Simulation of 8 kW Grid-tied Photovoltaic System With and Without P&O Algorithm

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Abstract: ***The following work presents the comparative analysis of the system having an 8 kW grid – tied PV system with and without MPPT. It is using P&O technique to enhance the power output from PV array. A PID controller works in conjunction with the MPPT in a closed loop feedback system to provide tuned DC output to the inverter. A 3 – level inverter which converts the DC to AC using NPC topology and hysteresis current control technique to provide constant current and enhanced power output to the loads. The dynamic model of a PV system is also developed to compare the output from the PV array to inverter with and without MPPT. Also the power from inverter to the loads is compared to validate the use of NPC and HCC. Also it has been studied in this work that the system is stable and the loads are synchronized with the power grid parameters such as frequency, voltage and current. System consists of a PV generating array of 8kW capacity with MPPT and a PID controller. The tuned output from PID controller (using hysteresis current control technique) is fed to inverter using IGBT as switching devices and is a three – level inverter with Neutral Point Clamped topology. The MPPT keep a track of the maximum power point and give enhanced PV generated output power.The converted output of the inverter is then fed to local loads of 12 kW and 24 kW respectively. The loads are switched at intervals of 2 seconds and the residual demands of the loads are fulfilled by the connected power gird. The loads are synchronized with the connected power grid parameters. This shows the stability of the proposed system.***

Keywords: Grid Connected PV system, MPPT, P&O Algorithm, HCC, NPC

1. Introduction

In this age, every country wholly agrees that electric energy is an essential factor in the economic development of the country. The advancement of technical progress, rapid industrialization and the necessities regarding the modern world has transformed electric energy into an important asset. Increase in its production runs parallel to the better and comfortable lifestyle and accumulation of wealth. Electric energy has been proved to be the most versatile form of energy which can be converted and utilized in any form and way, in the same way any form of energy could be converted and conserved as electric energy. Fossil fuels are main source of electric but due to their irreversible nature, they are being extinguished at an alarming speed.

To fulfill power demand in the world renewable energy proves out to be the best alternative. [1]. In order to meet this demand, the reliable and sustainable renewable energy sources are needed to supply power to the power grids. But this injection of renewable power creates some power quality issues and parameters of the electrical power grid fall down the standard values. [2]

By the survey of 2013 about 23,322 TWh of electricity generation was estimated all over the world and then it was it was discovered that 41% of that was generated by coal, 21% by natural gas, 19% by renewable sources, 10% by nuclear and 5% by oil.

With the mounting danger of extinguishment of conventional energy source, renewable energy has gained attention for the research of electric power generation. Renewable contribution to omnibus power utilization was 19.2% in 2012 and 23% to their production of electrical energy in 2013. the 9% of this power is utilised in accounting for biomass, 3.8% in hydroelectric power, 4.2% as energy in form of heat and 2% is coming from photovoltaic and CSP. More than US$214 billion have been globally invested in renewable energy production in the year 2013. [3].US and China have invested in solar, hydro and wind energy at a very large scale. Renewable power is derived from the resources which are infinitely available to humans such as geothermal heat, tidal waves, wind, biomass, and solar energy.

According to many recent pieces of research and study, [4], it is proved that greenhouse gas emitters are responsible for the damages caused to the environment. According to a survey, there is a walloping support for the promotion of renewable springs like solar power, wind energy, tidal energy on an international basis. Around 30 countries around the world draw more than 20% of energy from renewable resources. It has been perceived that the national renewable market is progressing at a rapid pace and is anticipated to boost colossally in the coming decades. Norway and Iceland along with a few other places have generated their 100% of their energy from renewable resources and many other nations aspire to attain 100% renewable energy, so much so that, Denmark Government has set its goal to achieve 100% renewable energy by 2050 and is working towards it by replacing energy supply such as electricity, mobility and heating or cooling by renewable resources.

