An Improved MPPT algorithm for Performance Improvement of 50 kW Grid Connected PV System

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Received: 20.02.2025 Accepted:18.03.2025

Abstract- In a grid-connected system, highly non-linear P-V characteristics of solar system having a challenging issues like maximum power point tracking (MPPT). During change in weather condition, it becomes more complex to handle this issue. To keep the output voltage constant in P-V array is even more challenging when PV system is interconnected with grid utility. This paper presents the design and analysis of an improved MPPT control approach for three-phase PV grid-connected system. Here, a medium size 50 kW grid connected PV model is designed and simulated. A single diode model is used for investigation. A DC-DC converter is applied to operate and control above system with an improved MPPT algorithm which maintains the voltage at inverter side constant by controlling the duty ratio for extracting maximum power. The three phase Voltage Source Inverter (VSI) along with voltage and current controller is connected to AC Utility grid through step-up transformer and PLL synchronization. This system is implemented using MATLAB/Simulink® and performance characteristics have been plotted under different insolation conditions. Simulation result shows that the proposed algorithm achieves 96-98 % efficiency which is better than traditional techniques. Furthermore, the algorithm achieves 30% faster tracking speed and reduces steady-state oscillations to less than 1%.

Keywords: Grid, maximum power point tracking, photovoltaic, phase locked loop, voltage source inverter.

1. Introduction

Demand of power plays a vital role in daily life and energy demand is increasing continuously due to industrialization in India and secondly owing to change in lifestyle of people. Conventional like Thermal energy sources are reducing as the requirement is increases and supply decreases, as a result is in shortage of Power, scheduled a load shading in large areas. Due to this reason now a day government encouraging generation for alternative and sustainable energy resources. Additionally global climate change, the target of reducing carbon dioxide emission and carbon neutrality accelerated the use of non-conventional energy sources referred to as the green square [1]-[3]. This has motivated the speedy development of solar energy with grid-connection photovoltaic (PV) in India [4]-[6].

The utilization of emerging energy resources, particularly wind and solar photovoltaic (PV) systems, is strongly advocated in the country like India where solar energy is available in ample quantity throughout year and also considering the technical constraints, the solar energy is becoming important alternative solution for future energy crises. [7]- [9]. The main advantages of PV system are like there are no moving parts, air pollution, noise-pollution and Electrical performance is controlled as per the consumer requirement [10]. The primary limitation of solar power generation is its reliance on daylight hours. However, PV-generated power systems can be interconnected with the grid utility, as illustrated in Figure 1. The system is designed with the aim that the PV array injects maximum power in the grid which can be controlled by DC-DC converter. The battery storage is also connected for maintenance and testing of the system in emergency. The grid interconnection is accomplished through the 3-phase-3-level voltage source

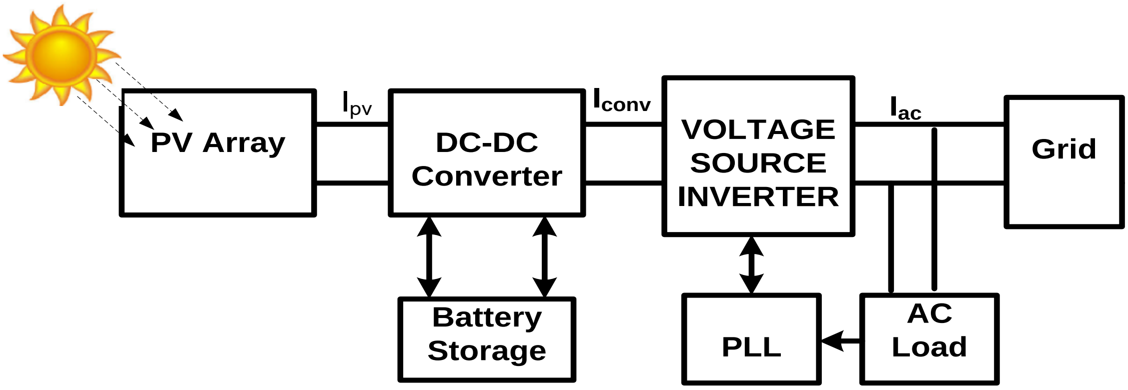

Fig. 1. Basic Block diagram of a Photovoltaic System connected to grid.

