Solar PV Interfaced with VSC and Single-Phase Grid with Battery Support

Vaishali Choudhary[1], Prof. CS Sharma[2], Dr. Pradyumn Chaturvedi[3]
[1, 2, 3] Dept of Electrical Engineering
[1, 2, 3] Samrat Asshok Technological Institute, Vidisha, India

Abstract- *In This paper we present an integration of solar photovoltaic system with battery support to a single-phase grid. The proposed system maintains a constant load current irrespective of worst environmental conditions such as change in irradiation level and sudden disconnection of solar photovoltaic system. The maximum power extracted from the solar PV array through perturbs and observe method is fed to the grid and the load. Boost converter with closed loop operation is used to boost the PV voltage. The system also demonstrates the battery dynamics during solar insolation, thus leveling the PV power fluctuations. Adaptive filtering method with LMS approach is used to extract fundamental value of load current for non-linear loads. The control designed for each converter is simple and easy to implement. The proposed system is designed for power of approximate 4.5 kW and is connected to a nonlinear diode bridge rectifier load of 350W. The experimental results of the proposed system and control are presented in MATLAB/Simulink*

Keywords- MPPT, Solar PV, Adaptive filtering, Boost converter.

I. INTRODUCTION

Now a days solar energy is the trend in the market of renewable energy sources. Several countries tried to increase their market share in the field of renewable energy. In 2017, photovoltaic capacity increased by 95 GW, with a 29% growth year-on-year of new installation. Cumulative installed capacity exceeded 401 GW by the top of the year, sufficient to produce 2.1 percent of the world's total electricity consumption. According to the research as of 2018, Asia was the fastest growing region, with almost 75% of worldwide installation. Among all renewable resources, solar energy is the fast--growing technology because of its unique features such as availability of sun on earth surface, ease of installation, ease of maintenance, no moving parts, negligible pollution level etc.

The only and main drawback of PV system is the unpredictability of power due to atmospheric condition such as monsoon and cloudy days. To overcome this problem MPPT algorithms have been devised. A Maximum point Tracking algorithm is important to extend the efficiency of the solar array. The comparison of various MPPT algorithms is given in [1] and [2], which depicts the advantage and disadvantages of each algorithm in terms of sensed parameters, calculation speed, accuracy, and complexity. Perturb and observe and incremental conductance are two main methods that require least calculation and pose least complexity at the cost of reduced accuracy. The effects of partial shading effect are another point of research in which research work is being carried out [3]– [5].

A several literature work has been proposed to study the effect of partial shading and how to minimize this effect. The efficiency of the solar system depends on the efficiency of individual converters. Coordinated voltage control of solar PV array with maximum power point tracking (MPPT) and a battery storage is presented. [6] A single-phase single-stage multifunctional grid interfaced solar PV system that specialize in the consequences and removal of grid side abnormal conditions is presented in [7]. Synchronizing solar array, battery and grid supply for development of smart power system for home is proposed [8]. To mitigate the effects of harmonics in power conversion stages the combination of system for VAR compensation and photovoltaic power generation based on modular multilevel converter is studied [9].

The unavailability of solar energy during night is overcome by a battery energy support system interfaced with PV system. The battery energy storage system (BESS) acts as a load and stores the energy while in excess and acts as a source to meet the demand of extra power by the load, thus increasing the reliability of the system. It also maintains a constant DC link voltage. An adaptive filtering is used to calculate the fundamental value of load current in case of non-linear loads. To achieve a stiff synchronization between the grid and load voltages, various phase-locked loop (PLL) has been presented [10]. PI controllers are used in closed loop operation of converters.