Table 1: Installed Grid Interactive Renewable Power Capacity in India as Of September 30, 2016

Generation type	Total installed capacity in MW	2022 target in MW
Solar Power	8513.23	100,000.00
Small Hydro Power	4323.35	5,000.00
Wind Power	28082.95	60,000.00
Waste-to-Power	115.08	10,000.00
Biomass Power	4882.33	
Total Generation	**44783.33**	**175,000.00**

2. Modelling of Solar Cell

Sunlight is captured by solar PV system and is directly converted into electricity. Mainly two factors are responsible for the solar cell output which are adaptable that is ambient temperature and irradiation. The output of the solar cell either increase or decrease is determined by the changes in these two factors. Mathematical equations and explaining and defining the physical characteristics of the PV cell are required for the modelling. [5]. A PV cell is a semiconductor diode whose p-n junction is open to the light. When the solar cell junction is struck by sunlight then generation of free electrons and holes occur and the load when short-circuited is delivered a current. In order to achieve large output voltage, PV modules are formed by connecting PV cells in series, and PV cells are connected in parallel in order to obtain large output current.

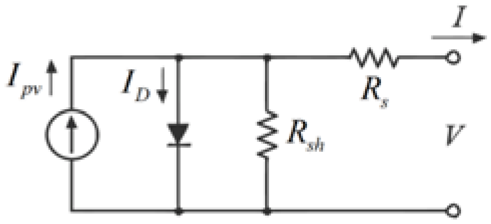

Figure 1: Equivalent circuit of a PV cell.

$$I = I_{PVcell} - I_{0cell}\left[\left(\exp\left(\frac{q(V+IR_s)}{nkT}\right)-1\right)-\left(\frac{V+IR_s}{R_p}\right)\right] \quad (1)$$

The temperature T_1 and T_2 govern the incident photocurrent.

$$I_{PVcell} = I_{PVcell} + K_0(T - T_1) \quad (2)$$

$$I_L(T) = I_{SC_{T_1}}\left(\frac{G}{G_{nom}}\right) \quad (3)$$

$$K_0 = (I_{SC_{T_1}} - I_{SC_{T_2}})/(T_2 - T_1) \quad (4)$$

G_{nom} is the reference solar radiation and G is the present solar radiation.

During the dark, the cell is inactive and behaves like diode. The shunt resistance is denoted by R_p and internal resistance of the solar cell is denoted by R_s. For the given resistive load, the maximum power is

$$P_{Max} = V_{Max} * I_{Max} \quad (5)$$

The efficiency of the solar cell is given by

$$\eta = \frac{P_{Max}}{P_{Min}} = \frac{(V_{Max}*I_{Max})}{A*G} \quad (6)$$

Here G is the incident solar radiation on cell and A is the area of the cell.

Fill Factor is the measure of the quality of the solar cell. The FF should be more than 0.7. It is inversely proportional to the cell temperature.

$$FF = \frac{(I_{SC}*V_{OC})}{(V_{Max}*I_{Max})} \quad (7)$$

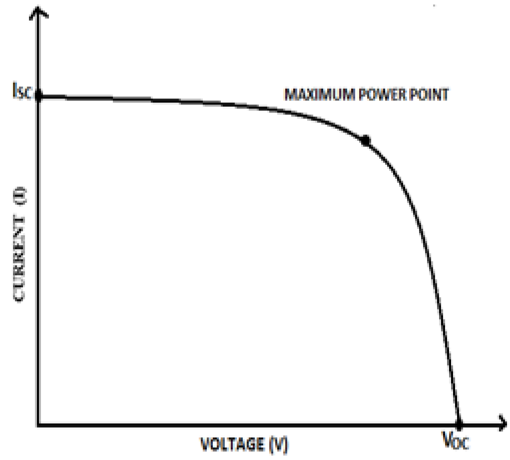

Figure 2: V - I characteristic of a solar cell

3. Designing of MPPT

The electrical energy converted by a conventional PV is only about 30 to 40 percent of the incident sunlight. On the other hand, the productivity of the PV array can be boosted by the medium provided by maximum power point tracker. The points provided by maximum power transfer theorem claims that if the load impedance is equal to Thevenin's impedance then the output power of the circuit will be maximum. Hence, the task of tracking maximum power point is now summarized to case of impedance matching. The duty cycle of the converter when altered accordingly will result in the matching of load impedance with source and in this case Thevenin's impedance. [6].