Inverter (VSI) and PLL. The voltage and current controllers are tuned to control gating pulses of Inverter for synchronization.

In this paper, an enhanced MPPT with novel inverter control strategy is proposed. This strategy will ensure maximum power output by continuously controlling voltage and current. It also results in improvement of power quality and stability without increasing the hardware cost. Figure1. Basic Block diagram of a Photovoltaic System connected to grid.

This paper is arranged in the following manner: in Section II the design specification of boost converter is discussed. In section III proposed scheme of novel control strategy for MPPT using feedback loop and MPPT algorithm implementation for tuning PI controller parameters. The VSI inverter specification along with controller for PLL synchronization is also considered in proposed system. The section IV deals with simulation of proposed grid connected 50 kW PV system for improved MPPT operation. Discussion about simulation results, at varying insolation conditions and temperature in section V. Finally, the performance of the proposed approach is concluded in section VI.

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2. Modelling and Design of PV Array

A PV power system, generally array is formed by connecting a combination of series parallel configuration of solar modules. This array is connected to dc load or battery through a dc-dc boost converter. Controlling of the load or charging of the battery is one of the challenging tasks in real time. The Boost converter arrangement is presented in Fig. 2 implemented in paper for simulation and testing. This converter (dc-dc) is connected with inverter to grid system. Current control mode is used during grid connected mode whereas during disconnection of the grid, voltage control mode is used. For the synchronization, PLL unit is required [11]-[13].

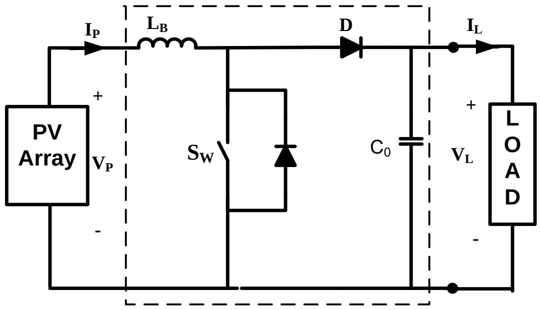

Fig. 2. Circuit diagram of boost converter for effective load matching.

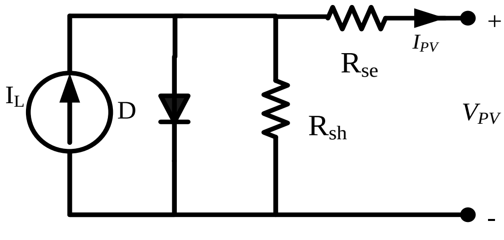

Fig. 3. A single diode model of a PV module.

From the literature survey [14]-[16], it has been observed that the performance of grid connected PV system mainly depends on the various parameters and conditions like temperature, insolation, partial shading conditions etc. By using the DC-DC converters, shifting of operating point of MPPT is possible. Working on the same concept, this paper proposed an improved design and controlling of converter for power extraction at its maximum level from PV system under different insolation conditions connected to grid utility [17].

Figure 3 shows the single diode PV model. It consists of current source connected parallel with diode and shunt resistance and series resistance.[18],[19] Under standard temperature and insolation, the I-V & P-V curves of the PV panel for varying loads are non-linear, the detail results are discussed in the sections IV. Here, PV module of capacity 305.2 W operating at 1000 W/m^2 insolation level at 25ºC is considered under different insolation and load conditions.

The mathematical model of the above PV system for generation of current can be expressed as follows,

$$I_{pv} = \left(\frac{S}{1000}\right) * I_L - I_0\left(e^{\frac{V_{pv}+IR_{se}}{u}} - 1\right) - \frac{V_{pv} + I_{pv}R_{se}}{R_{sh}}$$

$$u = \frac{n_s v KT}{q} \quad (1)$$

where, the symbols have their standard meaning [15-16].

