GMPPT of Photovoltaic System under Partial Shading Condition and integration of PV and battery system with grid using bidirectional AC-DC converter

Shilpa Kailas Patil
Electrical Engineering Department
Veermata Jijabai Technological Institute Mumbai, India

***Abstract*— Photovoltaic (PV) technology achieved interests all over the world due to the fuel cost is absolutely zero also once installed, its operation generates no pollution and no greenhouse gas emissions. Another advantage is the advance research in material science and power electronics field. The level of solar irradiance is crucial factor which directly effects the total power generated by PV system, particularly when Partial Shaded condition occurs i.e. clouds, trees, dust, weather and various other atmospheric conditions which causes less irradiance received by PV due to blockage and consequently PV system generates less power. Maximum power point tracking (MPPT) system is used to track peak power PV is able to generate from its PV characteristic curve but due to partial shading condition PV characteristic of array contains more than one peak power which makes it difficult for MPPT technique to track peak. This paper uses the algorithm to track MPPT under partial shaded condition and a configuration of a single-phase dual buck opposed current bidirectional AC-DC converter for PV/battery system integration with grid. Hysteresis current control scheme is used to control power flow between grid and PV/battery system by controlling gate pulses of switches of bidirectional AC-DC converter. This scheme assures that voltage at which power transfer take place is maintained constant and current entering or leaving grid follows reference current frequency. This model is tested in MATLAB/SIMULINK.**

Keywords—Maximum Power Point Tracking (MPPT), Global Maximum Power Point Tracking (GMPPT), Perturb and observe (P&O) algorithm, boost converter, battery energy storage system (BESS), bidirectional ac-dc converter.

1. INTRODUCTION

The issues of energy crisis and environmental concerns are increasing day by day. Research towards improving the efficiency of renewable energies is the topic of interest for many researchers, developers and manufacturers to solve these problems.

Efficiency of PV cell is very less 15 to 20%. So, efficiency of PV system can be increased by making it to operate at maximum power point which it is able to deliver under normal as well as partial shaded condition. During uniform irradiance condition since there is only one peak in PV characteristic it is easy to track peak power using conventional P & O algorithm but under non uniform solar irradiance modified P&O algorithm is used to track peak power as there are multiple peaks available in PV curve.

Battery is used in parallel with PV system. PV source is an intermittent source so in order to stabilize the fluctuation of PV output battery is connected in parallel with PV. Additionally, PV power is available only when sun irradiations are available that is during day time so when sun irradiations are not available then battery can be used to supply the load. To increase efficiency of PV system always maximum power must be extracted from it. But sometimes load is less and PV generation is more, then excess power can be stored in battery. Fig.1 represents PV system with grid integration which involves three subsystems, a PV/battery system, a dual buck opposed current bidirectional ac–dc converter, and the hysteresis current controller which controls the mode of operation, power flow in both ac and dc side and improves power quality. The bidirectional ac–dc converter works as the interface between the AC grid and the PV/battery pack, which should allow bidirectional power flow and ensure desired power factor and low total harmonic distortion. PV system and battery storage system operate parallel at DC link. PV system operates with P&O GMPPT method using boost converter. The basic half bridge inverter has switches are connected in series in phase leg so they have inherent fault path when both switches are on causes short circuit at dc source and waste of energy in switches. These refers to shoot through to avoid it dead time is provided between switching of switches but which in turn causes non linearity in power converter. The solution is found using opposed current half-bridge inverter architecture [4]. Two buck converters are operated in time opposition instead of time alteration, as in basic half bridge inverter and also has features of the conventional half-bridge inverter, it is named as dual buck half-bridge inverter. The converter exhibits two functions: first, shoot-through is limited by large in series inductances L1 and L2; it is also able to flow reactive power and energy transfer is seamless. Hysteresis current controller is used as control technique as it is simple and also during mode transitions it helps system get stabilize, allow smooth startup. Two separate high inductors are required which are costly, this issue is faced by mention converter. The details of the circuit working principle and control technique are illustrated in Section 2.

Section 3 represents the analysis of simulation results. Section 4 involve conclusions and references are mentioned at end of paper.