In order to choose the algorithm for selection of tracking techniques one must keep in mind the various factors such as computation time, complexity level, cost and effectiveness.

A. Perturb & Observe Technique

P&O is the simplest technique of MPPT. The very first step of tracking algorithm is to measure the initial sample of the working voltage V_{PV} at time instance T_1 and current I_{PV} also at time instant T_1. After taking the initial sample a second set of values for the working voltage $V_{PV}(T_2)$ and current $I_{PV}(T_2)$ is calculated. Considering the sedate data for current and voltage, the derivative of power is calculated ΔP_{PV}. If the value for ΔP_{PV} is coming positive, then the working voltage has to be altered in the course similar to the perturbation. If ΔP_{PV} is negative, the working voltage of the system has moved away from the maximum power point and it should be moved in direction opposite to the perturbation. Constant 'C' is the value by which the operating voltage has to be perturbed. The value of 'C' is taken to be as 0.1V as a suitable perturbation step value in the programming. If the photovoltaic output shows increment, then working voltage should also show increment, but with decrease in output power, the voltage should project decrement.

The working voltage should display increment if the photovoltaic output shows increment, in the same way when the output power decreases then the voltage should display decrement. The method proves to be advantageous as the previous knowledge of PV generator characteristics is not mandatory and it is simple comparing to other methods. The cost of the device is inexpensive as the P&O engages only one sensor, which is the voltage sensor, to detect the photovoltaic output voltage and therefore amicable in handling and assembling.

Table 2: Control actions for various output points in P&O technique

ΔP	ΔV	$\Delta P/\Delta V$	Direction of Tracking	Control action for Voltage
-	-	+	Bad direction	Increase voltage **V by ΔV**
+	+	+	Good direction	Increase voltage **V by ΔV**
+	-	-	Bad direction	Decrease voltage **V by ΔV**
-	+	-	Good direction	Decrease voltage **V by ΔV**

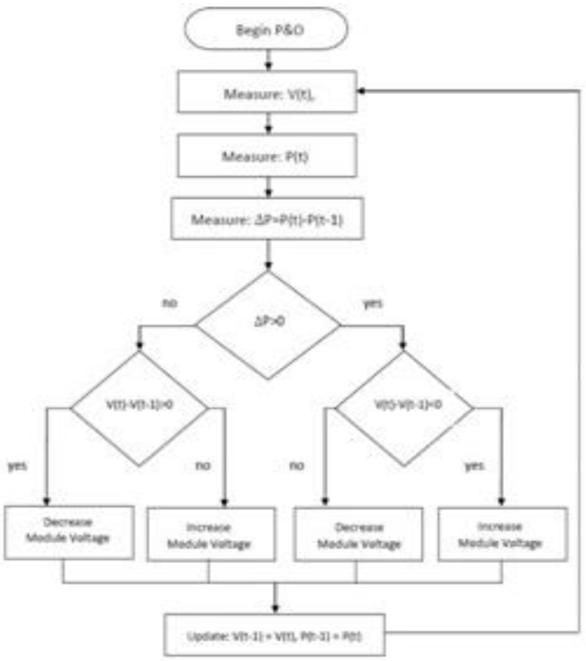

Figure 3: Flowchart of P&O technique

4. Model Implementation of PV System with – without MPPT

The specification for the solar module used in this simulation has been given in the table. The simulation model of the PV system with and without MPPT has been provided here. The resulting simulated waveforms of DC voltage from PV array to inverter, simulated Power waveforms from inverter to loads and the corresponding current and voltage waveforms have been provided below and compared.

