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Modified P&O Technique for Hybrid PV-Battery Smart Grid Integrated Scheme

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ABSTRACT This paper presents a PV-Battery smart grid photovoltaic system through use of a modified perturbs and observes (P&O) technique for energy efficient utilization and ensuring the maximum power point tracking (MPPT). The modified P&O is based on step by step power-change in the specified three distinct search zones using an assigned zone- duty cycle ratio of the chopper converter (D). The PV-Battery-smart grid integrated system utilized a proportional integral (PI) controller for Li-Ion battery charging with a feed forward battery current signal for fast charging. LC filter is used to reduce current ripple introduced by PWM switching and modulating of the grid-side voltage source inverter (VSI). Digital simulation results using the MATLAB/Simulink software environment validated the effectiveness of the proposed control scheme for efficient energy utilization and reduced ripple contents in the DC and AC side of the VSI-inverter as well as it provided fast battery charging.

Keywords: PV-Battery-Smart Grid, Modified P&O, Maximum Power Tracking, Fast Charging

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1. INTRODUCTION

Renewable energy resources (solar, wind, tidal, wave etc.) are increasingly considered as viable and economic alternative sources to the electric utility-generation mix. Conventional fossil-fuel energy sources are declining with increased use, population growth, growing concerns over gaseous emission and global warming. Photovoltaic (PV) array is considered to be promising power source in future low carbon electric grid. Photovoltaic arrays are subject to variations in power/energy output due to variations in insolation/irradiation and operating temperatures. One effective technique is to add multi-source and storage devices such as Li-Ion batteries, fuel cells, super-capacitors and superconductive magnetic energy storage (SMES) systems [1], and battery energy storage systems [2]. The diesel back-up for PV power systems is capable of providing a continuous 24-hours power supply but with low energy efficiency and additional fuel cost of low power output. SMES technology has a significant potential health risk due to strong ambient magnetic fields. The battery storage systems are considered a common way to store energy when the main source of power is sufficient to provide energy in case of light loads. Power electronic conversion devices are required for both DC and AC interface such as inverter and DC-DC converter. One of the main tasks of these devices is to continuously adapt the hybrid DC-AC interface system to ensure power matching between generation and load while ensuring the maximum power utilization from the PV array under varying weather and load conditions. Nonlinear characteristic of a PV power curve is a function of the irradiance level and temperature [4], for best efficient energy utilization it is necessary to operate the system at its Maximum Power Operating Condition MPP.

There are several methods used to achieve the maximum power tracking and efficient energy utilization. One of which is perturb and observe method (P&O) [5]. It is the most common method and widely adopted. Perturb and observe method has simple implementation yet it has drawbacks where the perturbation process will lead the operation point of the PV array to oscillate around the maximum power point (MPP). Secondly, the P&O method probably fails to track the MPP when the insolation level changes rapidly [5]. Incremental conductance (IC) method offers good performance under the rapidly changing conditions in insolation [6]. Regulation controllers require high sampling and fast dynamics to cope with sudden load excursions and variations in insolation/irradiation and operating temperatures. PV-Battery-Smart Grid interconnected schemes have two control loops. The first loop is a pulse width modulation (PWM), which regulates the output currents of the VSI-inverter, to meet the requirements of the waveform and phase. The second loop is to control the output power of the inverter based on MPP-maximum PV search. Both regulators use a two-stage tiered power conversion [7].

This paper deals with power/energy optimized management for a PV-Battery interfaced to smart grid, modified P&O is used to achieve MPPT under changes in weather conditions. The battery system is connected to the PV array and charging of the output power from the DC/DC converter. A new algorithm of charging controller is used to control the charging process through the PI controller with feed forward from the battery current. In addition, the power flow from PV- hybrid system is connected to the grid and controlled through a PI controller. The next section details the structure of the unified system components which comprised of PV, battery, filter capacitors and interface VSI-to smart grid system. The MPPT search was achieved using the modified P&O search algorithm. PI controller with battery current feedback is used for battery charging. Third section presents the structure of MPPT, where the goal of MPPT system is to provide a fixed input voltage and - or current to reach the maximum power point (MPP). Forth section presents the efficient battery charging controller to regulate the DC voltage. Fifth section presents the optimization algorithm for efficient energy exchange. Dynamic simulation results and conclusions are presented in sections 6 and 7, respectively.

2. PROPOSED SYSTEM

The block diagram that represents the proposed system is shown in Figure 1.