Further work in this paper is done using a SPR-305E-WHT-D module. Manufacturer specifications are shown in Table 1.

Table 1. SPR-305E-WHT-D module specifications

S.L.	Standard Characteristics Specification of Electrical System	Values
1	No of cells in each module	96
2	Power (Max)	305.2 W
3	Voltage at MPPT	54.7 V
4	Current at MPPT	5.58 A
5	Current at short circuit condition	5.96 A
6	Voltage at open circuit	64.2 V

Table 2. Design parameters of boost converter

S.L.	Boost converter specification	Symbol	Values
1	Input voltage	V_i	273 V
2	Output voltage	V_o	500 [V]
3	Switching frequency	f_S	5 [kHz]
4	Boost inductor	L	5 [m H]
5	Output capacitor	C_0	1000 [µ F]
6	Input rating of capacitor	C_i	50 [µ F]
7	Power rating	P	50 kW

In this paper for the simulation, (5×33) PV array (50 kW) is created by making a series and parallel arrangement of strings of PV panel as specified in table 1. The open circuit array voltage is 321 V and short circuit current is 196.68 A.

The detail design and calculation series and parallel resistances is discussed in [4], [8], [20]. Under standard operating condition, the I-V and P-V characteristics of (5×33) PV array are plotted as shown in Fig. 8 at 25˚ C and 100% insolation.

A DC-DC converter is used for MPPT and voltage regulation for grid connection. The types of topologies of DC –DC converters are Boost, Buck, and combination of buck-boost. In this paper the first Boost topology is used as shown in Figure 3 as required in the grid connected system to boost the DC voltage upto a certain level. The mathematical model based on state space average method which is discussed in [21] is applied for calculation of PWM converter.

3. Proposed PV Grid Connected System

Figure 4 shows the proposed PV system connected to grid utility using improved MPPT technique. This figure represents the control system block diagram of a full-bridge inverter with bidirectional power flow. In order to maintain the constant DC voltage in the DC bus, a voltage feedback control loop is introduced in this proposed system. During start up and cloudy conditions, this proposed system ensures constant voltage delivery at the output terminals. The boost converter is used for shifting the operating point of PV curve at peak point. The maximum peak power point is continuously obtained by applying P&O algorithm [22]-[24]. Figure 5 shows flowchart of improved MPPT technique for execution with adaptive steps of P&O algorithm which improves the voltage quality at the output terminals during various climate conditions. Traditional P&O methods suffer from fixed-step perturbations, causing oscillations around the MPP, particularly under dynamic atmospheric conditions. The improved method adjusts the perturbation step size dynamically based on the error voltage. The program is started by initializing a reference voltage (V_{ref}) 85 % of open circuit voltage of an array. This technique is called as fractional open circuit voltage technique, in which the array voltage is adjusted at 85 % of its OC voltage of PV module as a reference.

$V(n)$=85 % of V_{OC}

By giving small perturbation and controlling the reference voltage, PI controller generates the duty ratio of dc-dc converter and it is used to adjust and control the voltage and hence power output of PV array to maintain the operating point at MPPT. Whenever there is any disturbance in atmospheric condition, it is observed that due to fixed step of Perturbation, the working point is oscillating in both directions due to which it can't be stabilized on the maximum power point. Errors occurred many times for selection of the point in conventional P&O Method. [25]-[27].

Improved P&O algorithm adjusted the reference voltage and error voltage send to PI controller and hence shifts the operating point to corresponding peak point as shown in the Fig. 6. By using the fraction open circuit voltage as a reference, the response speed improved with PI controller and PWM signal adjusted and hence the output of the boost converter controlled. Now the output of boost converter is fed to 3-phase 3-level VSI [28-29]. The voltage controller adjusts the modulation index of VSI for PLL synchronization with grid [30-32].

