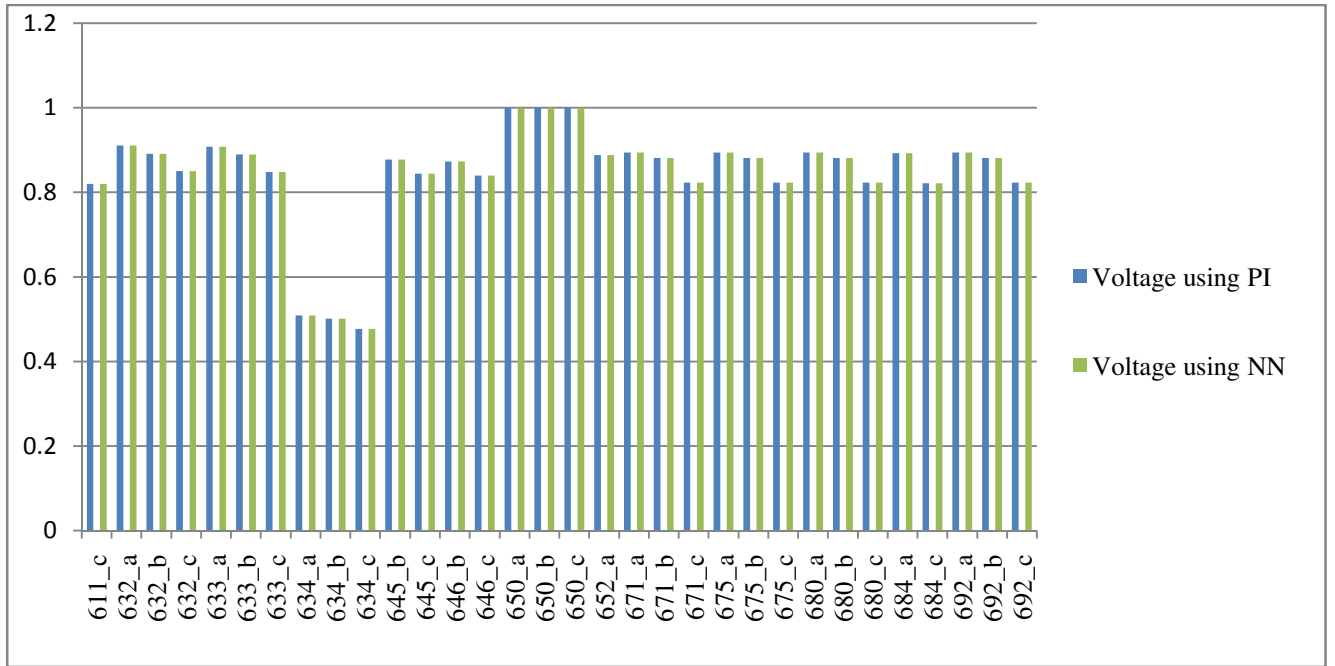
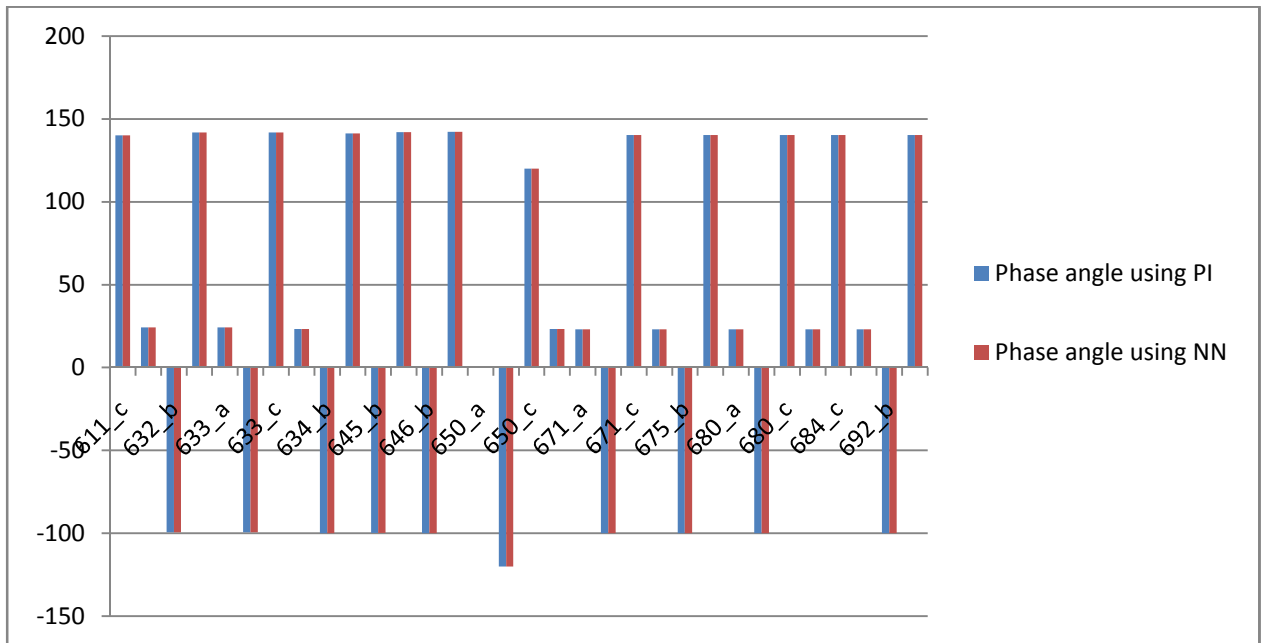


