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Design and Analysis of Grid Connected Photovoltaic Application

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***Abstract*—This paper provides the design details of 600W grid connected PV cell. Six PV cells are connected in parallel is considered as the source. The source voltage is then stepped up using a DC-DC boost converter. The boost converter is then provides the voltage to a single phase inverter, which provides the AC signal which can be injected to the grid.**

***Index Terms*— PV cell, DC-DC boost converter, inverter**

I. INTRODUCTION

The rising energy need of human being has forced the mankind to look for alternate energy sources. Therefore, a significant research is going on in renewable energy sources. The characteristic of renewable energy sources such as PV, fuel cell and wind energy and their grid integration has been widely studied. A comparative study of different MPPTs used in photovoltaic power system is reviewed in [1-3]. Development of different control algorithms for photovoltaic power system is discussed in [4-8]. Analog MPPT technique for distributed PV application has been discussed in [4]. Single stage grid connected inverter for PV application with a single current sensor has been discussed in [5]. Adaptive auto tuned MPPT for PV application with FPGA based real time application has been discussed in [6]. Partial shading of PV array using colony of flashing fireflies has been discussed in [8]. Not only in photovoltaic systems have other renewable energy system such as fuel cell found widespread application in generation of green energy. During rapid load changes there is a significant change in output energy therefore; research has been carried out to study the changes in voltage during rapid change in load profile [9]. Control and grid interfacing of solid oxide fuel cell has been discussed in [10]. FPGA based real time implementation of DC-DC converter connected to solid oxide fuel cell has been discussed in [11]. This paper provides the design details of 600W PV grid integrated system. In this system 6 PV panels are installed at the source side. The unregulated voltage from PV cell is then stepped up using a DC-DC boost converter. The stepped up voltage of the boost converter is then provided to the inverter which eventually provides the utility AC signal which can be injected to the grid.

LC filter is used to suppress the current and voltage harmonics of the inverter whereas current control and voltage control techniques are used for control techniques. This paper consists of eight sections. Section II comprises of discussion about PV system for distributed generation system. Section III provides mathematical model of different PV cells. Section IV presents different MPPT algorithm. Section V provides modeling of boost converter with PV cell. Section VI provides the modeling of DC-AC inverter and Section VII comprises of simulation results. Section VIII concludes the paper.

II. PV SYSTEM FOR DISTRIBUTED GENERATION SYSTEM

Figure 1 shows the basic concept of micro grid system. Figure 2 shows the grid integration of PV array. PV array provides a low voltage unregulated DC voltage which has to be converted in to utility AC voltage. DC-DC converter is used for regulating unregulated voltage of PV array and is used to step up the voltage to a certain level. Maximum power point technique (MPPT) is used to extract maximum power from the PV array. There are several well-known MPPT algorithms. DC-AC inverter is used to invert the voltage and feed it to the utility grid. Feedback control of converter and inverter is used for proper grid integration.

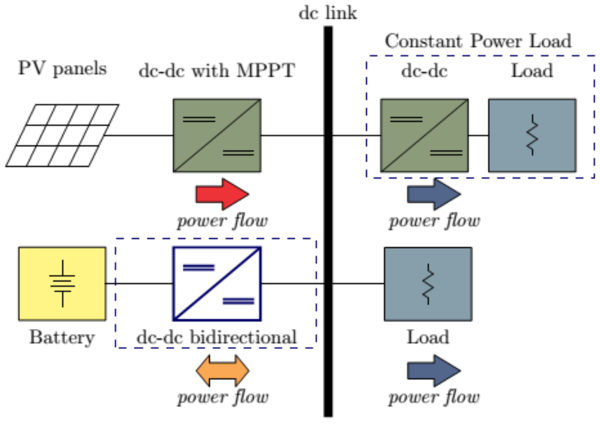

Fig. 1. Schematic of microgrid system

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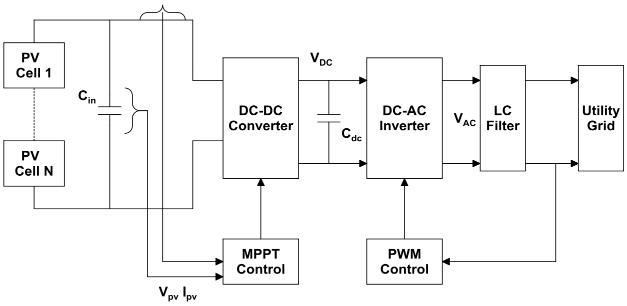