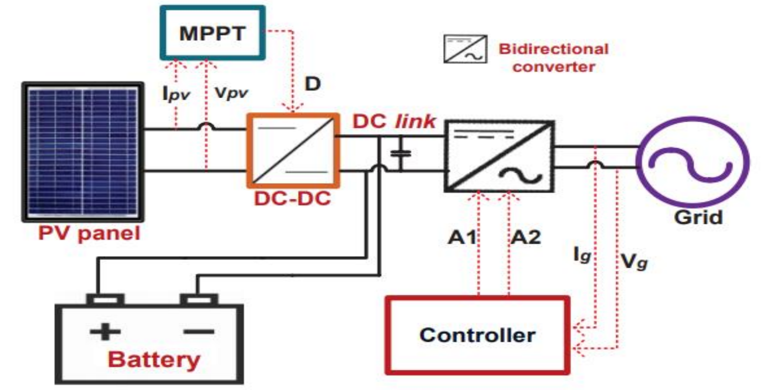

Fig. 1. Simplified diagram of the Grid integration with Photo Voltaic (PV) and Battery system.

2. CIRCUIT WORKING PRINCIPLE

A. Bidirectional AC – DC converter

Fig. 2 below shows the circuit diagram of the dual buck opposed current bidirectional ac-dc converter. The circuit consists of two split dc-bus capacitors C1 and C2, two inductors L1 and L2, two power switches A1 and A2 and two diodes D1 and D2. When the power is transferred from AC grid to DC source converter works as a rectifier and when the power is transferred from DC source to AC grid it works as an inverter. To ensure the circuit works properly throughout the whole line cycle voltage across each capacitor C1 and C2 should be always larger than the peak AC voltage.

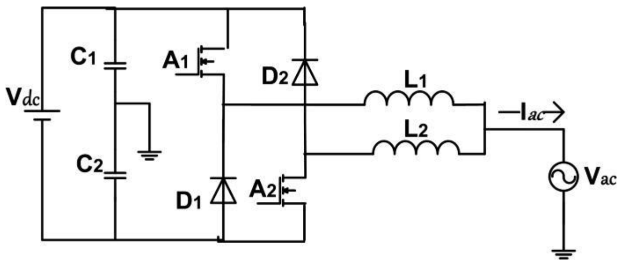

Fig. 2. Circuit Diagram of Bidirectional AC-DC Converter

Operating Principle:

The operation of rectifier and inverter is divided into four sub operation modes which depends upon conduction of switches A1, A2 and diode D1, D2 as shown in Fig. 3 and Fig. 4 for rectifier and inverter respectively.

i) Rectifier mode: Main principle of rectifier is to convert AC to DC. In case of rectifier power from grid is transferred to DC side through C1 and C2. Table below shows the operation of bidirectional converter as rectifier.

Half cycle of grid current	switch	iac	capacitor
+ve	A1 on	increases	C1 discharged
+ve	A1 off, D1 on	decreases	C2 charged
-ve	A2 on	increases	C2 discharged
-ve	A2 off, D2 on	decreases	C1 charged

ii)Inverter mode: Main principle of inverter is to convert DC to AC. In inverter mode power from PV/battery system is transferred to gird. Table below shows the operation of bidirectional converter as inverter

Half cycle of grid current	switch	iac	capacitor
+ve	A1 on	increases	C2 charged
+ve	A1 off, D1 on	decreases	C2 charged
-ve	A2 on	increases	C1 charged
-ve	A2 off, D2 on	decreases	C1 charged

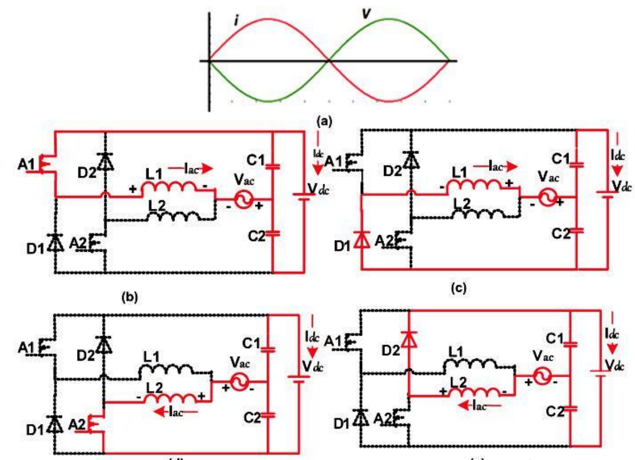

Fig. 3. Rectifier mode operation. (a) Voltage and Current waveforms. (b) A1 is ON. (c) D1 is ON. (d) A2 is ON. (e) D2 is ON.