Figure 5.3 Power output using PI and NN controller

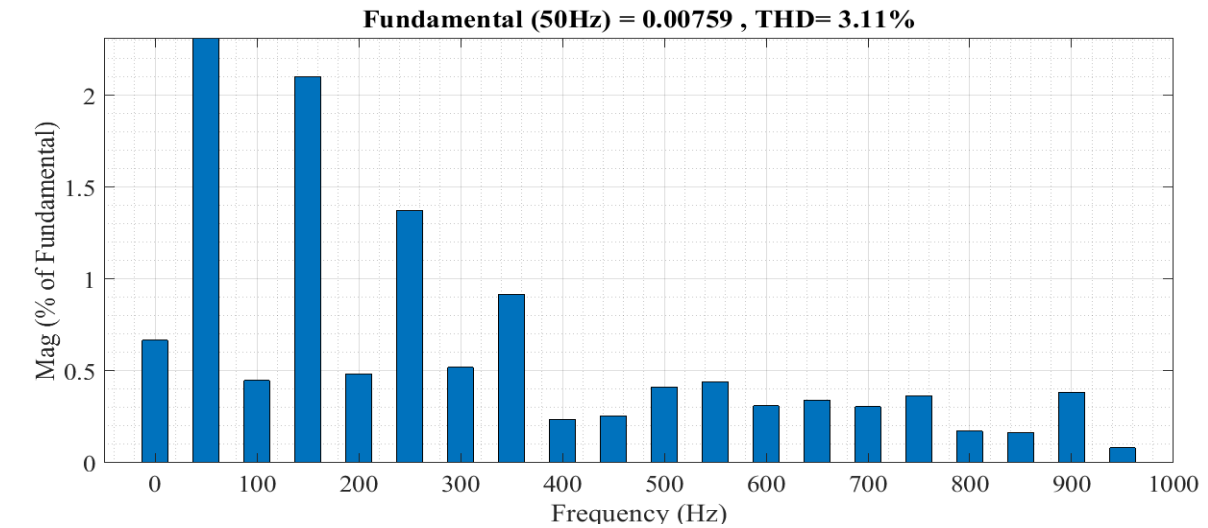


(a)