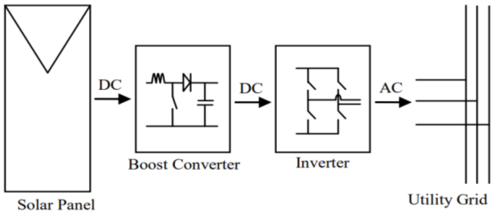


Fig. 1 Block diagram of grid connected PV system

II. SYSTEM CONFIGURATION AND DESIGN

Fig. 2 depicts the proposed system configuration. The system consists of a solar PV array generating a peak power of 4.5 kW. A MPPT algorithm is implemented through voltage control of the boost converter operating at a switching frequency of 20 kHz. The DC link voltage is maintained greater than the peak of ac grid voltage i.e., 360V through battery support system. Battery capacity is 360V, 7Ah, and non-linear rectifier load of 350W are connected. The values selected for proposed system design are shown in Table 1.

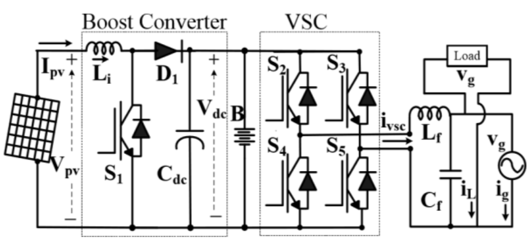


Fig. 2 Proposed system topology

TABLE 1

Selected values of the elements of the proposed topology

Element	Formula	Calculated	Selected
DC link Capacitor C_{dc}	$\frac{Idc}{2*2\pi f \Delta Vdc}$ $\frac{32}{(2*2*\pi*f*0.05*400)}$	2350 µF	3000 µF
Battery Inductor	$\frac{Vb\,DT}{\Delta Ib}$ $\frac{360\,(0.4)\,(50\mu)}{0.1\times 20}$	3.6 mH	2 mH
Filter inductor Lf Resistance RLf	$\frac{VdcDT}{4a\Delta Ig}$ $\frac{(400)\,(1)\,(100\mu)}{4\times1.2(0.1\times20.87)}$	2.66 mH	3 mH 0.01 Ω
Filter Capacitor Cf Resistance RCf	$\frac{1}{4\pi^2 f_r^2\,Lf}$ $\frac{1}{4\pi^2\,8\,50^2\,3\times10^{-3}}$	11.86 µF	15 µF 0.65 Ω

III. PROPOSED SYSTEM CONTROL

The system control consists a boost converter performing MPPT using voltage control by sensing instantaneous PV voltage and current, and the VSC performing current control through hysteresis control technique where the current reference generation is dependent on the PV power and the load power connected to the system. The hysteresis controller acts quickly as compared to the other form of switching techniques [10]. Each control is described in detail in this section.

A. MPPT control with the Boost converter

The main function of MPPT algorithm is to maintain the effective output resistance of the converter to match the varying solar insolation. The maximum power from the panel is extracted using a perturb and observe algorithm as it is easy to implement.

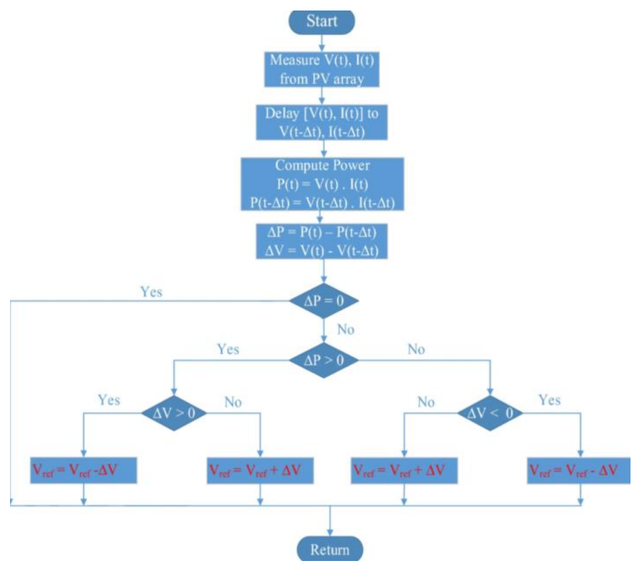


Fig. 3 Flow chart of Perturb and observe method

The reference voltage is then compared with the sensed PV voltage to generate PWM switching pulse for the boost converter to achieve MPPT is shown in fig. 2