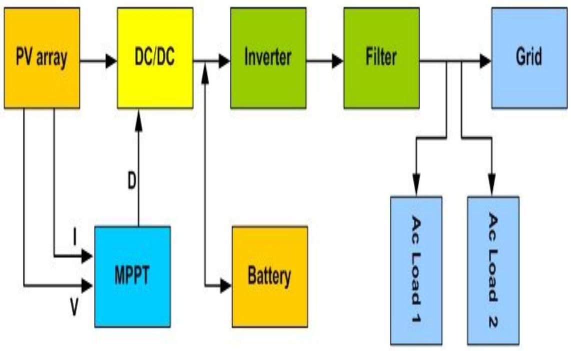
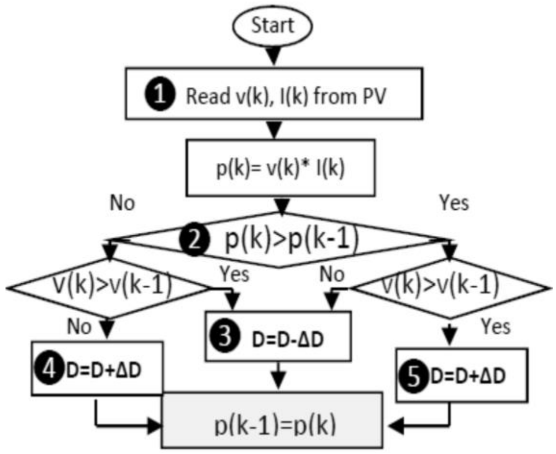


Fig. 1. Integrated PV-Battery- Inverter-Smart grid system

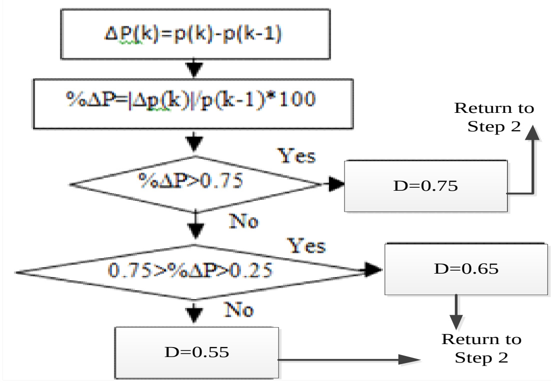
Figure 1 shows the schematic of the PV (11 kW) unified system with key subsystems. The PV is feeding the load (load 1 is 5 kW & 1 kVAr, load 2 is 3 kW & 1 kVAr) and ensures continuous charges the battery through a buck DC-DC chopper converter using the maximum power point tracking (MPPT) algorithm. The DC-DC converter is controlled by a PWM using modified P&O. The battery is continuously connected to the common voltage bus, through an additional DC-DC converter. The power may flow through the battery in both directions. The charging current is regulated by controlling the bus voltage. VSI-Inverter is used to provide the required AC power to the AC side loads.

3. POWER CONTROL OF PHOTOVOLTAIC SYSTEM

P&O algorithm shown in Figure 2 is preferred in industrial applications, due to its simplicity. Many ways are proposed to improve the response of P&O through control the perturbation steps such as modified P&O with fixed perturbation. Modified P&O with adaptive step by step zonal perturbations is proposed to achieve MPPT [5]. A photovoltaic cell has a nonlinear voltage-current characteristic with varying power/energy output due to the change in environmental conditions such as solar insolation level, ambient temperature, and the load.



(a)



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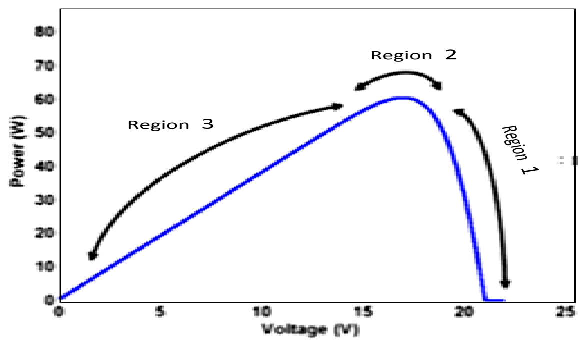


(c)

Fig. 2. (a) The algorithm of perturb and observe (P&O), (b) Proposed of perturb and observer, (c) PV cell (Power/Voltage) curve operating regions

The PV source needs to track the maximum power point (MPP) by controlling a DC-DC converter. This section represents the novel way to achieve MPPT. This proposed algorithm aimed to enhance the dynamic power utilization and increase the efficient operation of the traditional P&O method and eliminates its drawbacks. The modified P&O search algorithm based zonal power levels are scaled for the specified three selected zones. The power change in each zone has pre-assigned zonal-switching duty cycle ratio (D) for the DC-DC converter (chopper) with an initial preset value. Figure 2 represent the schematic diagram of the traditional P&O, search algorithm based on the modified P&O, and power/voltage of the PV system. The control strategy is divided into two parts: the first part deals with Power from the hybrid system "PV-Battery System", and the second part controls the power delivered to AC side using the VSI Inverter.