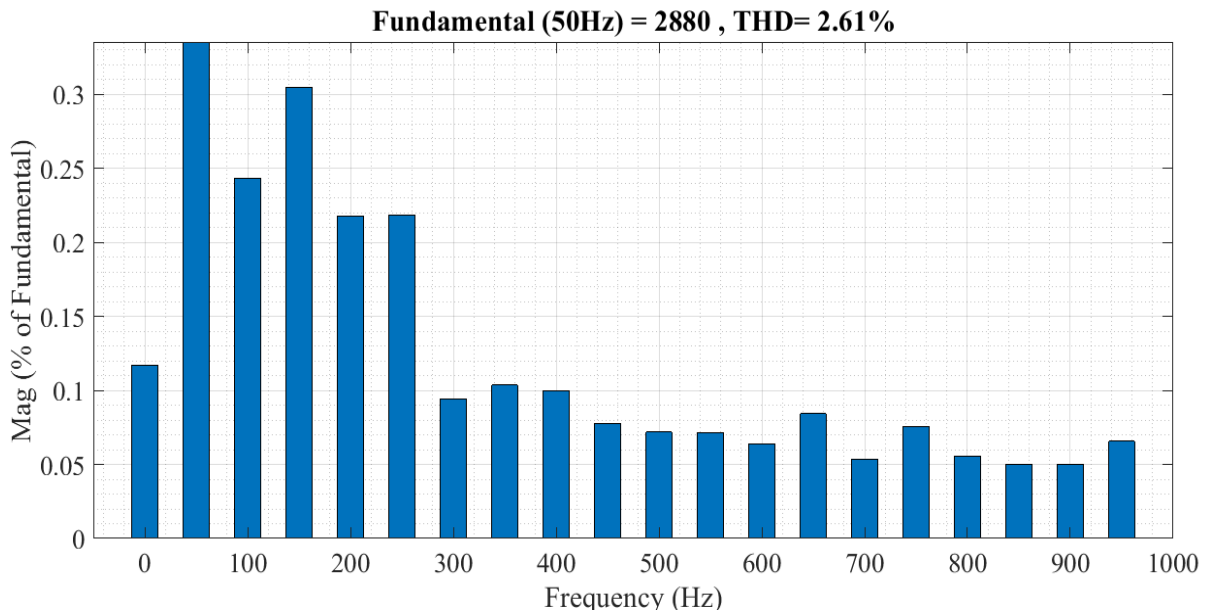


(b)

Figure 5.4 (a) Voltage variation, (b) Phase angle variation using PI and NN controller



(a)



(b)

Figure 5.5 (a) FFT using PI controller, (b) FFT using NN controller

From the above results it is observed that maximum fluctuation occurs during switching of circuit breaker and at the time when load is met by PV system. The minimum fluctuation is observed when grid supports the load. Also the output voltage and current of the PV system severely affect voltage and current of the grid side. THD in system is due to operation of power electronic devices. THD in voltage and current output is considerably reduced by using ANN controller. There is also improvement in voltage and phase angle. ANN proved to be an effective alternative against stand PI controller.

CHAPTER 6

CONCLUSION AND FUTURE WORK

6.1 Conclusion

In this dissertation the main objective is designing of PV connected grid system and implementation of 13 node test feeder system as grid with ensuring the power quality of the system. The designing of the model is achieved in Matlab simulink software. Different inverter controller systems are implement in basic PV connected grid model. The different inverter controller scheme includes PI control scheme and ANN control scheme. Perturb and Observe is used as MPPT algorithm for reaching the MPP with the purpose of extracting maximum power from the system under any atmospheric condition. Simulink results of PV connected grid system using both controllers are compared. The simulink results the power quality of the system i.e. Power output, THD (total harmonic distortion), voltage variation and phase angle variation. From the results it can be concluded that the ANN proves to be a better controller scheme than the standard PI controller scheme, as THD is reduces to considerable amount.

6.2 Future work

As further work can be done by adding battery back-up to system and designing a appropriate control scheme for regulating the battery switching according to the change in load requirement. Capital cost can also be calculated according to load requirement using various softwares like HOMER pro before planning about installation. This type of model provides the description about components and area used at installation site. It also reduces the onsite experimental cost of research and development.