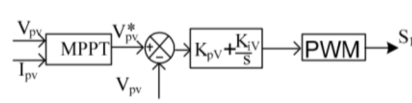


Fig. 4 Boost voltage control

B. VSC control method

VSC controller consists of weight of PV system, weight of filtering and battery control weight. Phase locked loop (PLL) is used for grid synchronization. Reference value of grid current is estimated with the help of mathematical calculation of individual parameters. Hysteresis controller is used to generate the pulses for VSC. The fundamental component of the nonlinear load current is obtained using the adaptive filtering technique.

1). Grid synchronization method

The PLL method used for grid synchronization is show Fig. 5

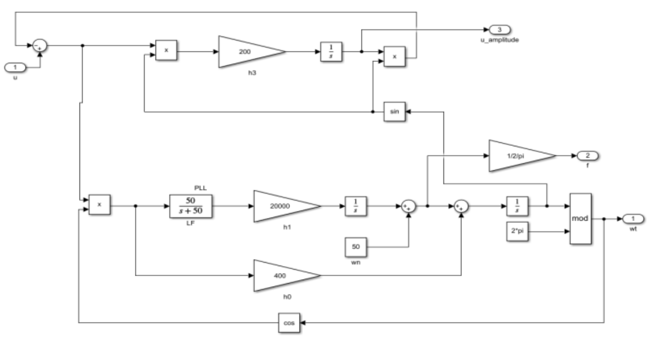


Fig. 5 PLL control

$$Vm = \sqrt{Vd^2 + Vq^2} \qquad (1)$$

Where, up represents a unit sinusoidal signal in phase with the grid voltage, Vm is the value of maximum grid voltage and, Vd is the direct axis component of grid voltage and Vq is the quadrature axis component of grid voltage.

2). Load Compensation

The adaptive filter helps in extraction of peak value of fundamental component of the load current. The governing equations of the adaptive filter are as [11],

$$W_L(n+1) = W_L(n) + [e_{pa}(n) \times \tau_p \times u_p(n)] \qquad (2)$$

$$e_{pa} = i_L - (W_L * u_p) \qquad (3)$$

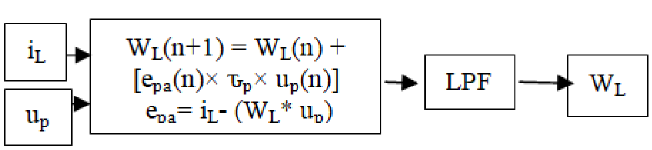


Fig. 6 Filtering

Where, e_{pa} is the error signal between the sensed load current (i_L) and the extracted filtered current. A proper tuning of this gain causes reliable extraction of the fundamental current.

3). DC link voltage with battery control

In DC link voltage control actual DC link voltage is compared with reference DC link voltage and error is minimized through PI controller.

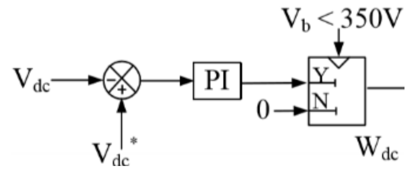


Fig. 7 DC link voltage control

Where, Vdc is the actual dc link voltage and Vdc* is the reference dc link voltage. A battery control is provided. If the battery voltage is higher than 350V the output of the control is set to zero but if the deep discharge in battery happens it will set the conroller value to value after PI controller.

3). Weight Calculation of PV term

Weight of PV term is calculated with this mathematical model shown in Fig. 8

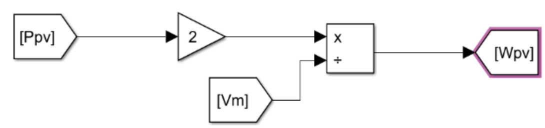


Fig.8 Calculation of Wpv

Where, Wpv is the weight of PV system, Ppv is the solar array power and Vm is the maximum grid voltage.