A fractional open circuit voltage taken as set value at the starting. After which it reads the voltage and power at that instant and depending on the condition the decision taken. The response speed will be improved once the reference voltage set to its peak point.

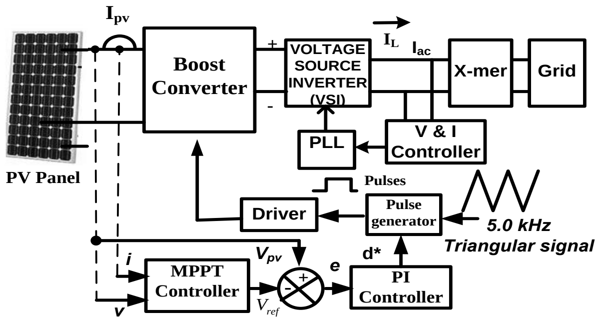

Fig. 4. Proposed PV –Grid connected system using Improved MPPT.

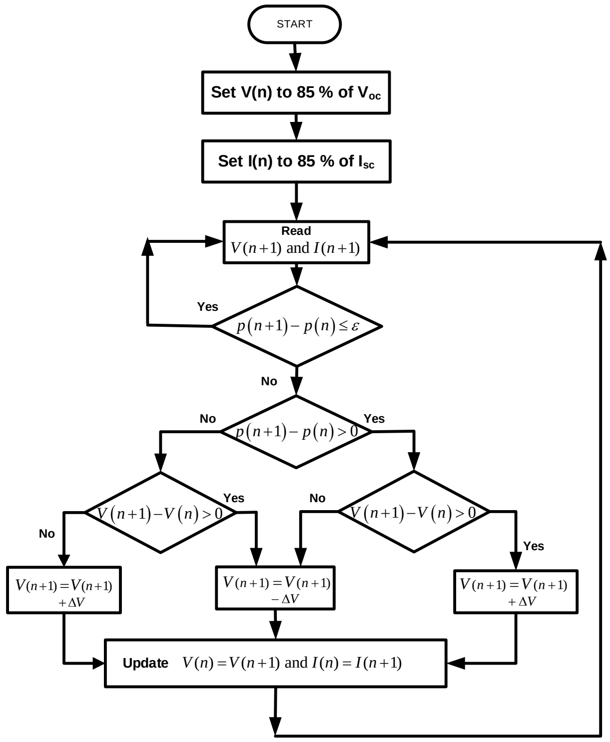

Fig. 5. Flow chart for Improved MPPT process of a 50 kW PV array.

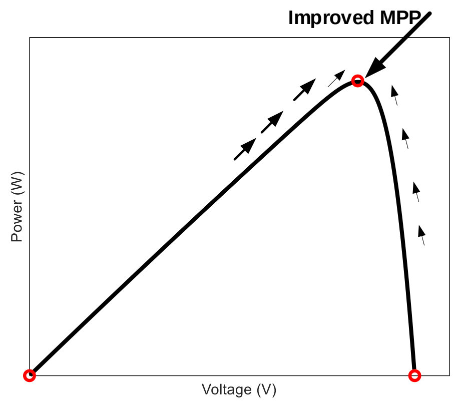

Fig. 6. Shifting of operating point to corresponding peak point.

The decision-making block will help to select the point of the maximum power. Once the fractional technique implemented at the starting after which the P&O method will be implemented as shown in the chart.

4. Simulation Analysis of the Proposed PV System

The verification of the performance analysis of the proposed system is carried out by using MATLAB software. It contains the PV generating system along with boost converter, controller, VSI, transformer connected to utility grid. The boost converter parameters used for simulation is shown in Table 2. The switching frequency used for boost converter is 5 kHz.

The I-V and P-V characteristics of the PV system are illustrated in Fig. 7 under standard test conditions (STC), revealing its nonlinear behaviour. Modelling and parameter identification for PV systems have been extensively discussed by various researchers, serving as references for simulations. In Figure 7 the I-V and PV characteristic are shown by changing the temp of 100 to 500. The ideal temp condition for the panel is 250˚ C. for the curve solar irradiation unchanged.

