International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-9 Issue-2, December, 2019

Decoupled Control of Three Phase Grid Connected Solar PV System

Pradeep K. Khatua, Vigna K. Ramachandaramurthy, Jia Ying Yong, Jagadeesh Pasupuleti

Abstract: A reliable grid connected Photovoltaic (PV) system require effective control schemes for efficient use of solar energy. This paper presents a three-phase grid tied PV system with decoupled real and reactive power control to achieve desired power factor with Maximum Power Point Tracking (MPPT) controller to get maximum solar energy. The synchronous reference frame (dq) control along with decoupling concept is used to control the DC-AC inverter output, while the Phase Locked Loop (PLL) synchronization technique is used to monitor and synchronize the voltage and current at the grid side. The DC-DC converter with Incremental Conductance (InC) based MPPT model is also designed in this paper due to better accuracy compared to Perturb & Observe (P&O) algorithm. The simulation is performed in MATLAB/SIMULINK and a 31.5 kW PV system is modelled to get 30 kW power with the help of MPPT at Standard Test Conditions (STC). Any power factor value between 0.85 lagging to 0.9 leading can be obtained by changingreference q current in this inverter control strategy. The simulation results show that the change of reactive powerdoes not affecttheactive power values of the system, which verifies the effectiveness of the decoupled control strategy of the inverter.

Keywords: PV System; Decoupled Power Factor; InC Based MPPT; Boost Converter; Grid Synchronization.

I.INTRODUCTION

The exponential growth of PV technology has revealed its prospective to become a measure origin of renewable power source worldwide. Most of the PV systems are grid connected, which demands an effective power electronic interface between the grid and PV system. In grid connected PV system, the DC-DC converter and the inverter are crucial power electronic devices to be controlled to synchronize the grid voltage and frequency [1].Asolar PV system contains a PV panel, MPPT controller, DC-DC converter, inverter with low pass filter, and grid. The Boost converter is placed among the PV panel and the inverter to regulate and step-up the PV output voltage. Different MPPT algorithms are used to manage the gate pulses of Boost converter for extricating the peak power from PV source.

To select the best MPPT algorithm, different criteria such as system application, PV implementation technologies, output power efficiency, and cost factor are considered [2-4]. The InC and P&O algorithms are extensively used MPPT algorithms due to their simple circuitry. These algorithms also provide good performance due to their maximum value theory mechanisms [5]. At steady state, the main problem with P&O algorithm is the oscillations near the Maximum Power Point (MPP). The advantages of using InC algorithm are that fast tracking of MPP, better accuracy, and free from oscillation problem around MPP [5, 6]. In this paper, a PV array is modelled based on LG350Q1C PV model data sheet and an InC based MPPT controller is designed with DC-DC converter to get the maximized power.

The grid connected inverter can be connected to the grid through low pass filter to smoothen the inverter output. Synchronization block senses the voltage and current of the grid to synchronize the inverter with it. PLL is a well-known method for synchronization to get the phase angle of grid for generating reference signal of inverter [7]. To control the inverter output and to get the controlled power factor, dq axis control technique is typically used with Pulse Width Modulation (PWM) technology [8-11]. A control scheme is proposed in this system which can decouple active (P) and reactive (Q) power to achieve lagging, leading, and unity power factor.

Hence, this paper presents a grid connectd PV system and the control strategy of the inverter is based on decoupling of P and Q to achieve desired power factor. The InC based MPPT controller for DC-DC converter is designed in this paper. The rest of the paper is structured as: Section 2.0 describes the PV system. Implementation of PV system is described in Section 3.0 and all the control strategies related to the PV system are discussed in Section 4.0 with respective susections. The results and conclusion are discussed in Section 5.0 and 6.0 respectively.

II.SYSTEM DESCRIPTION

The modelled architecture of three-phase grid tied PV system is shown in Figure 1. The entire model can be considered as two segments i.e. direct current (DC) and alternate current (AC). The DC segment is composed of PV panel, MPPT controller, and Boost converter whereas AC segment is composed of inverter, transformer, load, grid, dq transformation, PLL, decoupling circuit, and PWM.