Fig. 2. Grid integration of PV cell

III. Mathematical Model of PV System

The mathematical model of PV cell is discussed in this section. The equivalent circuit diagram of PV cell is shown in Figure 3. PV cell is a combination of current source with a diode in reverse bias mode. The physical structure of PV cell is equivalent to PN junction subject to irradiance and change in temperature.

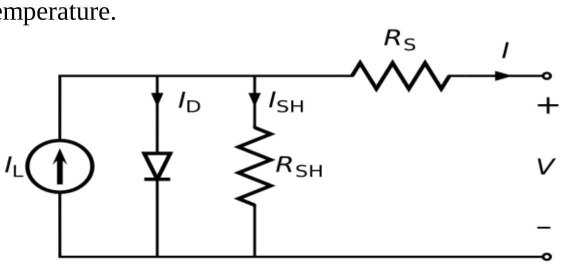

Fig. 3. Equivalent circuit diagram of PV cell

The current of the PV cell can be represented as,

$$I = I_L - I_D - I_{sh} \quad (1)$$

Here I_L is the current generated by the light, I_D is diode current and I_{sh} is the shunt current.

Diode current I_D can be expressed using Shockley equation such as $I_D = I_o\left[e^{\frac{qV_d}{nkT}} - 1\right]$ (2)

The shunt current is defined as $I_{sh} = \frac{V + IR_s}{R_{sh}}$ (3)

Substituting the values in eq(1),

$$I = I_L - I_o\left[e^{\frac{qV_d}{nkT}} - 1\right] - \frac{V + IR_s}{R_{sh}} \quad (4)$$

IV. Maximum Power Point Tracking

MPPT is a method that compensates for changing voltage and current characteristic of solar panel and maximum utilization of solar energy from panel. Maximum power point tracking, or MPPT, is the automatic adjustment of the load of a photovoltaic system to achieve the maximum possible power output. PV cells have a complex relationship between current, voltage, and output power, which produces a non-linear output. This output is expressed as the current-voltage characteristic of the PV cell. Constant fluctuations in external variables such as temperature, irradiance, and shading cause constant shifts of the I-V curve upwards and downwards. A change in temperature will have an inversely proportional effect on output voltage, and a change in irradiance will have a proportional affect on output current. Perturb and Observe (P&O) method periodically increments or decrements the panel voltage and compares the PV output power with that of the previous cycle. If the perturbation leads to an increase/decrease in module power, the subsequent perturbation occurs in the same/opposite direction. However, it has two parameters: the step size and the time between algorithm iteration. Hence, for faster tracking with accuracy, a trade-off is made between the two parameters.