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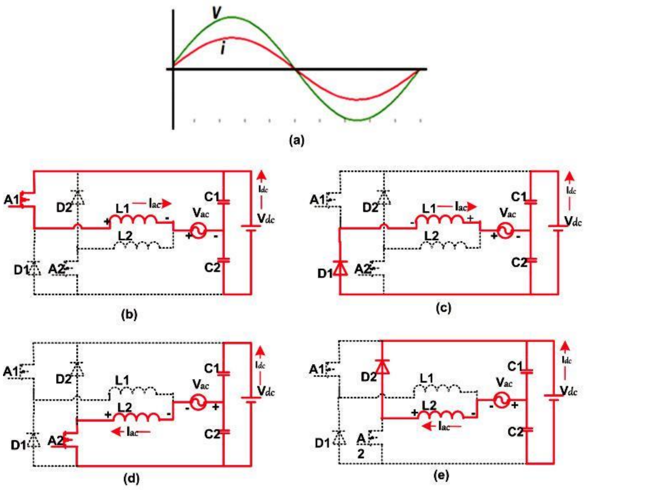


Fig. 4. Inverter mode operation. (a) Voltage and Current waveforms. (b) A1 is ON. (c) D1 is ON. (d) A2 is ON. (e) D2 is ON.

B. Hysteresis Current Controller for Bidirectional AC-DC converter

Hysteresis current controller is used to simplify the controller and during the mode transitions stabilize system can be achieved. Fig. 5 shows *Bidirectional AC-DC converter* with hysteresis current control loop. Active power P and reactive power Q are given as reference input to hysteresis controller and Current command *iref is* obtained from Pref and Qref. Im and θ can be calculated using reference active and reactive power input as shown below:
Im = ((P+ Q)/(Vpk/2))
θ = tan-1(Q/P)

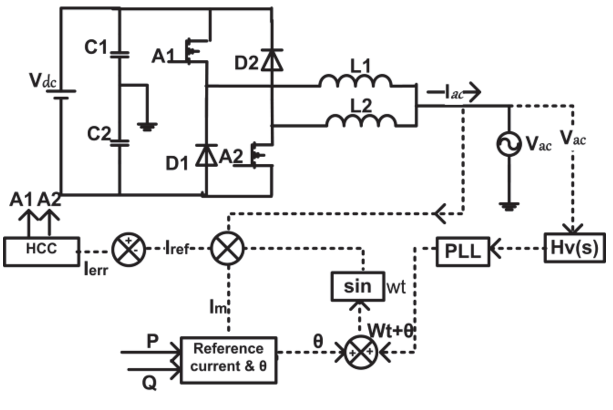


Fig 5. Circuit Diagram of the Converter with proposed Hysteresis current control loop

In Fig.5 Vac is grid voltage which is used as feedback voltage. The voltage sensor gain, Hv(s) is used to compensate feedback voltage. P and Q will give angle θ which when added to wt, voltage angle of grid obtained from PLL will generate reference current waveform. This reference current waveform is compared with actual grid current to produce error current ierr. This error current is then fed to hysteresis current controller to produce gate pulses for switches A1 and A2. If reference power is positive then power is fed to grid from dc source hence bidirectional converter acts as inverter. Grid current and voltage are in phase in inverter mode of operation. If reference power is negative then power is delivered from grid to dc source hence bidirectional converter acts as rectifier. Grid current and voltage are 180 degree out of phase in rectifier mode of operation. The tables below show conduction of switches depending on error sign and half cycle for rectifier and inverter case.