The gate signal of DC-DC converter is managed by MPPT to get maximum solar energy with respect to temperature and irradiance. The DC power from converter output is transformed to AC by inverter and the filter is used to eliminate high frequency switching noise and harmonics.

Revised Manuscript Received on December 30, 2019.
* Correspondence Author
Pradeep K. Khatua, Institute of Power Engineering, Department of Electrical Power Engineering, Universiti Tenaga Nasional, Jalan IKRAM-UNITEN, 43000 Kajang, Selangor, Malaysia.
Vigna K. Ramachandaramurthy, Institute of Power Engineering, Department of Electrical Power Engineering, Universiti Tenaga Nasional, Jalan IKRAM-UNITEN, 43000 Kajang, Selangor, Malaysia.
Jia Ying Yong, Institute of Power Engineering, Department of Electrical Power Engineering, Universiti Tenaga Nasional, Jalan IKRAM-UNITEN, 43000 Kajang, Selangor, Malaysia.
Jagadeesh Pasupuleti, Institute of Power Engineering, Department of Electrical Power Engineering, Universiti Tenaga Nasional, Jalan IKRAM-UNITEN, 43000 Kajang, Selangor, Malaysia

A step-up transformer is placed to maintain the voltage level same as grid voltage and to provide galvanic isolation.

The PLL used in this system will lock the phase and frequency to synchronize the inverter with grid and also provides the required angle for dq transformation. The rotating frame components (d and q) of grid variables are provided and compared with reference values in decoupling circuit to decouple P and Q. The switch in Figure 1 is used for switching purpose to get desired leading and lagging power factor. The output of decoupling circuit is transformed back to three phase (abc) components and they are passed through PWM to provide required pulses for inverter operation.

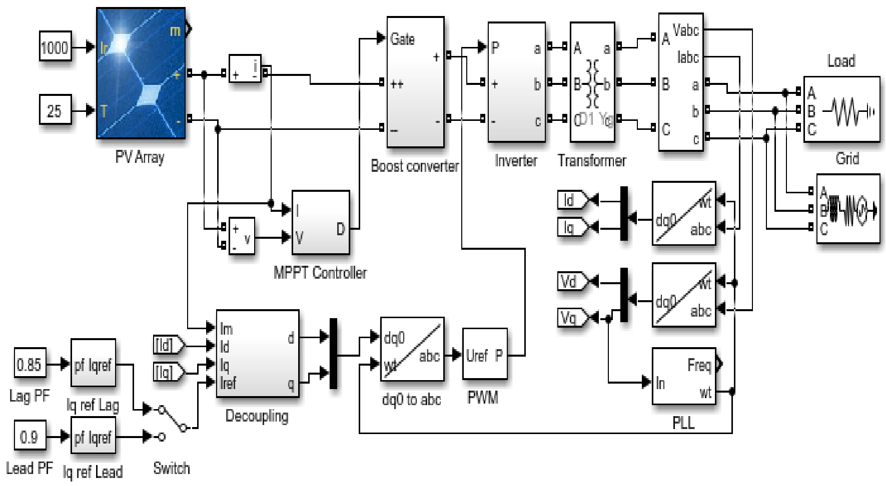

Fig. 1 Grid connected PV system with its control scheme

III.PVSYSTEM IMPLEMENTATION

3.1 PV Array

A PV panel is the series and parallel combination of PV modules and a PV module is a series connection of solar cells. In this system, the PV panel is mathematically modelled by using the equation [5, 6, 12]. The PV module generates 350 W and consists of 60 cells in series as per LG350Q1C specification. The variables at Standard Test Condition (STC) are presented in Table 1.

Table. 1 PV module variable specifications at Irradiance 1000W/m^2 and Temperature 25 °C

Variables	**Values**
Maximum Power (P_{mpp})	350 W
MPP Voltage (V_{mpp})	36.1 V
MPP Current (I_{mpp})	9.7 A
Open Circuit Voltage (V_{oc})	42.7 V
Short Circuit Current (I_{sc})	10.77 A

In this system, a 31.5 kW PV panel is implemented by combining six modules in series and 15 modules in parallel.