Table 3: Technical specification of a PV module

S. No.	Parameters	Values
1.	Voltage at Maximum power	70.4 V
2.	Current at Maximum power	1.93 A
3.	Open circuit voltage	86.8 V
4.	Short circuit current	2.02 A
5.	Reference Temperature	55°C

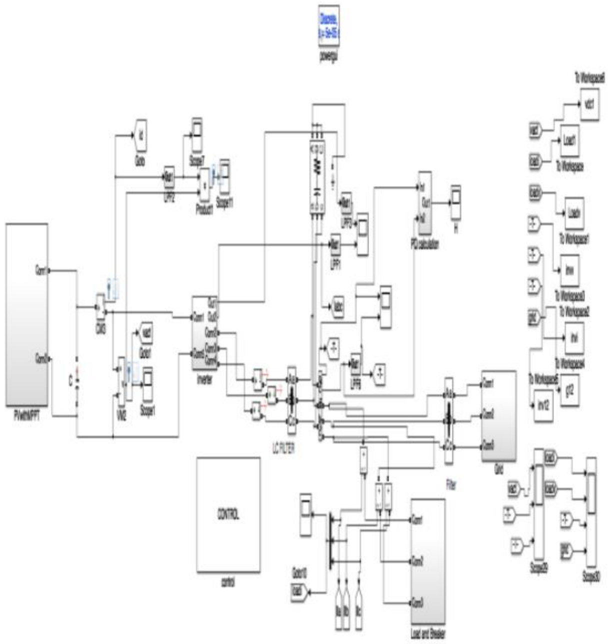

Figure 4: Simulation main model of the PV system

A. PV subsystem with MPPT

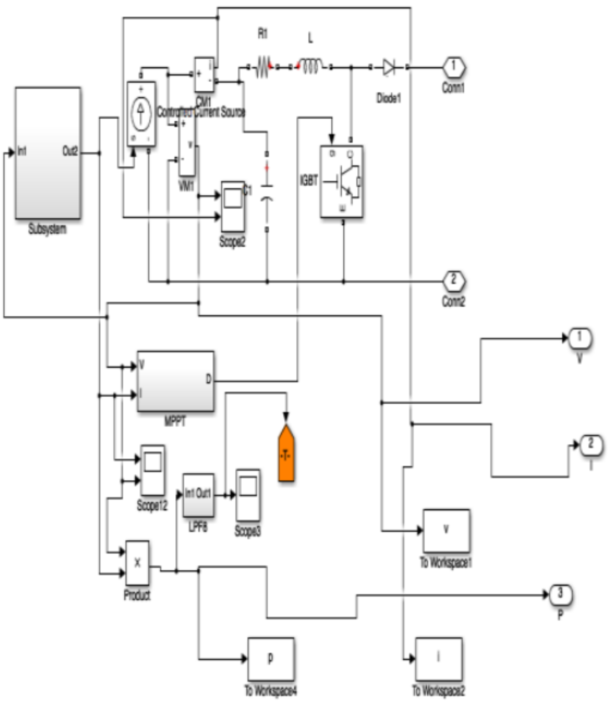

Figure 5: Simulation model of PV subsystem with MPPT

The figure on previous page is the PV subsystem simulation model with MPPT and PID controller. The tuned output from this subsystem is fed to the inverter subsystem.

B. PV Subsystem Without MPPT

The figure below is of PV subsystem without MPPT. The maximum power point is not achieved in this technique and the power from the PV array lost in many folds. The PWM technique is used in this to provide gate pulse to the inverter switches.