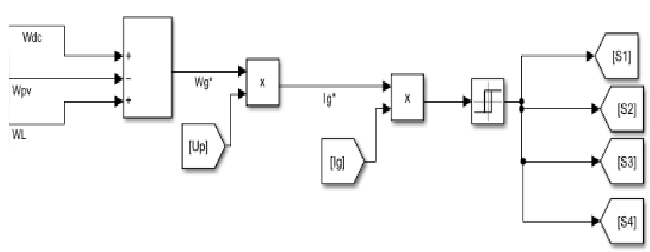


Fig.9 VSC control

Where, Wg* is rhe reference weight of the grid. Hysteresis controller is used to generate firing pulses for VSC.

IV. SIMULATION RESULTS

The proposed system is modelled in MATLAB/Simulink. The experimental results of solar PV interfaced system to the grid with a battery support are recorded in MATLAB.

A. Steady State Performance of the system under Nonlinear Load

Figs. 10(a)-(f) depict the response of the proposed solar PV system when subjected to a nonlinear load. Figs. 10(a)-(b) show the load voltage (V_L), load current (i_L), grid voltage (vg), grid current (ig) Figs.10 (c)-(d) show the total harmonic distortion (THD) of i_L and V_L. Figs. 10(e)-(f) shows an active power of grid and load. Figs. 10(g)-(h) shows a I-V and P-V characteristic of solar panel. Maximum voltage and current at maximum power point are shown. Fig.10 (i) shows a grid synchronism after Phase-locked loop.

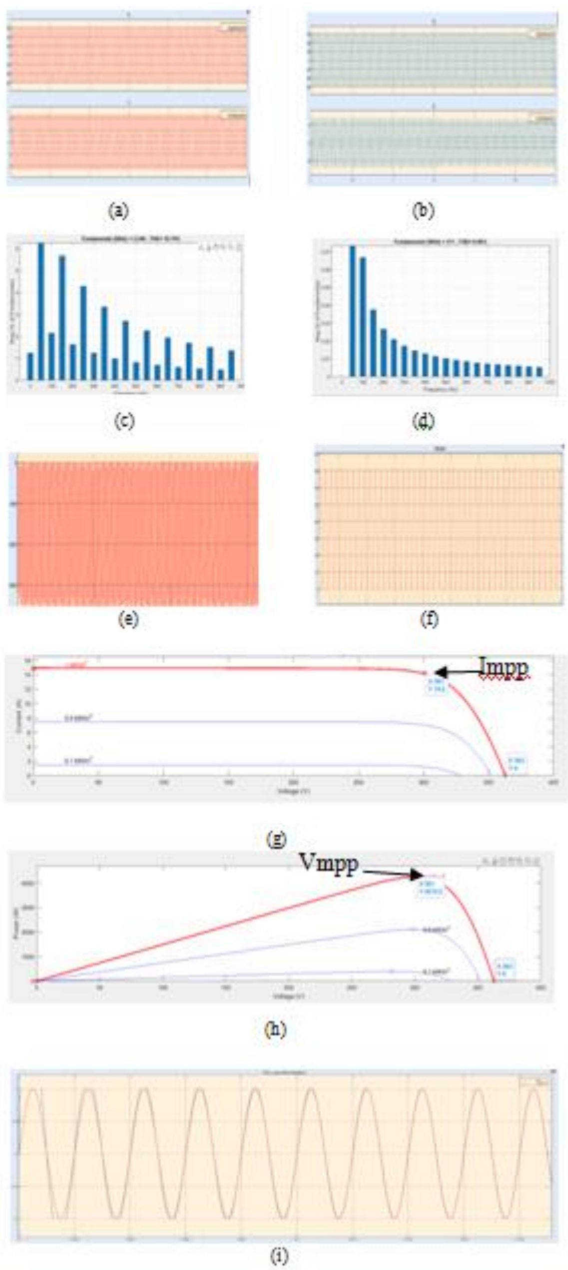
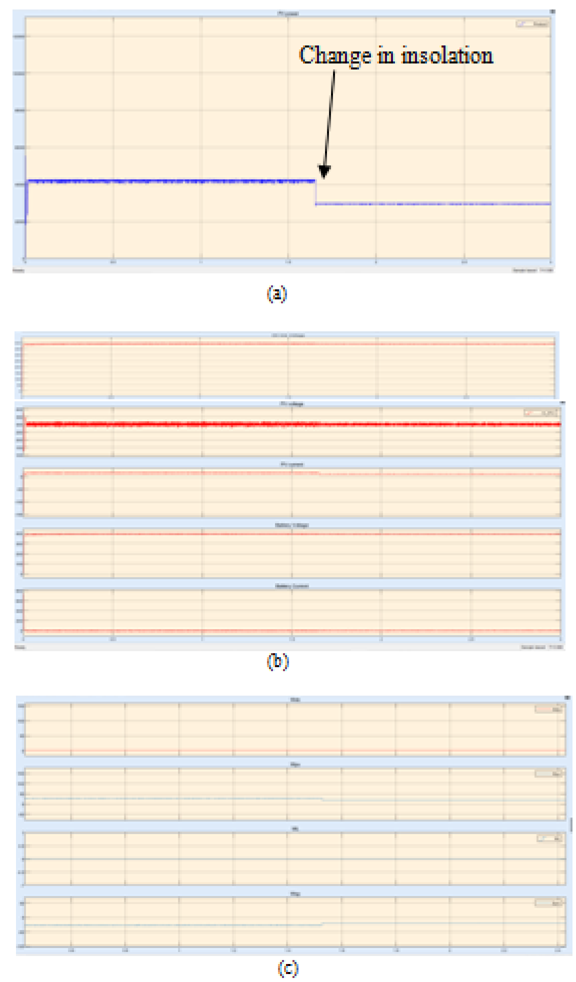
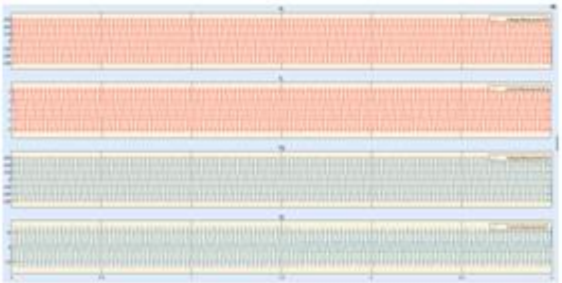