The criterion proposed in the flowchart of the proposed controller (MPPT) divides the P-V curve into three regions, as shown in Fig 2(c). The three levels of the perturbation step are as follows: D=0.75 for region 3; D= 0.55 for region 2; and D=0.65 suits for region 1.

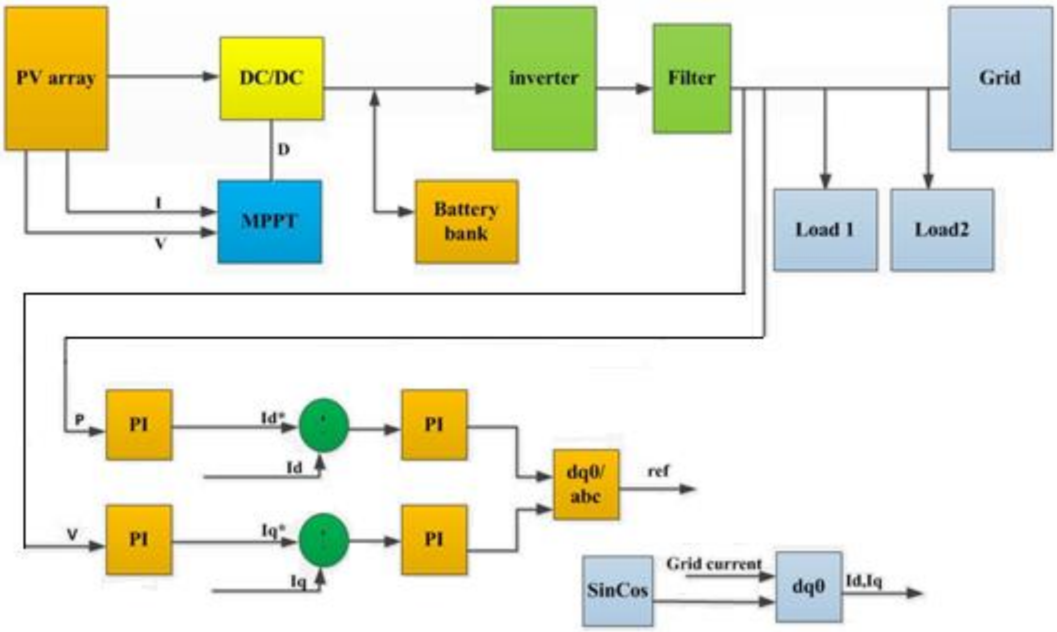


Fig.3. Complete system layout

4. MODIFIED CONTROL STRATEGY

Power from PV array is utilized to feed the load and charging the battery. The weather conditions has a great effects on the output power of the PV array, hence the MPPT is used. To ensure that the value of the DC bus voltage is maintained within the required range, DC-DC converter is used to charge the battery. PI controller is used to control the DC-DC converter, through generating the required duty cycle (D). Feed forward from the battery current (I_b), and the state of charge of the battery (SOC) are considered [6]. From AC side, to simplify the way of the control design for PV grid-connected system, there are many methods of transformation are utilized to reduce the mathematical model of the system [8, 9]. Figure 3 represents the complete system layout. The most common methods of transformations are αβ transformation and d-q transformation (Park transformation). Park's transformation was used in this study. Park's transformation converts a three-phase (A, B, C) into a two-dimensional system (d-q) as αβ transformation is carried out. The differences is appeared in the coordinate, where in αβ the coordinate is stationary, while in Park's transformation the coordinate rotates with a constant frequency. To connect the PV with the grid system, synchronization considered to be the essential part to achieve connection with the grid. To achieve the synchronization, the amplitude and phase value of the grid voltage need to be well known. This information is essential for the voltage and current control loops in order to work at its optimal point. There are various methods used to achieve synchronization with the frame such as zero crossing, phase locked loop (PLL) [10]. PLL was preferred in current study. This algorithm had a better rejection of the harmonic and disturbance compared to zero-crossing [11].

PV systems in the grid required additional functionality from the inverter, such as synchronization, active and reactive power control [12-14]. The control of the inverter is based on a decoupled control of the active and reactive power. The proportional-integral controller (PI) is used to control the output power (P) from the inverter, it provides the active direct current reference (Id*) in a synchronous reference frame. The quadrature component (I_q) that effects on the reactive power is controlled through PI controller. Applying the inverse Park's transformation to d–q frame current vector components, the desired I_{d_ref} &I_{q_ref} a-b-c phase current references were obtained. Each component is passed to a unique PI controller, which outputs the pulses to drive the inverter. Figure 4 represents the structure of system components where the PV array was chosen so that the output voltage of the DC-DC converter suits the inverter's requirements. In this case, a 440V AC grid was chosen, so the requirement for the inverter will be 650V in DC bus to operate properly.