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APPENDIX I

IEEE 13-Node test feeder impedances

$$1\text{Miles} = 1.609344 \text{ km}$$

$$1 \text{ Feet} = 0.0003048 \text{ km}$$

$$1 \text{ Microsiemens} = \frac{0.5 \pi}{60 \times 10^{-6}} \text{ Farads}$$

$$R_{[601 - 607]} = \frac{R_{[601-607]}}{1.609344}$$

$$L_{[601 - 607]} = \frac{X_{[601 - 607]}}{0.00427108}$$

$$C_{[601 - 607]} = \frac{B_{[601 - 607]}}{0.00425752 \times 10^{-6}}$$

Configuration 601

$$R_{601} = \begin{bmatrix} 1.0179 & 0.5017 & 0.4236 \\ 0.5017 & 1.0478 & 0.3849 \\ 0.4236 & 0.3849 & 1.0348 \end{bmatrix}$$

$$X_{601} = \begin{bmatrix} 1.0179 & 0.5017 & 0.4236 \\ 0.5017 & 1.0478 & 0.3849 \\ 0.4236 & 0.3849 & 1.0348 \end{bmatrix}$$

$$B_{601} = \begin{bmatrix} 6.2998 & -1.9958 & -1.2595 \\ -1.9958 & 5.9597 & -0.7417 \\ -1.2595 & -0.7417 & 5.6386 \end{bmatrix}$$

Configuration 602

$$R_{602} = \begin{bmatrix} 0.7526 & 0.1580 & 0.1560 \\ 0.1580 & 0.7475 & 0.1535 \\ 0.1560 & 0.1535 & 0.7436 \end{bmatrix}$$

$$X_{602} = \begin{bmatrix} 1.1814 & 0.4236 & 0.5017 \\ 0.4236 & 1.1983 & 0.3849 \\ 0.5017 & 0.3849 & 1.2112 \end{bmatrix}$$

$$B_{602} = \begin{bmatrix} 5.6990 & -1.0817 & -1.6905 \\ -1.0817 & 5.1795 & -0.6588 \\ -1.605 & -0.6588 & 5.4246 \end{bmatrix}$$

Configuration 603

$$R_{603} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 1.3294 & 0.2066 \\ 0 & 0.2066 & 1.3238 \end{bmatrix}$$

$$X_{603} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 1.3471 & 0.4591 \\ 0 & 0.4591 & 1.3569 \end{bmatrix}$$

$$B_{603} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 4.7097 & -0.8999 \\ 0 & -0.8999 & 4.6658 \end{bmatrix}$$

Configuration 604

$$R_{604} = \begin{bmatrix} 1.3238 & 0 & 0.2066 \\ 0 & 0 & 0 \\ 0.2066 & 0 & 1.3294 \end{bmatrix}$$

$$X_{604} = \begin{bmatrix} 1.3569 & 0 & 0.4591 \\ 0 & 0 & 0 \\ 0.4591 & 0 & 1.3471 \end{bmatrix}$$

$$B_{604} = \begin{bmatrix} 4.6658 & 0 & -0.8999 \\ 0 & 0 & 0 \\ -0.8999 & 0 & 0 \end{bmatrix}$$

Configuration 605

$$R_{605} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1.3292 \end{bmatrix}$$

$$X_{605} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1.3475 \end{bmatrix}$$

$$B_{605} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 4.5193 \end{bmatrix}$$

Configuration 606

$$R_{606} = \begin{bmatrix} 0.7982 & 0.3192 & 0.2849 \\ 0.3192 & 0.7891 & 0.3192 \\ 0.2849 & 0.3192 & 0.7982 \end{bmatrix}$$

$$X_{606} = \begin{bmatrix} 0.4463 & 0.0328 & -0.0143 \\ 0.0328 & 0.4041 & 0.0328 \\ -0.0143 & 0.0328 & 0.4463 \end{bmatrix}$$

$$B_{606} = \begin{bmatrix} 96.8897 & 0 & 0 \\ 0 & 96.8897 & 0 \\ 0 & 0 & 96.8897 \end{bmatrix}$$