Fig. 10 (a) V_L, i_L, (b) Vg, ig (c) harmonic spectrum of load current (d) harmonic spectrum of V_L (e) Active power supply to grid (f) active power absorbed by load (g) I-V (h) P-V characteristic of PV panel (i) phase synchronism with PLL

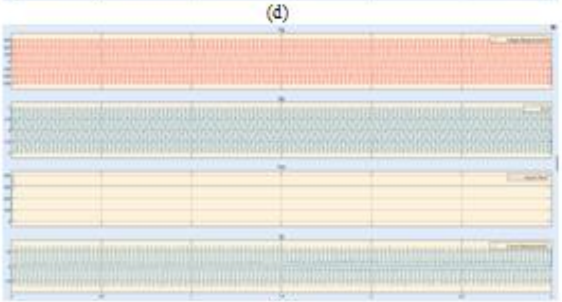
B) Response of the system for change in insolation level

Figs. 11(a) – (e) show the dynamic response of the system when the insolation is changed from 1000W/m^2 to 700 W/m^2. Fig. 11(a)-(b) shows the effect of decrease in insolation on the PV power voltage and current which has caused an equivalent decrease in the losses of the system resulting in reduced battery current. Fig.11(c) depicts the change in internal parameters (WL, Wpv, Wdc, Wsp). With decrease in insolation level, Wpv decreases with no effect on the WL and Wdc resulting in reducing grid current reference. Fig. 11(d) shows the reduction in grid current due to reduced PV power. However, the load current is unaffected during this transition.