5. DYNAMIC SIMULATION RESULTS

To validate the effectiveness of the proposed control scheme, a step dynamic response of the proposed P&O was examined. The irradiance level was 900W/m². Figure 4 (a) shows the proposed controller that tracks the operating point very quickly. From the battery side, PI battery charging controller is utilized to regulate the DC voltage, through generating the required duty cycle. The output control signal from the control algorithms based on calculating the DC bus voltage with its reference value. Feed forward from the battery current is used to improve the charging response in addition SOC.

Figure 4 (b) represents the response of the DC bus voltage using the battery charging controller. It can be noticed that the DC bus voltage fast conversion to the reference value was achieved when PI controller with DC-DC converter is used. Figure 5 (a), represents the load output power. Figure 5 (b) represents the output power from the voltage source control (VSC), the power from PV array is the same as in Figure 4(a). From the Figure 5 (c), it is observed that when load one is energized the output power from the inverter is higher than the demand power, P_{inv} > PL, then the remaining power feeding into the grid. The load two is energized, then the total power output from the inverter is P_{inv} > PL, but in this case the remaining is less than as compared before. The load was changed (increased), but the power feed into the grid is still. The response for the controller was tested under the partial shadowing. The PV array is subjected to the irradiance level based on the profile levels given in Figure6 (a). The response of battery charging PI controller achieved good tracking for the voltage reference value as compared with direct charging. In addition, active and reactive power are measured at the load (load 1+load 2) to determine the effectiveness of the battery charging controller. Figure 6 (b) depicts active and reactive power at the load with battery controller. Figure6-c shows that load 2 (30 kW as a new value) is increased and the total load changed from 8 kW to be 35 kW, P_{inv} < PL. The grid compensates the remaining required power. Figure 6 (c) shows the battery current when P_{inv}< PL, there is no compensation from the battery. In Figure 7, the power at night is supplied to the load via the battery. Another test was performed under fault conditions on the inverter side, then the load is totally feeding from the grid. Figure 8 (a) shows the power flow from the grid to the load and Figure 8 (b) represents the RMS value of the AC voltage. According to the proposed power flow, there are four scenarios as follows: First priority is to feed the load from PV, if the output power from the PV is much higher than the load power. Secondly is to feed the load from PV system and the grid when the output power from the PV is not sufficient hence, the grid compensates the required power to the load. Third priority is to feed the load from battery bank at night. The last priority is to feed the load from grid in case of no power output from the PV hybrid system or the PV hybrid system is failed. The observation from Figure 9 (a, b & c) and the obtained results show the effect of using an inductive filter not only in the AC side, but also in the DC voltage. One of the major aims to use filtering is to eliminate the harmonics and suppress the undesired. Figure 10 shows the MATLAB/Simulink model with all system components.