3.2 DC-DC Converter

To increase the low voltage from PV panel, a boost converter is designed. It contains an inductor (L), a diode, a capacitor (C), and a high frequency operated switch like IGBT/MOSFET. This switch is managed by the pulse signal output of MPPT controller. The selection of L and C values are crucial factor for continuous conduction mode operation of boost converter. In this system, L and C values are calculated using following equations [13]:

$$L = \frac{V_S \times D}{f_S \times \Delta I_L} \quad \textbf{(1)}$$

$$C = \frac{I_{o(max)} \times D}{f_S \times \Delta V_C} \quad \textbf{(2)}$$

where Vs is source voltage; D is duty ratio; fs is switching frequency; ΔI_L is inductor ripple current; $I_{o(max)}$ is maximum output current and ΔV_C is capacitor ripple voltage.

Three-Phase Inverter

The inverter is used to transform DC signal to AC signal. Typically, it consists of six high frequency switches along with a low pass filter. This system uses six MOSFETs and LC filter for three-phase AC conversion as presented in Figure 2. The MOSFETs are controlled by PWM signals. The L and C values of the filter are properly tuned which depends on the filter cut-off frequency to get smooth sinusoidal signals.

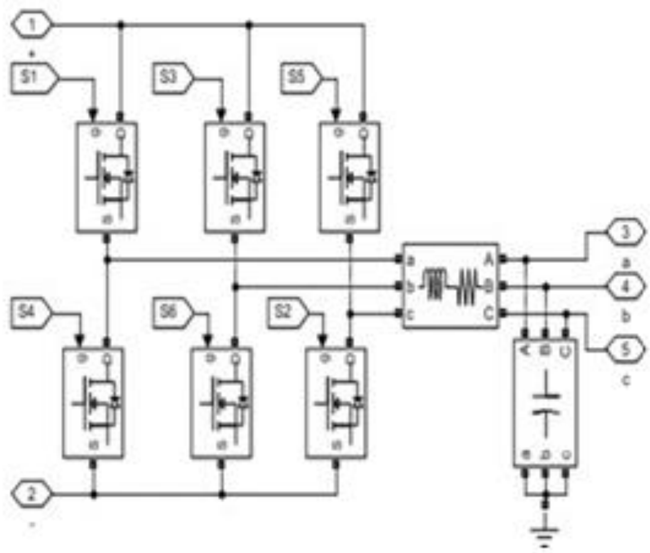

Fig. 2 Three-phase inverter with LC filter

Retrieval Number: B4933129219/2019©BEIESP
DOI: 10.35940/ijeat.B4933.129219
Journal Website: www.ijeat.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

IV.MODELLING OF CONTROL SCHEME

4.1 MPPT Controller

For getting maximum power at certain irradiance and temperature, InC based MPPT controller is designed. Figure 3 represents the flowchart of InC algorithm used in this PV system. The duty ratio (D) in the algorithm is combined with carrier triangular signal to produce pulse for the MOSFET of DC-DC converter to supply 30 kW PV power continuously at STC.

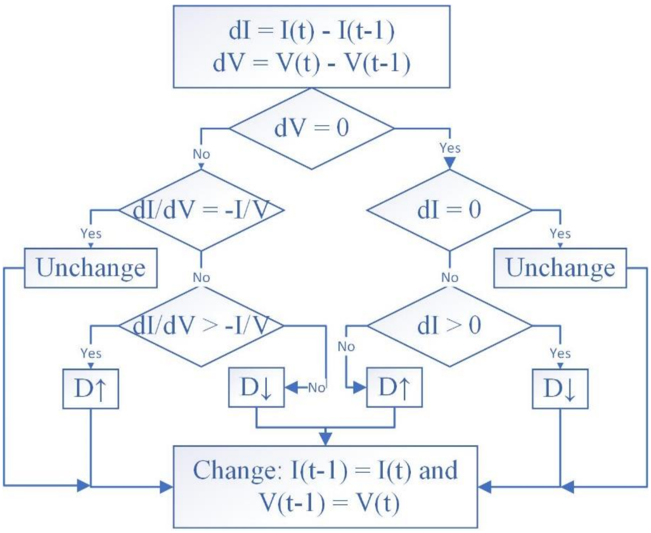

Fig. 3 InC algorithm flowchart

4.2 Grid Synchronization

Synchronization of grid is the first stage of inverter controller, which is implemented in two steps. At first step, the abc reference frame components are converted to rotating reference or direct-quadrature frame. This conversion also known as Park transformation is carried out as given in (3).

$$\begin{bmatrix} d \\ q \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \sin\theta & \sin\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) \\ \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \end{bmatrix}\begin{bmatrix} a \\ b \\ c \end{bmatrix} \textbf{(3)}$$

The second step of the grid synchronization is the PLL implementation, in which the angle (θ) required for above transformation is estimated. The diagram of PLL is presented in Figure 4.