(d)

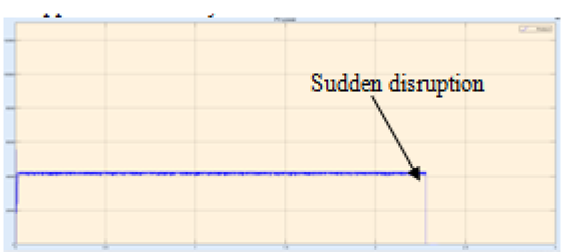


(e)

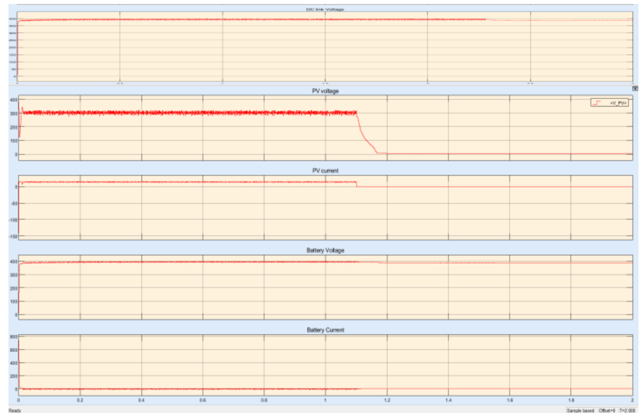
Fig. 11 Dynamic performance for change in insolation (a) Ppv (b) Vdc,Vpv, Ipv, Vb, Ib (c) internal parameter Wdc, Wpv, WL, Wsp (d) V_L,I_L,Vg,Ig (e) Vg, up,Vm,Ig From 1000W/m^2 to 700W/m^2

C) Response of the system for sudden disruption in solar PV array

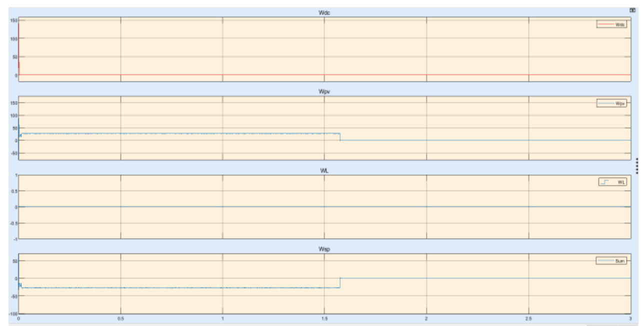
Figs. 12 (f)-(j) demonstrate the dynamic performance of the system, under very low solar insolation. This is a very common situation occurring due to passing clouds or rainy environment. Fig. 12(f)-(g) depicts the sudden decrease in solar PV power current and voltage to zero. To maintain the continuous flow of power to the load, the grid supplies current to the load while maintaining sufficient DC link voltage as shown in the Fig. 12(g). However, the battery continues to discharge to satisfy the losses in the system. Due to very low grid current and no PV voltage fluctuations, the ripples in the battery current are reduced.



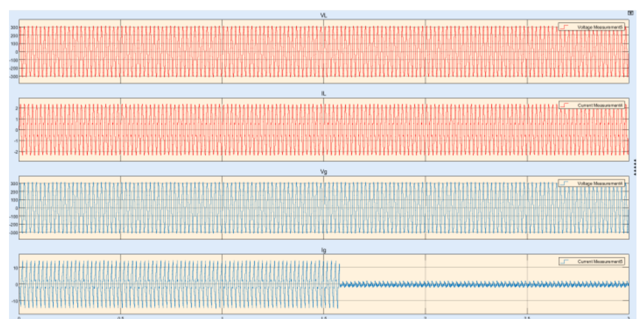
(f)