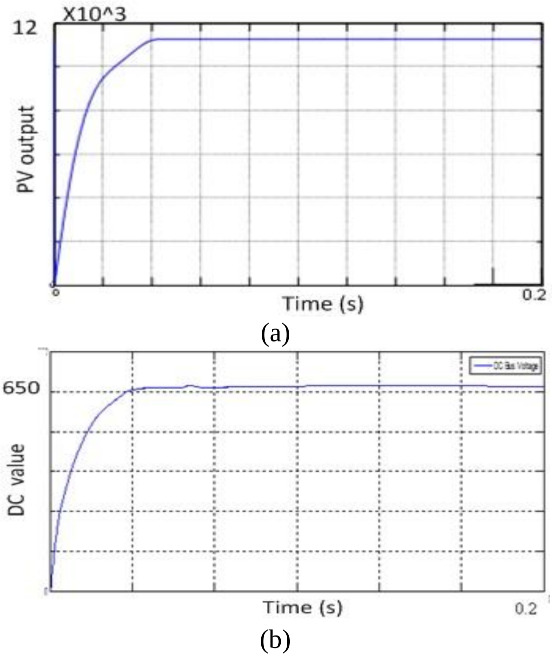


Fig. 4. (a) Output power under irradiance level 900W/m², (b) DC bus voltage

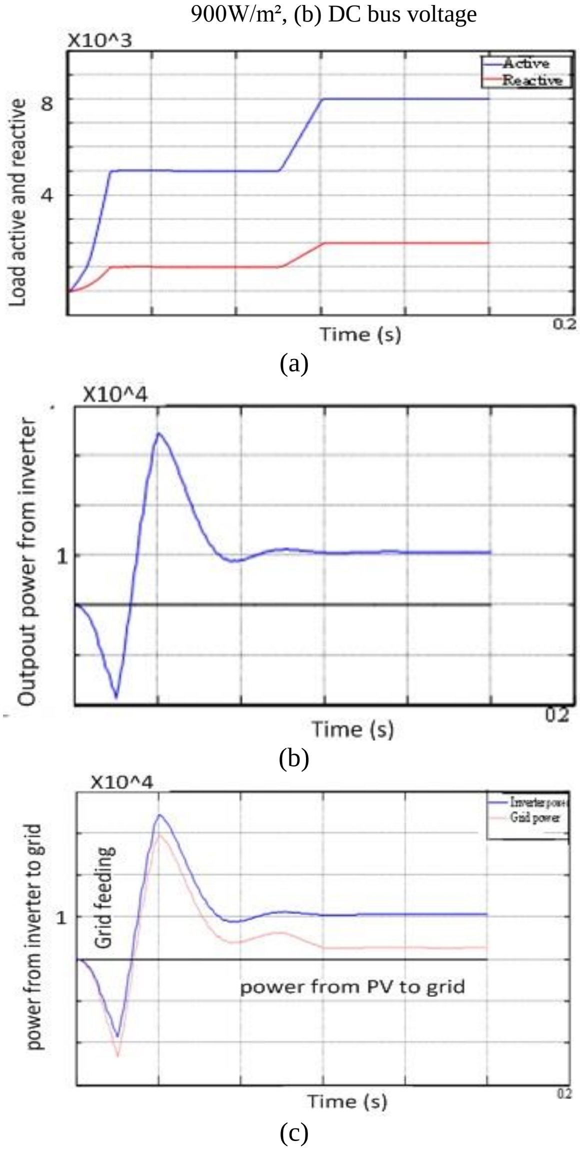
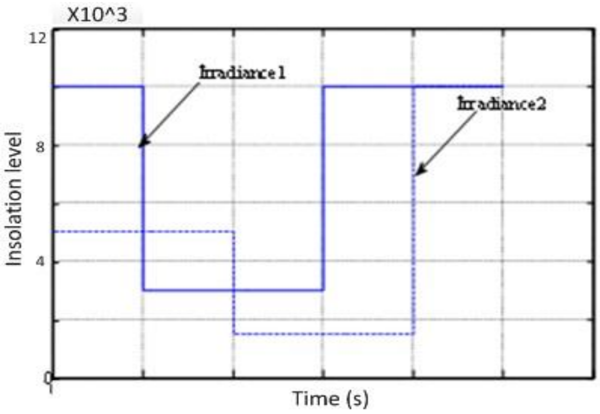
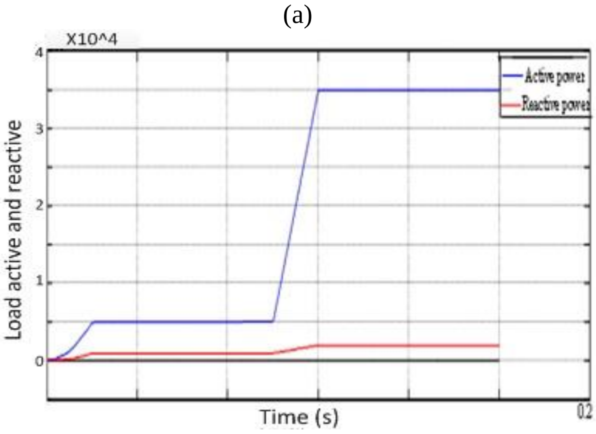


Fig. 5. (a) Load demand power, (b) Inverter output power, (c) Output power from the inverter to grid



(a)



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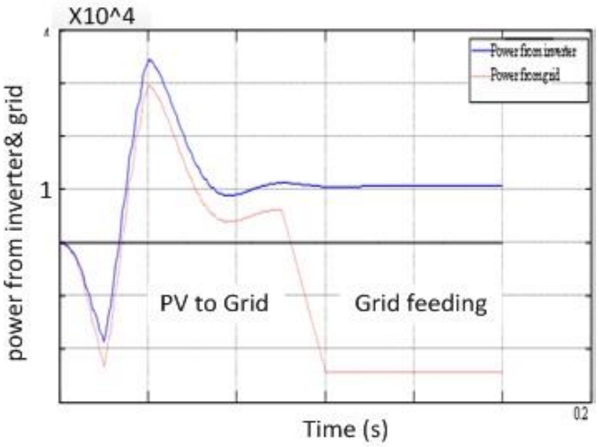