Configuration 607

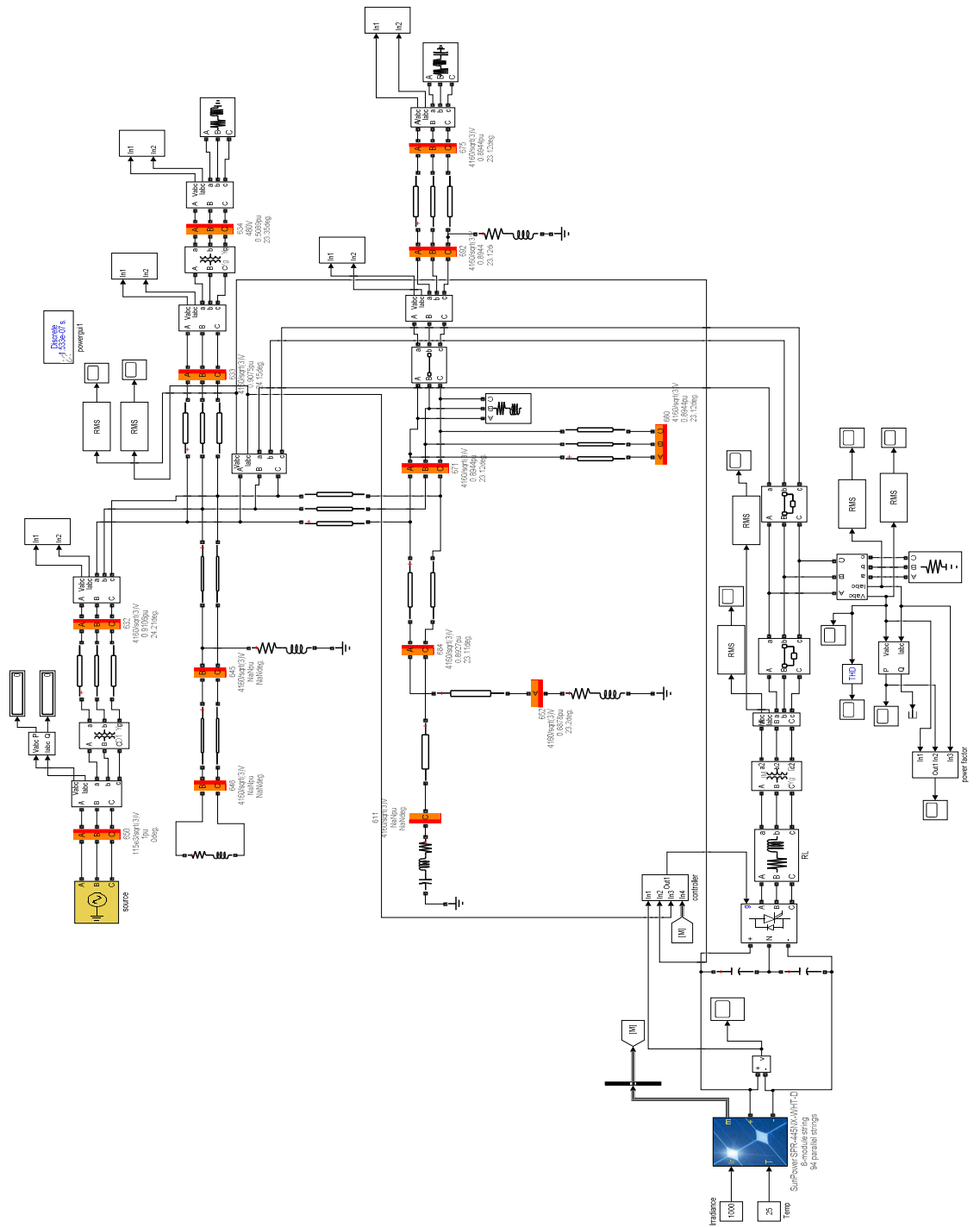
$$R_{607} = \begin{bmatrix} 1.3425 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

$$X_{607} = \begin{bmatrix} 0.5124 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

$$B_{607} = \begin{bmatrix} 88.9912 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

APPENDIX II

Simulink model of PV connected IEEE 13 node feeder system



LIST OF PUBLICATION

- Jyoti Gupta, Jitender Kaushal and Prasenjit Basak, “ Power Quality Analysis using ANN controller of PV based Microgrid System suitable for Marine Applications” Indian Journal of Geo-Marine Sciences (IJMS), NISCAIR Publications (communicated).

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