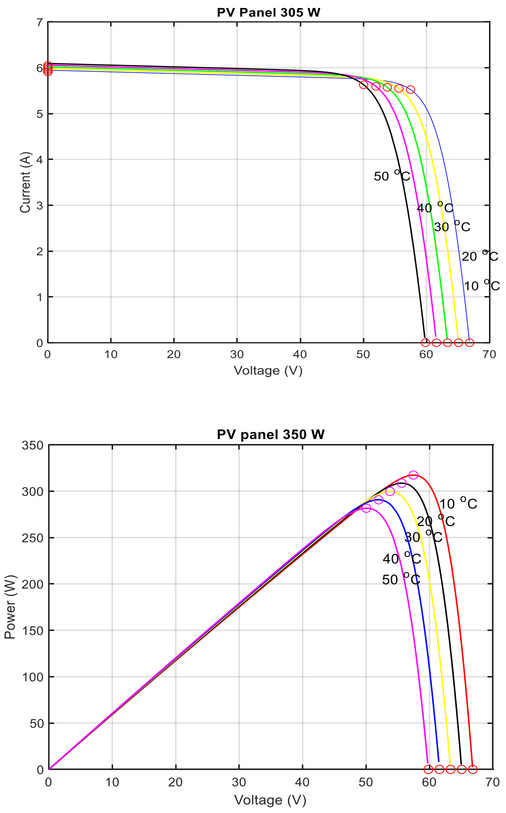

Fig. 7. I-V &P-V characteristics of 305 W PV array plotted under three different temperature (0º, 25º, 50º) conditions.

It is observed that for constant short circuit current the open-circuit voltage decreases when the temperature increases. The output power of PV array decreases with the increase of temperature and try to reaches the maximum at a certain point finally. For this simulation the VSI is connected to 500 V DC link voltage to 260 V. AC and maintains the power factor close to unity. Figure 8 V-I &P-V characteristics of a 305 W PV module plotted under insolation varying from 0.2 kW/m^2 to 1 kW/m^2 by keeping the temperature constant.

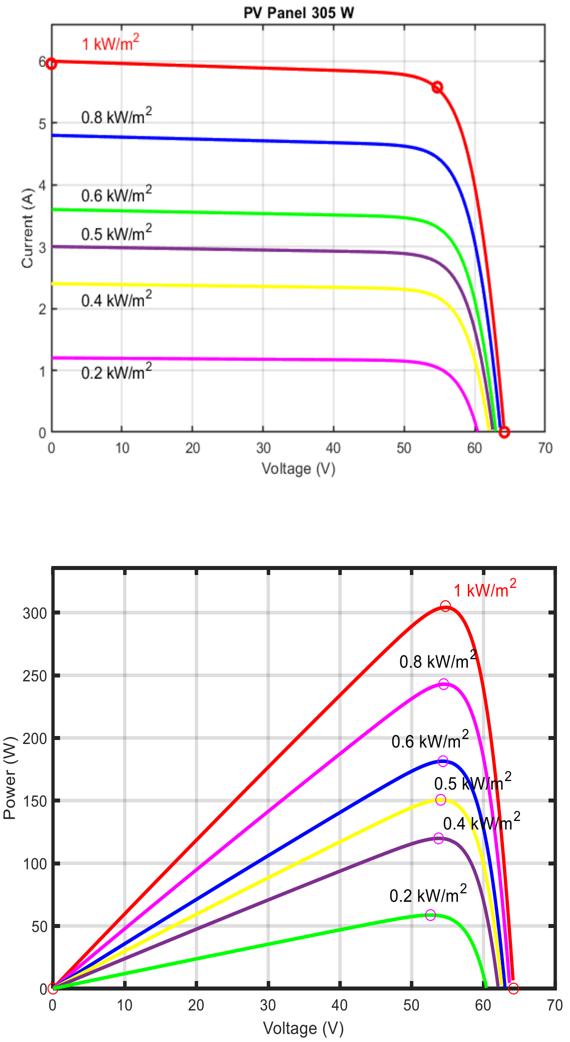

Fig. 8. I-V &P-V characteristics of a 305 W PV module plotted under insolation varying from 0.2 kW/m^2 to 1 kW/m^2