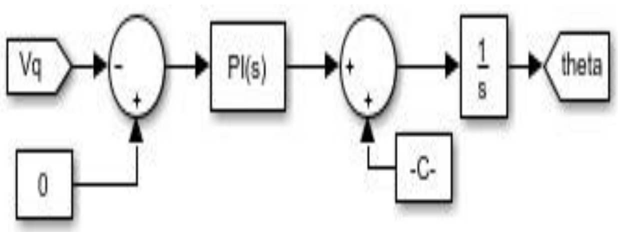

Fig. 4 PLL algorithm

The quadrature voltage is compared with zero to get the error signal and passed across a PI controller to generate angular frequency (ω). The ω is added with fundamental angular frequency (ω_f = 2π*50) and passed across an integrator to obtain instantaneous phase angle.

4.3 Decoupling of Active and Reactive Power

To decouple P and Q, the three-phase inverter to grid circuit is simplified to a one phase circuit as presented in Figure 5.

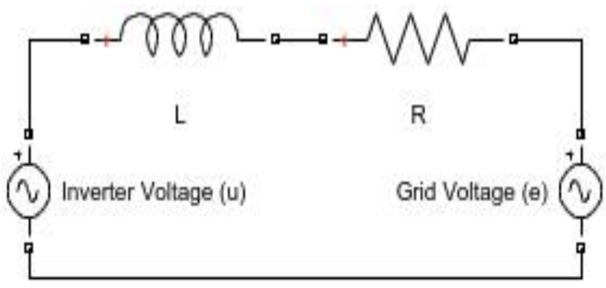

Fig. 5 Inverter to grid equivalent one phase circuit

In Figure 5, the inductance (L) is the combination of both filter and grid inductance, and R is the total resistance between inverter and grid. By applying Kirchhoff Voltage Law (KVL) in the above circuit,

$$L\frac{di}{dt} + Ri = \Delta V \textbf{(4)}$$

where ΔV = u-e and for three-phase circuit, i can be replaced by iabc and V can be replaced by V_{abc}. The equations obtained after transforming from abc to dq and differentiating i with respect to time are:

$$u_d = e_d + Ri_d + L\frac{di_d}{dt} - \omega L i_q \textbf{(5)}$$

$$u_q = e_q + Ri_q + L\frac{di_q}{dt} + \omega L i_d \textbf{(6)}$$

For controlling of P and Q independently, u_d should depend only on d components and u_q on q components only. The voltage drop due to the impedance between grid and inverter can be compensated by taking PI controller as shown in (7), (8).

$$u_d = e_d + \left(K_P + \frac{K_I}{s}\right)\left(I_{d,ref} - I_d\right) - \omega L i_q \textbf{(7)}$$

$$u_q = e_q + \left(K_P + \frac{K_I}{s}\right)\left(I_{q,ref} - I_q\right) + \omega L i_d \textbf{(8)}$$

The P and Q in synchronous reference frame are

$$P = \frac{3}{2}\left(u_d i_d + u_q i_q\right) \textbf{(9)}$$

$$Q = \frac{3}{2}\left(u_d i_q - u_q i_d\right) \textbf{(10)}$$

For decoupling of P and Q, the d-axis is aligned with voltage space vector by making u_q=0. Hence, P depends on id only whereas Q depends on iq only in this PV system.

V.SIMULATION RESULTS AND DISCUSSIONS

The simulation is performed in SIMULINK tool and the results are shown in Figure 6.1–6.6. The value of P is unchanged whereas Q value is changed to achieve the required power factor. The reference quadrature current is changed to obtain the simulation results.