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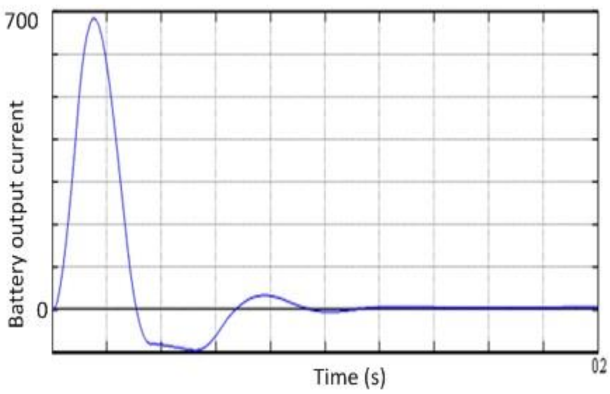


(d)

Fig. 6. (a) Irradiance level, (b) Load demand power, (c) Power from inverter& grid compensation, (d) Battery current when the PL>P_{inv}

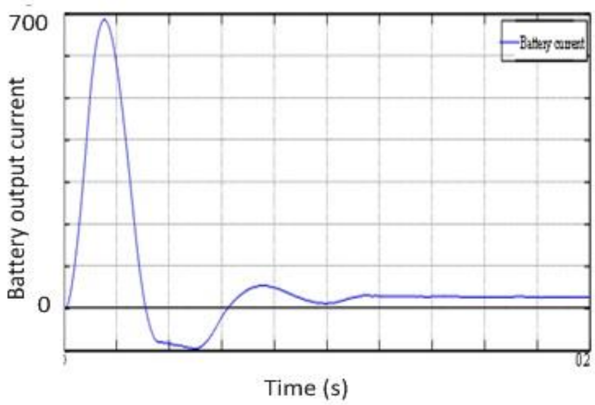


Fig. 7. Battery current during night

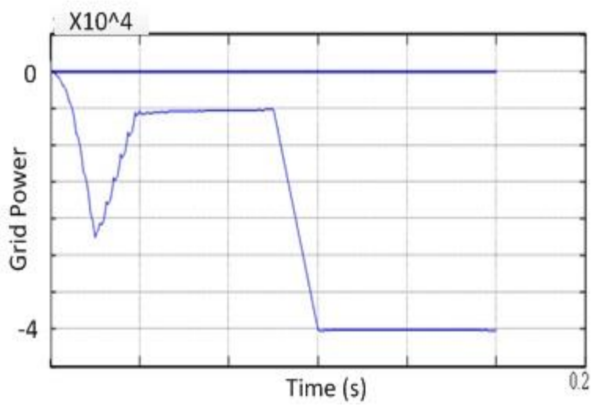
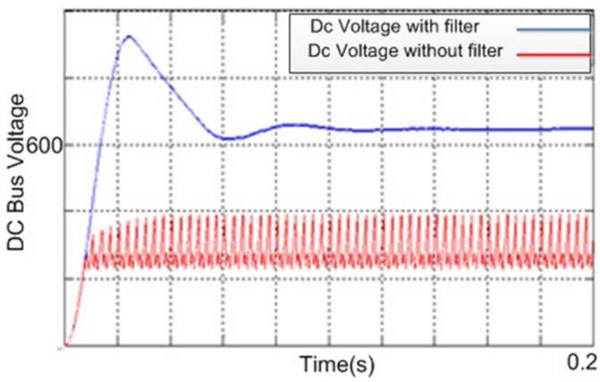
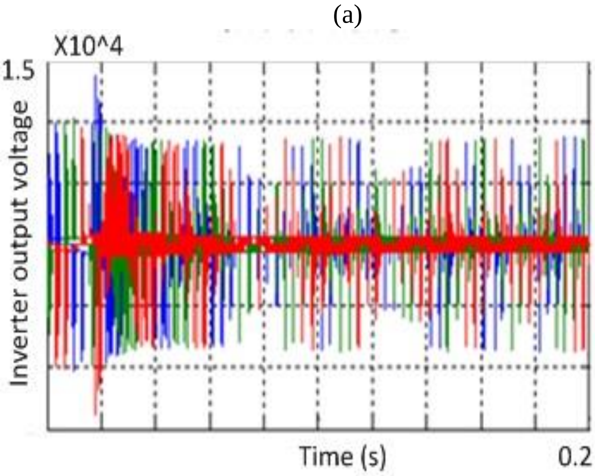


Fig. 8. Power from grid supplied to load



(a)



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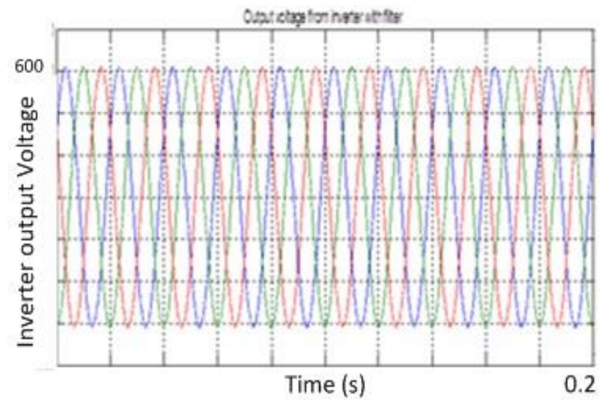