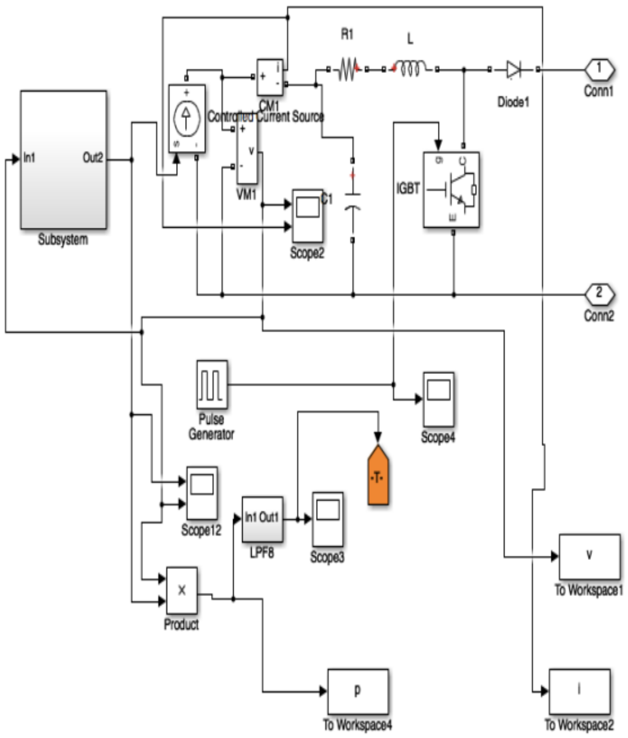

Figure 6: Simulation model of PV subsystem without MPPT

C. Simulated output waveforms of the implemented design model with – without MPPT

There are several simulated output waveforms or curves of the PV system simulation model with and without MPPT we obtained or plotted and comparative analysis has been done.

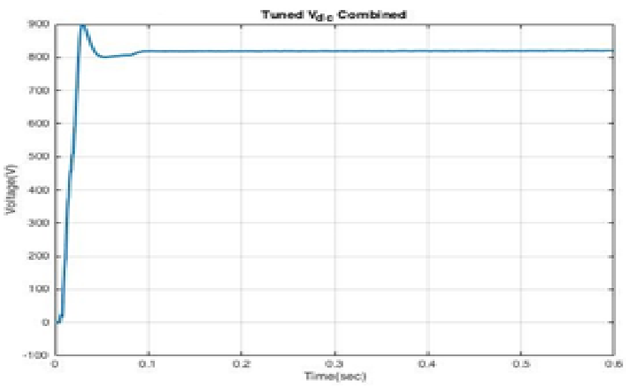

Figure 7: Simulated tuned Vdc output waveform with MPPT

The figure 7 shows the tuned Vdc output from PV array and the power from inverter to the load is shown in figure 8 which is constant and enhanced power out of PV array and three – phase inverter current to load is controlled shown in figure 9 using MPPT.