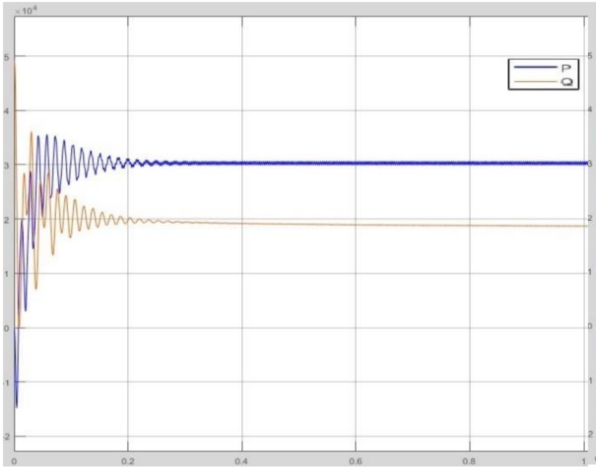

Fig. 6.1 0.85 Power factor (Lagging)

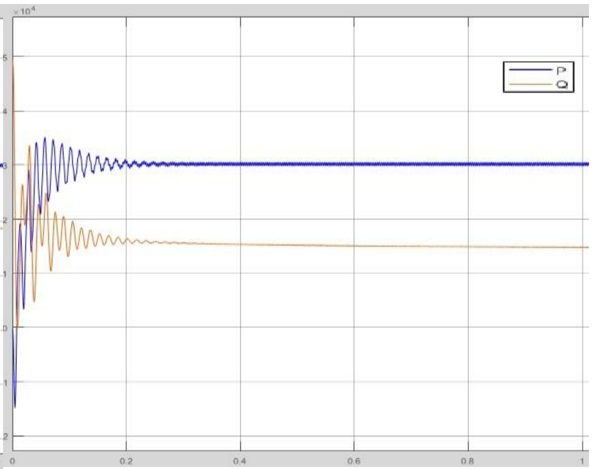

Fig. 6.2 0.9 Power factor (Lagging)

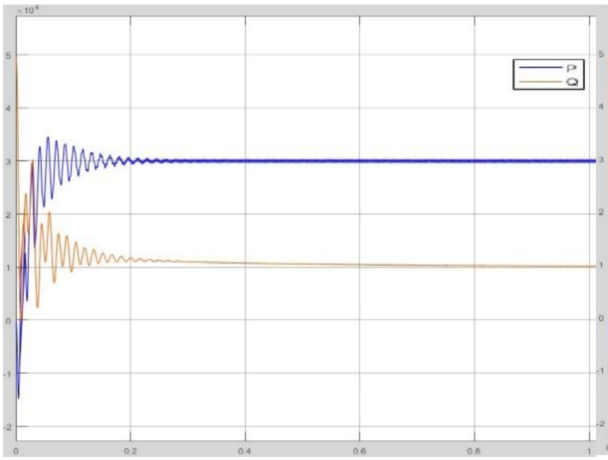

Fig. 6.3 0.95 Power factor (Lagging)