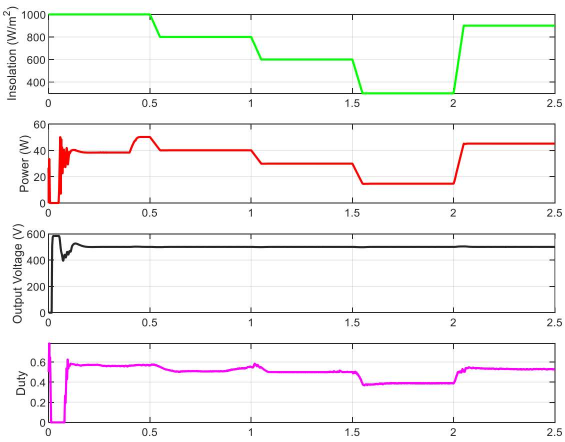

Fig. 9. Results of improved PV system for MPPT operation for transient response of different insolation and temperature

Table 3. Comparison of proposed MPPT with traditional methods

Parameters/Algorithm	**P&O MPPT *[22]-[24]***	**Incremental Conductance MPPT *[5], [6], [22]***	**Proposed Improved MPPT**
Tracking Speed (ms)	40–60 ms	30–50 ms	**20–35 ms (~30% faster)**
Steady-State Oscillations (%)	**2-5% fluctuation** *[5]*	**1-3% fluctuation** *Ref. [22]*	**≤1% fluctuation (Minimal oscillations)**
Efficiency (%)	90-93% *[5], [6]*	93-95% *[22], [6]*	**96-98% (Higher extraction efficiency)**
Response to Irradiance Variations	Moderate (fixed step) *[22]*	Fast (adaptive step) *[6], [22]*	**Very fast (adaptive & predictive)**
Convergence to MPP	May settle near local maxima *[5]*	More accurate, but slower *[6], [22]*	**Fastest & most accurate MPP tracking**
Harmonic Distortion (THD) in Grid	**~3-5%** *[22], [6]*	**2-3%** *[6]*	**≤2%** *(Improved inverter control in this work)*

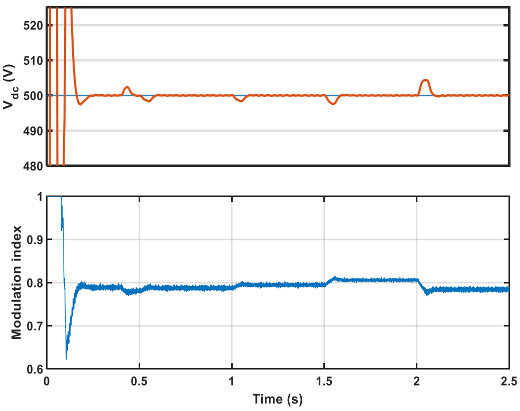

Fig. 10. Results of controlled reference voltages and modulation index waveform for a 3-level VSI.

5. Results and Discussion

Figure 7 has shown the characteristics of 50 kW (5×33) PV array at three different temperature conditions with constant insolation of 1 kW/m^2 operation. These different conditions represent the system behaviour during intermittent climatic conditions such as moving clouds.

Figure 8 has shown the V-I and P-V characteristics of 305 W PV module plotted under insolation varying from 0.2 kW/m^2 to 1 k/ m^2 in 0.5-second intervals over 5 seconds, followed by a rapid decrease back to 0.2kW/m^2. The non-linear electrical characteristics of the PV module are as given by Eqn. 1. The PV array is subjected to varying insolation from 100 % to 25 % and the controller performance is observed as shown in Figure 9 & Figure 10.