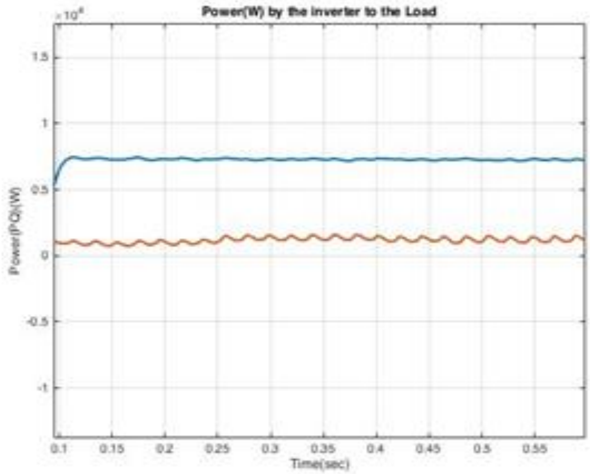

Figure 8: Simulation waveform of power from Inverter to the load with MPPT

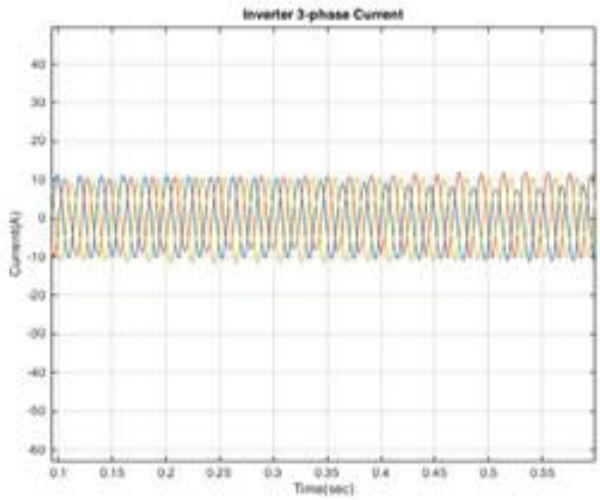

Figure 9: Simulated waveform of inverter three –Phase current to the load using MPPT

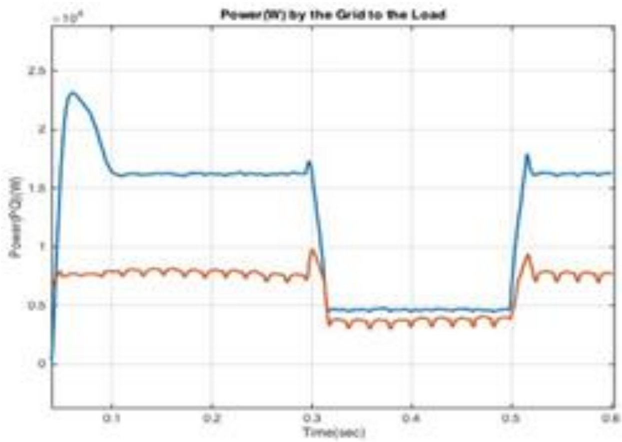

Figure 10: Simulated waveform of the power from grid to load(with MPPT)

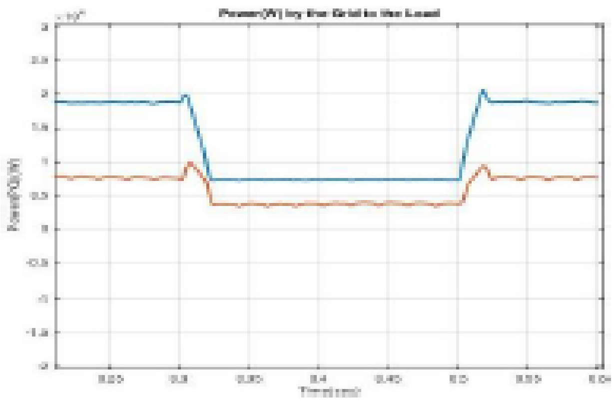

Figure 11: Simulated waveform of power from grid to load (without MPPT)

Figure 10 shows the simulated waveform of power from grid to load feeding residual demands of each load at switching intervals of 2 seconds with loads being fed using MPPT technique. It is evident from figure 11 that the system feeding loads without MPPT draws more power from grid to fulfill demands of the loads.