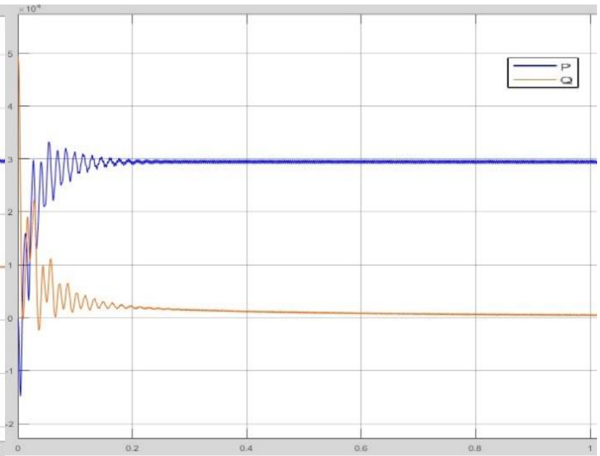

Fig. 6.4 Unity Power factor

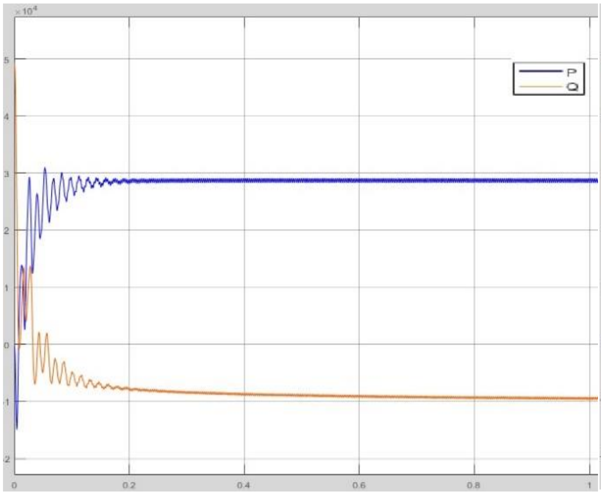

Fig. 6.5 0.95 Power factor (Leading)

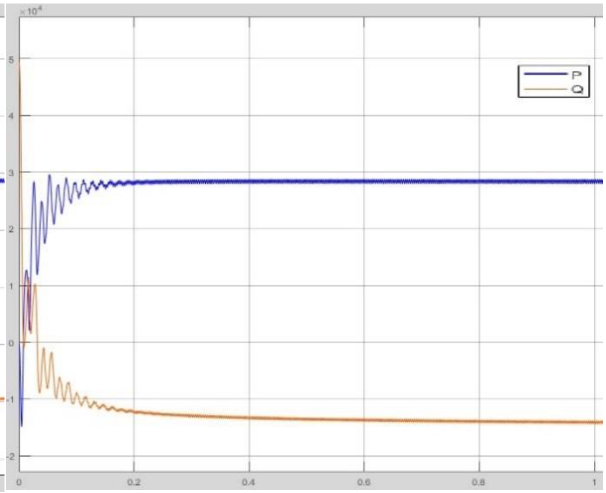

Fig. 6.6 0.9 Power factor (Leading)

The results in Figure 6.1 – 6.6 indicate that the simulated power P and Q follow the reference values. The P value is kept constant as 30 kW by maintaining the reference d current of the system. The reference q current is changed to adjust the value of Q in this system for different required power factor. The unity power factor is obtained by setting Q = 0, whereas the lagging and leading power factor are obtained by maintaining positive and negative values of Q. Initially, the reference q current is fixed to get the positive value of Q for lagging power factor. Then, reference q current is changed to achieve unity and leading power factor. From the results, it is remarked that the change in Q has no effect on the P value, which validates the decoupled control strategy of the system.

For different values of power factor, the simulated Q values are approximately similar to the theoretical values presented in Table. 2.

Retrieval Number: B4933129219/2019©BEIESP
DOI: 10.35940/ijeat.B4933.129219
Journal Website: www.ijeat.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

The negligible difference between the theoretical and simulated values of reactive power is due to harmonics present in the inverter and other components of the PV system.

Table. 2 Theoretical and simulated values of Q for certain power factor

Power Factor	Q(theoretical) (kVAR)	Q(simulation) (kVAR)
0.85 (Lagging)	18.6	18.7
0.9 (Lagging)	14.5	14.5
0.95 (Lagging)	9.9	10
1	0	0.5
0.95 (Leading)	-9.9	-10.1
0.9 (Leading)	-14.5	-14.3

VI.CONCLUSION

A grid tied PV system with a decoupled real and reactive power control strategy is successfully implemented to achieve desired power factor. This system is equipped with a 31.5 kW PV panel to generate 30 kW power with the assistance of InC based MPPT controller. The low voltage grid is synchronized by PLL and the rotating frame variables of grid are compared with the reference variables in decoupling circuit. The reference d current is kept constant in this system to fix 30 kW active power and the reference q current is adjusted to change the reactive power according to the required power factor. The results show that the proposed control works effectively for different scenarios of power factor from 0.85 lagging to 0.9 leading.

ACKNOWLEDGMENTS

This research is funded by the Universiti Tenaga Nasional Internal Grant (UNIIG 2018) – J510050850.