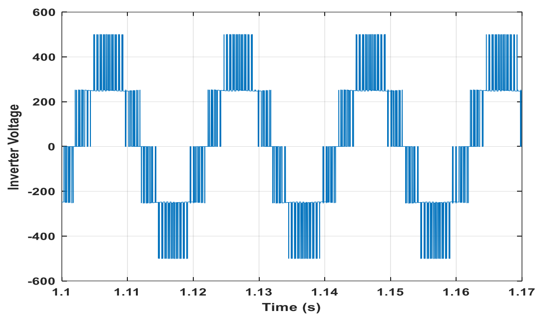

Fig. 11. Simulation results showing output voltage waveform of a 3-level VSI.

The Power curve indicates the power drawn from the PV array is always maximum irrespective of change in atmospheric conditions. The improved MPPT algorithm along with perturbation and observation method is used to generate reference voltage which corresponds to maximum power is feed to PI controller. The PI controller output is compared with 5 kHz triangular pulses to generate gate pulse which is feed to dc-dc boost converter to shift operating point to peak power point which is a stable operating point. Hence the overall efficiency of PV system is improved. For synchronization of three phase inverter voltage with grid, the voltage and current controller outputs are used to generate the three modulating signals for the PWM generator which is connected with three phase 3-level voltage source inverter along with PLL. Figure10 shows the variation of modulation index with variation of input voltage to inverter with respect to reference voltage. The three-level output of voltage source inverter is shown in Figure 11 which is constant for any atmospheric change. To get synchronized pulses for switching of VSI, the sensors of pulse generator, voltage and current controller are properly tuned. Table 3 summarizes comparison analysis of the proposed MPPT technique with traditional MPPT techniques. Various performance parameters such as tracking speed, steady state oscillations, output efficiency of the solar panel, response to variation in solar irradiance, convergence of maximum power point and harmonic distortion in grid during interference was focused during the analysis. Table 3 clearly shows the advancement of the proposed MPPT technique over the traditional MPPT techniques.

6. Conclusion

This paper has analyzed the (5×33), 50 kW PV generating system connected to utility grid. A 3-phase 3-level bridge voltage source inverter with the PLL unit is used for the synchronization of inverter output with the grid utility. A Simulink model is implemented to obtain the characteristics of a PV array like (P–V and I–V), with series-and/or parallel-connected panels, under different insolation conditions.

The PV characteristics show highly non-linear behaviour under different load conditions. Therefore, it becomes very difficult for controller to operate at maximum power point. The position of peak is dependent on the factors like insolation level and temperature along with shading pattern groups formed. Improved MPPT algorithm has been proposed to keep the inverter voltage constant by achieving the maximum power. The algorithm proposed in this paper has been verified with the simulation and found that for different temperature as well as for different isolation level the inverter voltage is constant and it track the maximum power at that condition. The proposed MPPT technique improves upon the conventional Perturb and Observe (P&O) method by integrating the fractional open-circuit voltage method with an adaptive perturbation step and a PI controller. For keeping the voltage constant, the duty ratio in the circuit is controlled. The variation of the voltage observed with modulation index for further improvement of inverter voltage. Comparing the results with the conventional P&O algorithm shows that MPPT is tracked smoothly and accurately with the proposed algorithm. The proposed algorithm demonstrates improved results compared to traditional MPPT techniques while comparing various performance parameters such as tracking speed, oscillations, efficiency, robustness to irradiation change, and harmonic performance. The algorithm assumes a smooth and continuous PV curve, however, under extreme partial shading; multiple peaks can appear on the P-V curve. Tuning of the PI controller will be one of the challenges.

In future, the proposed technique can be improvised considering various modifications in the presented circuit.

•The PI controller can be implemented along with intelligent controllers such as FLC or Neural Network based controllers.

•Solar system may be integrated with variety of energy storage systems like batteries, super capacitors etc.

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