Rectifier mode

Error	Switch	Half cycle of voltage
negative	A1 on	Negative
positive	A1 off	Negative
negative	A2 on	Positive
positive	A2 off	Positive

Inverter mode

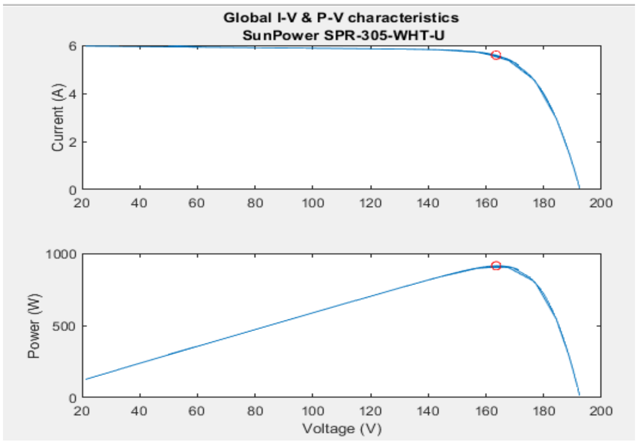
Error	Switch	Half cycle of voltage
negative	A2 off	Negative
positive	A2 on	Negative
negative	A1 on	Positive
positive	A1 off	Positive

C. PV Array with GMPPT

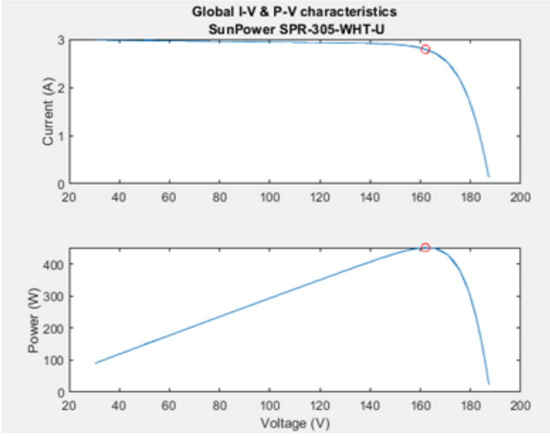
In this paper, the power generation of the PV Array is tracked by P&O GMPPT technique using DC-DC Boost converter. Both the voltage and current of PV array is measured and the signals are fed to the GMPPT algorithm, which in turn will generate duty ratio according to power and voltage variations. This duty ratio is compared with repeating sequence to generate PWM for IGBT switch of boost converter. So that maximum power is extracted from PV array.

PV Array used in this paper consist of 3 solar panels. When 3 panels receive same irradiation then only one peak will be there in P-V characteristic but due to weather and atmospheric condition 3 solar panels may receive different irradiations. Under this condition P-V curves has 3 peaks. Out of them one will be global peak which can be achieved using GMPPT P & O algorithm. The figures below show GMPPT point is achieved at various irradiance conditions received by PV array. GMPPT point is shown by red circle.