REFERENCES

1. A. H. M. Nordin, A. M. Omar and H. Zainuddin, "Modelling and Simulation of Grid Inverter in Grid-Connected Photovoltaic System",International Journal of Renewable Energy Research, vol. 4, no. 4, pp. 949-957, 2014.
2. K. Padmanathan, U. Govindarajan, V. K. Ramachandaramurthy, S. O. T. Selvi and B. Jeevarathinam, "Integrating solar photovoltaic energy conversion systems into industrial and commercial electrical energy utilization-A survey",Journal of Industrial Information Integration, vol. 10, pp. 39-54, 2018.
3. T. Esram and P. L. Chapman, "Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques",IEEE Transactions on Energy Conversion,vol. 22, no. 2, pp. 439-449, 2007.
4. N. Karami, N. Moubayed and R. Outbib, "General review and classification of different MPPT Techniques",Renewable and Sustainable Energy Reviews, vol. 68, no. 1, pp. 1-18, 2017.
5. H. Islam, S. Mekhilef, N. B. M. Shah, T. K. Soon, M. Seyedmahmousian, B. Horan and A. Stojcevski, "Performance Evaluation of Maximum Power Point Tracking Approaches and Photovoltaic Systems",Energies, vol. 11, no. 2, pp. 1-24, 2018.
6. S. S. Mohammed and D. Devaraj, "Simulation of Incremental Conductance MPPT based Two phase Interleaved Boost Converter using MATLAB/Simulink"IEEE International Conference on Electrical, Computer and Communication Technologies, Coimbatore, India, 2015, doi: 10.1109/ICECCT.2015.7225987.
7. X. Q. Guo, W. Y. Wu and H. R. Gu, "Phase locked loop and synchronization methods for grid interfaced converters: a review",PrzeglądElektrotechniczny (Electrical Review), vol. 87, no. 4, pp. 182-187, 2011.
8. P. A. Pattanaik, N. K. Pilli and S. K. Singh, "Design, Simulation & Performance Evaluation of three phase grid connected PV panel", IEEE Power, Communication and Information Technology Conference, Bhubaneswar, India, 2015, doi: 10.1109/PCITC.2015.7438159.
9. A. Naderipour, Z. A. Malek, H. N. Afrouzi, V. K. Ramachandaramurthy and J. M. Guerrero, "A Novel Compensation Current Control Method for Grid-Connected PV Inverter to Improve Power Quality in Micro-Grid", IEEE PES Asia-Pacific Power and Energy Engineering Conference, Kota Kinabalu, Malaysia, 2018, pp. 143-148.
10. A. Rizqiawan, P. Hadi and G. Fujita, "Development of Grid-Connected Inverter Experiment Modules for MicrogridLearning",Energies, vol. 12, no. 3, pp. 1-16, 2019.
11. L. Hassaine, E. Olias, J. Quintero and V. Salas, "Overview of power inverter topologies and control structures for grid connected photovoltaic systems",Renewable and Sustainable Energy Reviews,vol. 30, pp. 796-807, 2014.
12. H. J. El-Khozondar, R. J. El-Khozondar and K. Matter, "Parameters influence on MPP value of the photo voltaic cell",EnergyProcedia, vol. 74, pp. 1142-1149, 2015.
13. A. Hauke, "Basic Calculation of a Boost Converter's Power Stage",Texas Instruments Application Report -SLVA372C, 2014.

AUTHORS PROFILE

Pradeep K. Khatua, Institute of Power Engineering, Department of Electrical Power Engineering, Universiti Tenaga Nasional, Jalan IKRAM-UNITEN, 43000 Kajang, Selangor, Malaysia.

Vigna K. Ramachandaramurthy, Institute of Power Engineering, Department of Electrical Power Engineering, Universiti Tenaga Nasional, Jalan IKRAM-UNITEN, 43000 Kajang, Selangor, Malaysia.

Jia Ying Yong, Institute of Power Engineering, Department of Electrical Power Engineering, Universiti Tenaga Nasional, Jalan IKRAM-UNITEN, 43000 Kajang, Selangor, Malaysia.

Jagadeesh Pasupuleti, Institute of Power Engineering, Department of Electrical Power Engineering, Universiti Tenaga Nasional, Jalan IKRAM-UNITEN, 43000 Kajang, Selangor, Malaysia