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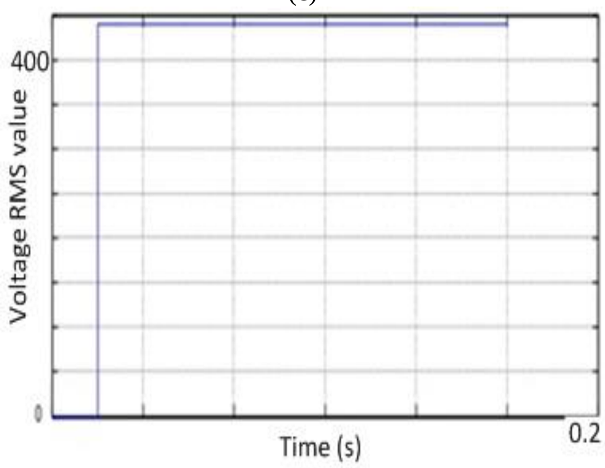

(d)

Fig. 9. (a) Effect of using filter on DC bus voltage, (b) 3Q voltage from inverter without filter, (c) 3Q voltage from inverter when using filter, (d) Voltage RMS value.

6. CONCLUSION

This paper presented a unified integrated PV-Battery-inverter interface to smart grid energy utilization using DC-AC interface. A multi-regulation pulse width modulation (PWM) is switching control scheme using a modified P&O to ensure energy efficient operation. The Modified P&O algorithm is based on multi-zonal pre-specified power change to update duty cycle. The new search algorithm was used to control battery charging with minimal current ripple content through battery current dynamic feedback signal. This is performed using a PI controller combined with feed forward with battery current (I_b). The multi-regulator control scheme for integrated PV-Battery-Inverter fed smart grid with DC and AC side loads are validated for variations in insolation levels, load changes as well as "fault conditions". The integrated scheme with the controllers is validated and assessed for fast dynamic performance, efficient PV solar energy utilization, reduced current ripples as well as fast Li-ion battery continuous charging. An additional LC filter was added to reduce harmonic content and smooth VSI-inverter waveforms at the smart grid interface bus. The inverter control is implemented using Park's transformation with -Phase Locked Loop (PLL) synchronization with AC grid, a second PI controller is used to control the amount of power delivered to the AC side from the VSI-inverter to the smart grid. The modified P&O search and PI controllers for battery charging and decoupled inverter P&Q control will be extended to hybrid PV-Wind-Fuel Cell-Smart Capacitor-Li Ion storage systems, LED lighting schemes and standalone micro grid applications in village/resort/island electricity as well as hydrogen production.