1.PV, IV characteristic curves for Uniform irradiation

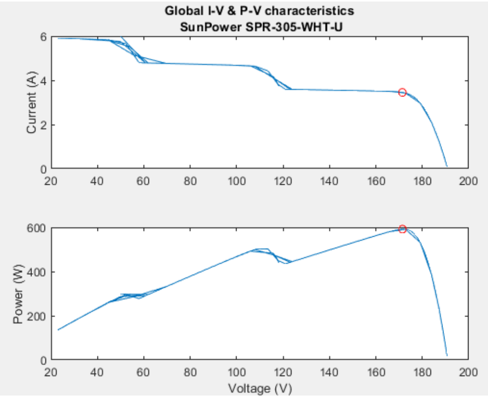


1000 W/m2

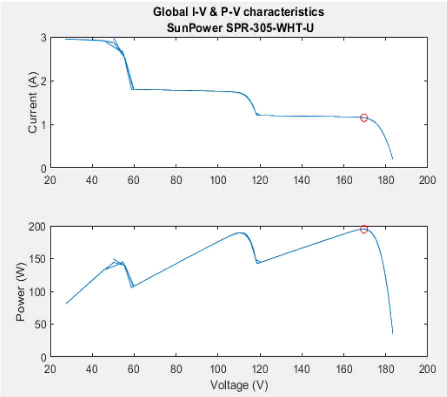


500 W/m2

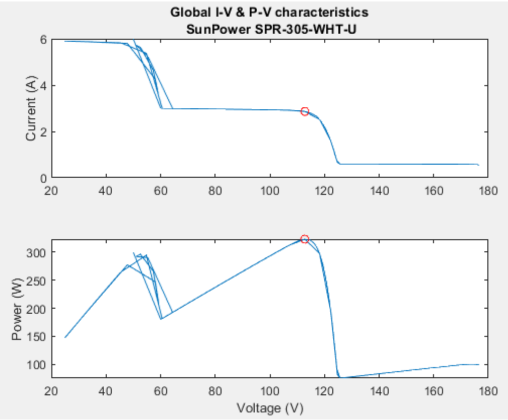
2.PV, IV characteristic curves for partial shading



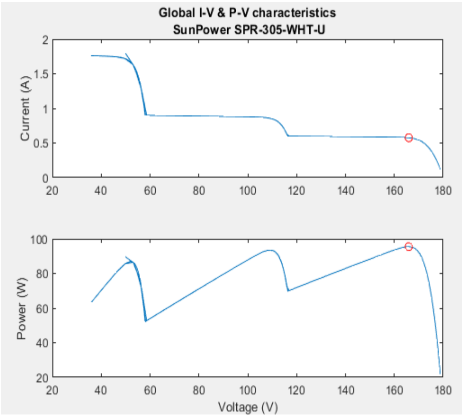
600 W/m2, 800 W/m2, 1000 W/m2



300 W/m2, 200 W/m2, 500 W/m2



100 W/m2, 1000 W/m2, 500 W/m2



300 W/m2, 150 W/m2, 100 W/m2

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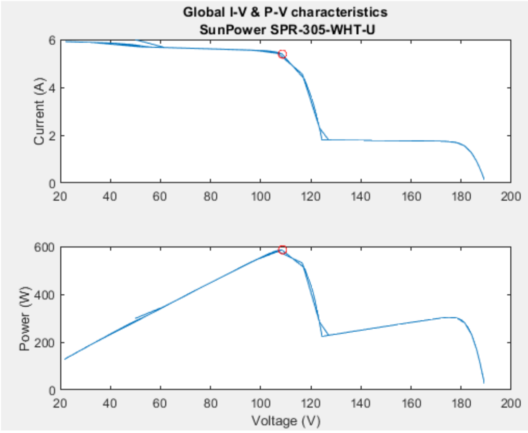
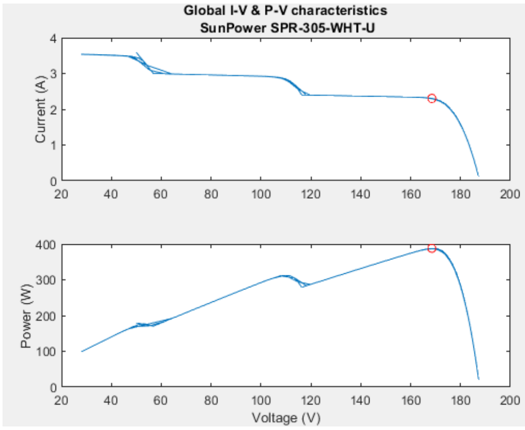