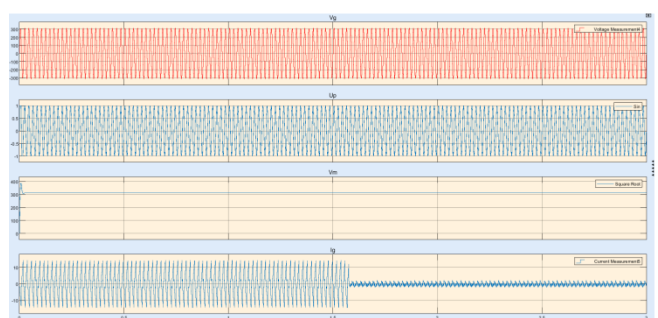
(g)



(h)



(i)



(j)

Fig. 12 Dynamic performance of the system for sudden disruption in PV panel (f) Ppv (g) Vdc, Vpv, Ipv,Vb,Ib (h) internal parameter Wdc, Wpv, WL, Wsp (i) V_L,I_L,Vg,Ig (j) Vg, up,Vm,Ig

V. CONCLUSIONS

The proposed converter topology feeds a PV array power with a BESS to the grid irrespective of the nonlinear load connected at the PCC. The Simulink results have demonstrated at varying environmental conditions. The DC link voltage is maintained constant in all environmentally occurring dynamic situations thereby increasing the reliability of the system. The use of energy storage element increases the reliability of the system at the cost of slightly reduced efficiency.

REFERENCES

[1] M. A. G. de Brito, L. Galotto, L. P. Sampaio, G. de Azevedo e Melo, and C. A. Canesin, “Evaluation of the main MPPT techniques for photovoltaic applications,” IEEE Trans. Ind. Electron., vol. 60, no. 3, pp. 1156–1167, Mar. 2013.
[2] L. Gil-Antonio, M. B. Saldivar-Marquez, and O. Portillo-Rodriguez, “Maximum power point tracking techniques in photovoltaic systems: A brief review,” in Proc. 13th Int. Conf. Power Electron., Jun. 2016, pp. 317–322.
[3] B. K. Bose, “Global warming: Energy, environmental pollution, and the impact of power electronics,” IEEE Ind. Electron. Mag., vol. 4, no. 1, pp. 6–17, Mar. 2010.
[4] K. S. Tey and S. Mekhilef, “Modified incremental conductance algorithm for photovoltaic system under partial shading conditions and load variation,” IEEE Trans. Ind. Electron., vol. 61, no. 10, pp. 5384–5392, Oct. 2014.
[5] Y. Mahmoud and E. F. El-Saadany, “Fast power-peaks estimator for partially shaded PV systems,” IEEE Trans. Energy Convers., vol. 31, no. 1, pp. 206–217, Mar. 2016.
[6] E. B. Ssekulima and A. A. Hinai, “Coordinated voltage control of solar PV with MPPT and battery storage in grid-connected and microgrid modes,” in Proc. Mediterranean Electrotechnical Conference (MELECON), Lemesos, Cyprus, 2016, pp. 1-6
[7] C. Jain and B. Singh, “Single-phase single-stage multifunctional grid interfaced solar photo-voltaic system under abnormal grid conditions,” IET Gener., Transmiss. Distrib., vol. 9, no. 10, pp. 886–894, 2015.
[8] P. Kumar, I. Ali and M. S. Thomas, “Synchronizing solar cell, battery and grid supply for development of smart power system for home,” in Proc. IEEE India Conference (INDICON), New Delhi, pp. 1-5, 2015.
[9] B. Tai, C. Gao, X. Liu and J. Lv, “Combination system of VAR compensation and photovoltaic power generation based on modular multilevel converter,” in Proc. IEEE Conference on Industrial Electronics Society, IECON, pp. 002932-002937, Yokohama, 2015.
[10] Nicastri and A. Nagliero, “Comparison and evaluation of the PLL techniques for the design of the grid-connected inverter systems,” in Proc. IEEE Int. Symp. Ind. Electron., Jul. 2010, pp. 3865–3870.
[11] R. K. Agarwal, I. Hussain, and B. Singh, “LMF-based control algorithm for single stage three-phase grid integrated solar PV system,” IEEE Trans. Sustain. Energy, vol. 7, no. 4, pp. 1379–1387, Oct. 2016.