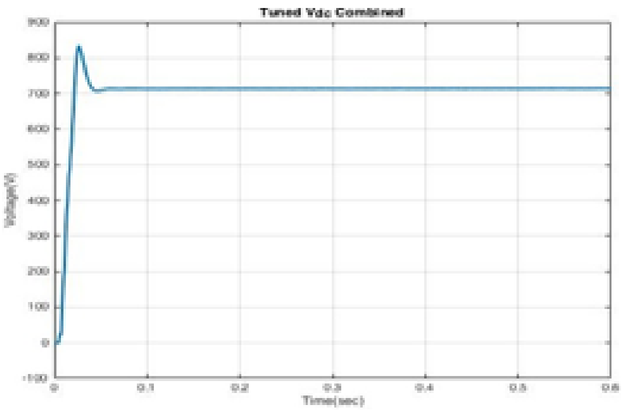

Figure 12: Simulated tuned Vdc output waveform without MPPT

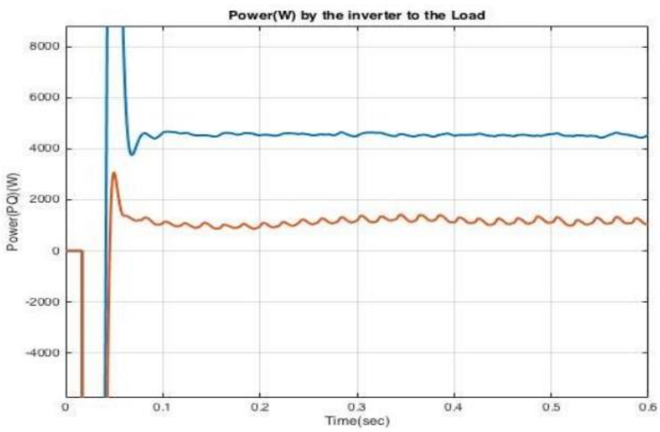

Figure 13: Simulation waveform of power from inverter to the load without MPPT

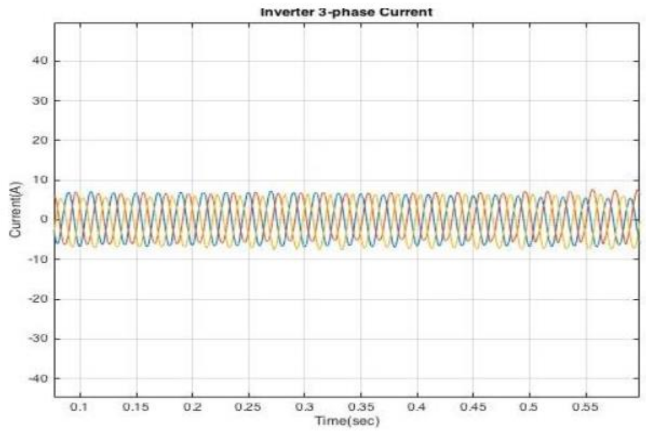

Figure 14: Simulated waveform of inverter three –phase current to the load without MPPT