300 W/m2, 950 W/m2, 1000 W/m2



400 W/m2, 500 W/m2, 600 W/m2

D. PV Array with and without GMPPT

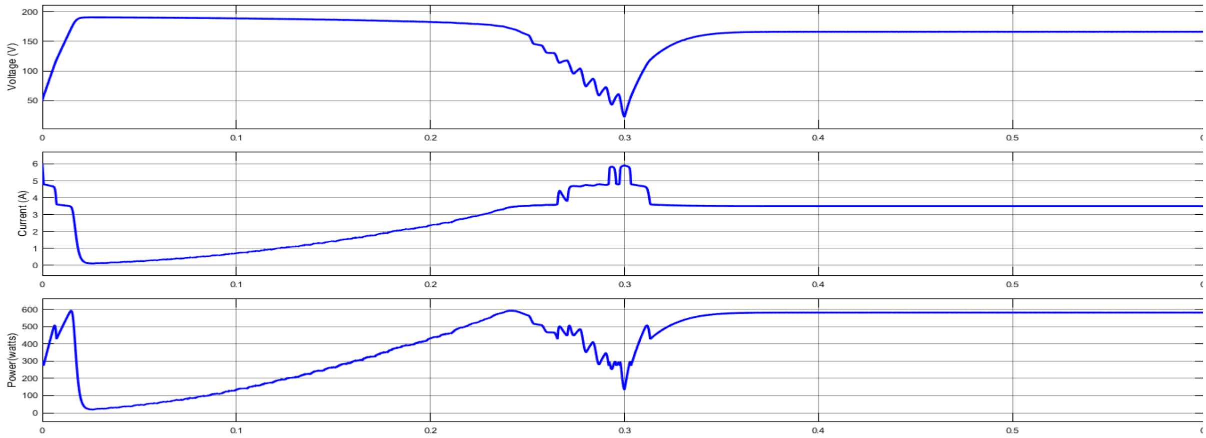


Fig. 6a. PV Array Voltage, Current, Power waveforms at partial shading condition with solar panel 1 ,2,3 receiving 1000,800,600 W/m2 irradiance respectively with GMPPT.

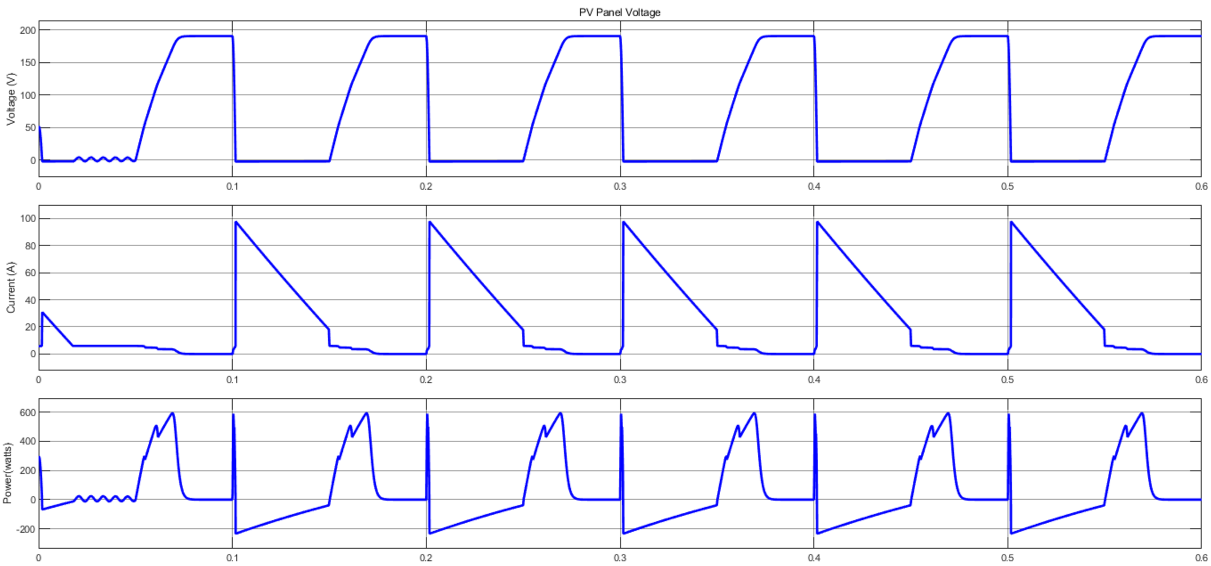


Fig. 6b shows PV Array Voltage, Current, Power waveforms at partial shading condition with solar panel 1 ,2,3 receiving 1000,800,600 W/m2 irradiance respectively without MPPT

Fig. 6a. shows PV Array Voltage, Current, Power waveforms at partial shading condition with solar panel 1 ,2,3 receiving 1000,800,600 W/m2 irradiance respectively with GMPPT. Maximum power extracted from PV array is