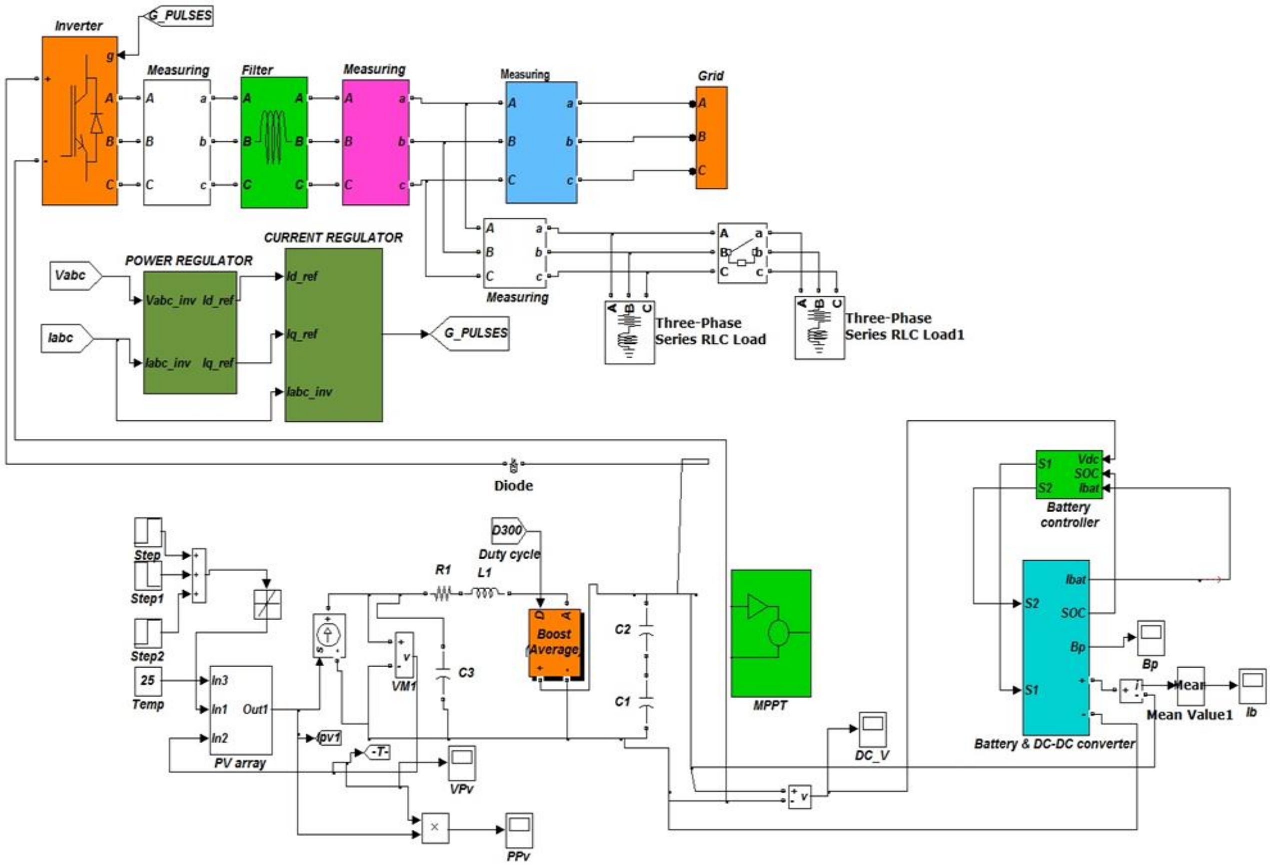

Fig.10. MATLAB/Simulink system model

REFERENCES

[1] T. Zhou, and W. Sun, Study on maximum power point tracking of photovoltaic array in irregular shadow, Electrical Power and Energy Systems, Volume 66, 227-234, (2015).

[2]D. Rekioua, E. Matagne, Optimization of photovoltaic power systems: Modelization, Simulation and Control Green Energy and Technology, 1865-3529, (2012).

[3]A. Mohammedi, D. Rekioua, N. Mezzai, Experimental study of a PV water pumping system Journal of Electrical Systems, 9(2), 212-222, (2013).

[4]M. S. Ebrahim, A. M. Sharaf, A. M. Atallah, and A. S. Emarah, PV solar-optimal maximum power search using a modified P&O technique. EJERS, European Journal of Engineering Research and Science 2(5), (2017).

[5]M. S. Ebrahim, A. M. Sharaf, A. M. Atallah, and A. S. Emarah, An Efficient Controller for Standalone Hybrid- PV Powered System, Turkish Journal of Electromechanics & Energy 2(1), 9-15, (2017).

[6]C. Wang, and M. H. Nehrir, Power Management of a Stand-Alone Wind/Photovoltaic/Fuel Cell Energy System, IEEE Transactions on Energy Conversion, 23(3), 957-967, 2008.

[7] I. A. Aden, H. Kahveci, M. E. Şahin, Single Input, Multiple Output DC-DC Buck Converter for Electric Vehicles, Turkish Journal of Electromechanics & Energy 2(2), 7-13, (2017).

[8] Y. Bo, L. Wuhua, Z. Yi, and H. Xiangning, Design and analysis of a grid connected photovoltaic power system, IEEE Trans. Power Electron., 25(4), 992–1000, (2010).

[9] S. E. Evju, Fundamentals of grid connected photovoltaic power electronic converter design, Ph.D. dissertation, Department of Electrical Power Engineering, Norwegian University of Science and Technology, (2007).

[10] H. Li, Y. Xu, S. Adhikari, D. T. Rizy, F. Li, and P. Irminger UT-Battelle LLC, Tech. Rep, Real and reactive power control of a three-phase single-stage PV system and PV voltage stability, (2012).

[11] F. Blaabjerg, R. Teodorescu, M. Liserre, and A. Timbus, Overview of control and grid synchronization for distributed power generation systems, IEEE Transactions on Industrial Electronics, 53(5), 1398–1409, (2006).

[12] Y. Riffonneau, S. Bacha, F. Barruel, and S. Ploix, Optimal Power Flow Management for Grid Connected PV Systems with Batteries, IEEE Transactions on Sustainable Energy, 2(3), (2011).

[13] B. Lu and M. Shahidehpour, Short term scheduling of battery in a grid connected PV/battery system. IEEE Trans. Power Syst., 20(2), 1053–1061, (2005).

[14] B. Indu Rani, G. S. Ilango, and C. Nagamani, Power flow management algorithm for photovoltaic systems feeding DC/AC loads. Renewable Energy vol.43, 267-275, (2012).

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