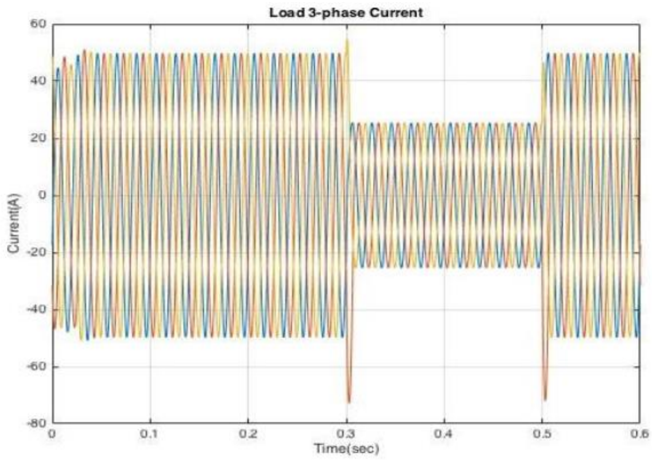

Figure 15: Simulated waveform of three–phase load current with MPPT

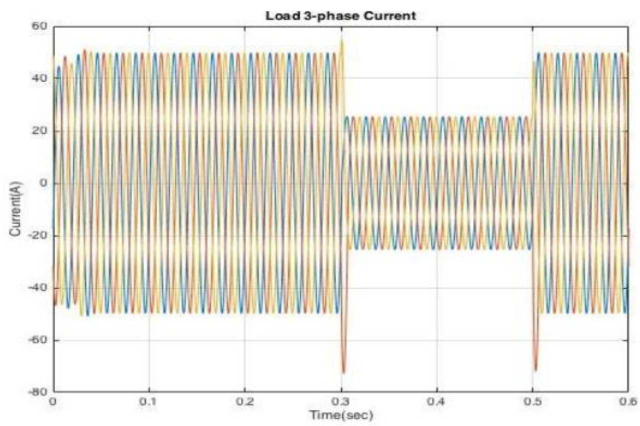

Figure 16: Simulated waveform of three –phase load current without MPPT

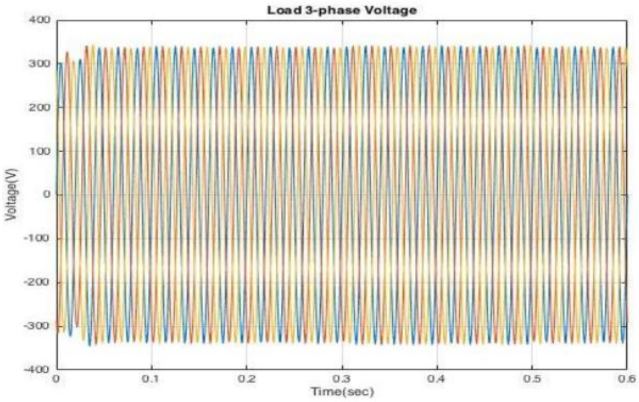

Figure 17: Simulated waveform of three–phase load voltage with MPPT

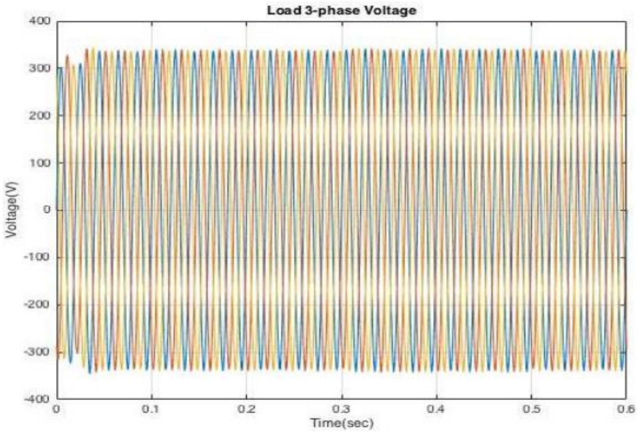

Figure 18: Simulated waveform of three –phase load voltage without MPPT

5. Result and Discussion

The tuned V_{dc} simulated waveforms indicated in figure 7 and figure 12 for both conditions i.e. with MPPT and without MPPT techniques is obtained. There is a decrease in DC voltage waveform without MPPT of about 100 volts. The power from inverter to loads for both conditions have been analyzed and the corresponding waveforms have been obtained as shown in figure 8 and 13.

The simulated three – phase current waveforms from inverter as shown in figure 9 and 14 have been obtained for both conditions showing the compression in the current without MPPT technique. Figures 15 – 18 are the simulated output waveforms of 3 – phase load current and voltage obtained showing that the system is dynamically stable under varying load conditions. Figures 10 and 11 obtained are the simulated waveform of the remaining power demands of the loads fulfilled by the power grid. For both the conditions (with and without MPPT technique) the power fed to the loads by the power grid is shown.

It has been found that by using MPPT P&O algorithm, PID controller, NPC three – level inverter with hysteresis current control technique, the efficiency of the system is increased and the dynamic stability of the system connected to the grid also maintained.

Table 4: Final result with and without MPPT

	POWER	V_{DC}
With MPPT	7.5 kW	810 V
Without MPPT	4.5 kW	710 V

6. Conclusion

In this paper an attempt has been made to develop a simulation model for grid – tied 8 kW PVsystem with and without MPPT (feed local loads at remote places) in MATLAB to study the enhancement in the efficiency, reliability and sustainability of the system. The output waveforms for both the models (with and without MPPT) have been obtained and are verified. Both the models are compared and the generated output waveforms have been studied comparatively. The simulation model proposed in this paper using MATLAB performs well and effective and can be developed for grid – tied PV systems at remote places or to promote renewable energy usage, using MPPT technique.

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