580 watts using GMPPT algorithm. Now MATLAB Simulation is run without considering GMPPT algorithm. Hence Pulse generator is used to give gate pulses to IGBT switch of boost converter instead of using PWM technique. In other words, duty ratio of switch is not controlled corresponding to GMPP. So as expected maximum power will not be extracted from PV array. Fig. 6b shows PV Array Voltage, Current, Power waveforms at partial shading condition with solar panel 1,2,3 receiving 1000,800,600 W/m2 irradiance respectively without MPPT. We can compare two figs 6a and 6b for power extracted from PV array. In fig 6a once GMPP is tracked PV array will deliver maximum power continuously for given irradiation condition wherein fig 6b without using MPPT algorithm maximum power equal to 580 watts for same given irradiations is not extracted continuously. It keeps on fluctuating. Hence this is advantage of GMPPT that it extracts maximum power from PV array which PV array is able to deliver under given irradiation independent of load. Efficiency of solar system increases by using GMPPT algorithm.

3.ANALYSIS OF SIMULATION RESULTS

MATLAB Simulation is run for 0.6 secs. Reactive power transfer is kept 0, so only pure active power flow is taking place between ac and dc side. For first 0.4 secs reference active power is 300 watts. It means that DC side is supplying grid so bidirectional AC-DC converter acts as inverter. Hence grid voltage and current waveforms are in phase with each other. For next 0.2 secs reference active power is -200 watts which means grid is supplying power to dc side so bidirectional AC-DC converter acts as rectifier. Hence grid voltage and current waveforms are 180 degree out of phase. Various waveforms are as follow.

Fig. 7 shows Active power transferring to grid Vs time, Fig. 8 Active Power generated by PV array Vs time, Fig. 9 Battery Power Vs time, Fig. 10 Battery current Vs time, Fig. 11 Battery Voltage Vs time, Fig. 12 State of charge of battery vs time, Fig. 13 Grid voltage and sending current Vs time. Total Harmonic Distortion (THD) for Utility grid is analyzed with the help of Fast Fourier Transform using MATLAB SIMULINK. The Fig.14 shows that total harmonic distortion in grid current is less than 5% is achieved.

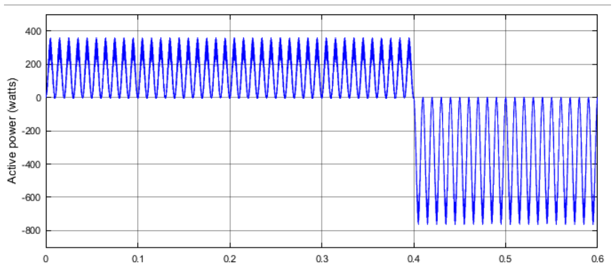


Fig. 7. Active power transferring to grid Vs time

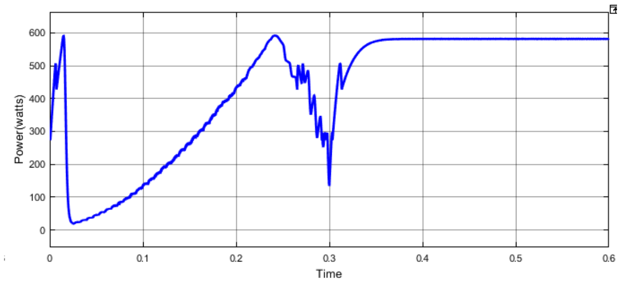


Fig. 8. Active Power generated by PV panels Vs time

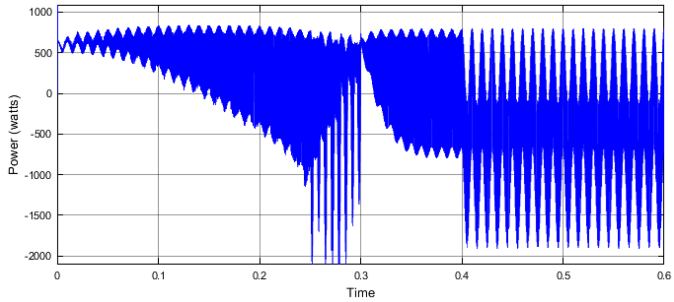


Fig. 9. Battery Power Vs time

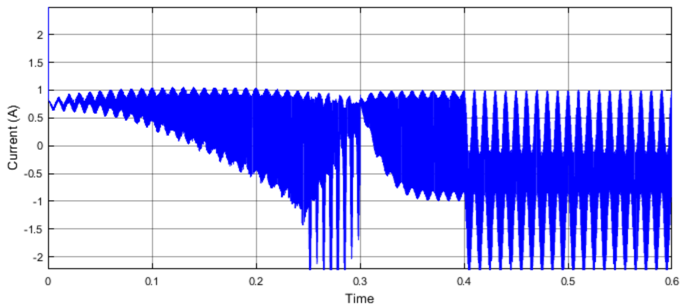


Fig. 10. Battery current Vs time

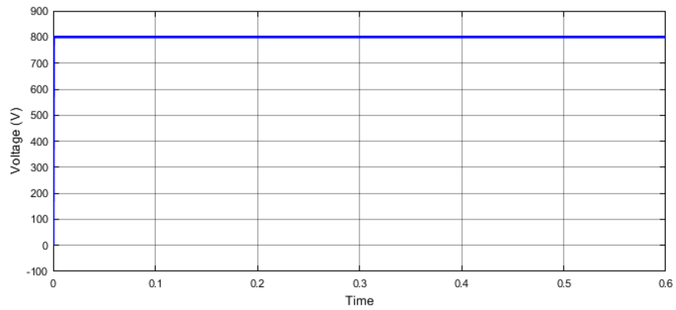


Fig. 11. Battery Voltage Vs time

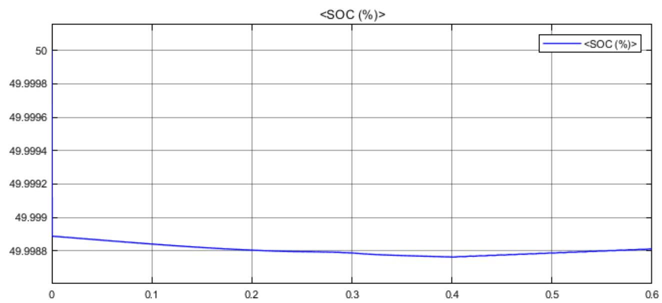


Fig. 12. State of charge of battery vs time

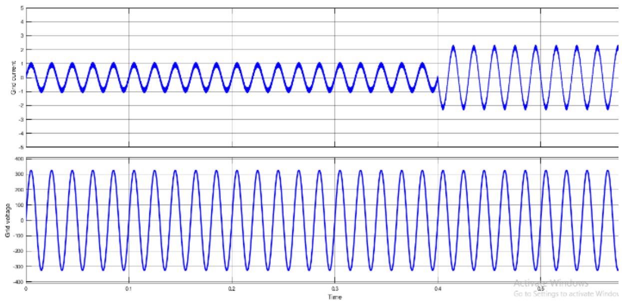


Fig. 13. Grid voltage and current Vs time

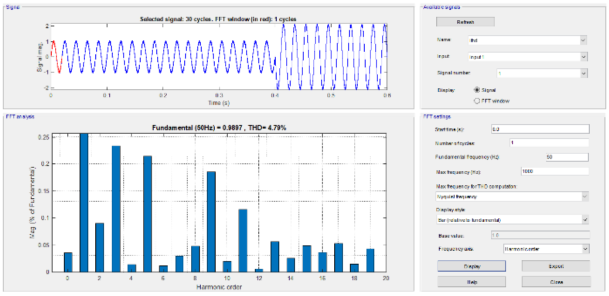


Fig. 14. THD in grid current

4. CONCLUSIONS

When the solar irradiance is uniform, the conventional P and 0 algorithm is able to track the maximum power for PV array. However, under PSC the PV array has multiple MPP in its P-V characteristic. The conventional P and 0 algorithm will cause PV system to operate at the local MPP instead of global MPP. Modified P and 0 algorithm is used to overcome the problems of conventional P and 0 algorithm. From results we can conclude that the GMPPT works very well even during partial shading effects since it checks PV array voltage even when local MPP is found in search of global MPP. The proposed GMPPT is able to generate more power because of operation at absolute MPP even under the partial shading of certain PV modules. The result shows successful performance of proposed modified MPPT method and Global MPPT point is tracked for different solar irradiations. From results it is clear that the proposed ac-dc converter is able to transfer power in both directions. For future requirement a three-phase converter can be used by adding two-leg configuration and connecting the neutral points together.

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