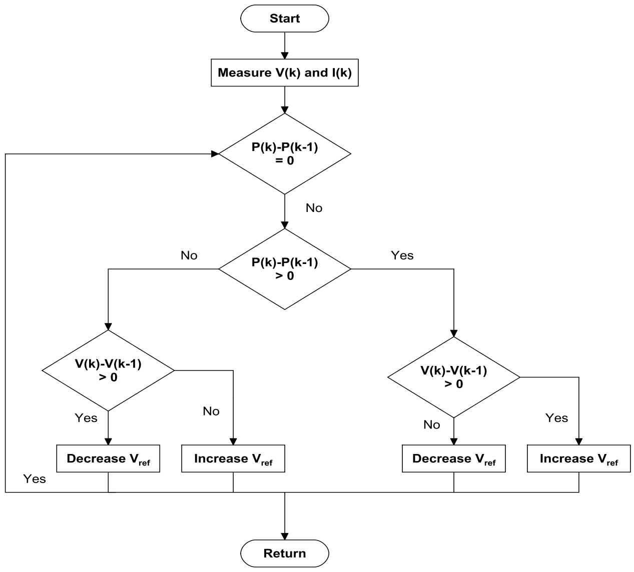

Fig. 4. Flow chart of P&O MPPT method

V. DC-DC Boost Converter

DC-DC boost converter regulates and steps up the unregulated voltage of PV cell. In this paper, state space avergae model of boost converter is used to model the boost converter. In state space average model, the dynamics of the converter changes with the instantaneous change in status of the switch i.e S = ON or S = OFF. The state space representation of system when S = ON is represented by

$$\begin{cases} \dot{x}_1 = A_1 x_1 + B_1 u_1 \\ y_1 = C_1 x_1 + D_1 u_1 \end{cases} \quad (5)$$

Here the state variables are $x = \begin{bmatrix} I_L \\ V_c \end{bmatrix}$

When S = ON, the state space representation of boost converter is represented as

$$A_1 = \begin{bmatrix} 0 & 0 \\ 0 & \frac{-1}{RC} \end{bmatrix} \quad B_1 = \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} \quad C_1 = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$$

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When S = OFF, the state space representation of boost converter is represented as

$$\begin{cases} \dot{x}_2 = A_2 x_2 + B_2 u_2 \\ y_2 = C_2 x_2 + D_2 u_2 \end{cases} \quad (6)$$

$$A_2 = \begin{bmatrix} 0 & \frac{-1}{L} \\ \frac{1}{C} & \frac{-1}{RC} \end{bmatrix} \quad B_2 = \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} \quad C_2 = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$$

The state space representation of boost converter is shown by combining the two stages. It can be represented as

$$\begin{cases} \dot{x} = Ax + Bu \\ y = Cx + Du \end{cases} \quad \begin{cases} A = A_1 d + (1-d) A_2 \\ B = B_1 d + (1-d) B_2 \\ C = C_1 d + (1-d) C_2 \\ D = D_1 d + (1-d) D_2 \end{cases} \quad (7)$$

$$\begin{bmatrix} \dot{I}_L \\ \dot{V}_c \end{bmatrix} = \begin{bmatrix} 0 & \frac{-(1-d)}{L} \\ \frac{1-d}{C} & \frac{-1}{RC} \end{bmatrix} \begin{bmatrix} I_L \\ V_c \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} V_{in} \quad (8)$$

$$\begin{bmatrix} V_o \\ I_{in} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} \begin{bmatrix} I_L \\ V_c \end{bmatrix} \quad (9)$$

VI. SINGLE PHASE DC-AC INVERTER

DC-AC inverter converts the regulated DC voltage to AC signal which is fed to the utility grid.

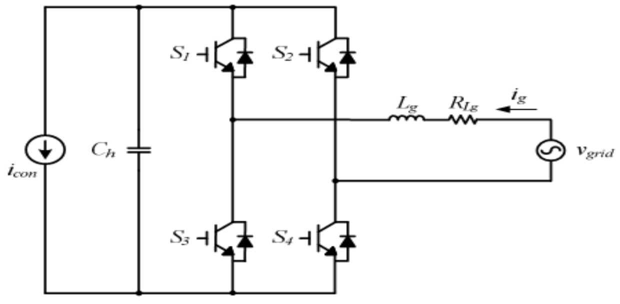

Fig. 5. Circuit diahram of single phase DC-AC inverter

The first and second sub interval of single phase DC-AC inverter is represented below.

$$\begin{bmatrix} L_g & 0 \\ 0 & C_h \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_g \\ v_{ch} \end{bmatrix} = \begin{bmatrix} -R_{Lg} & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} i_g \\ v_{ch} \end{bmatrix} + \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix} \begin{bmatrix} i_{con} \\ v_g \end{bmatrix} \quad (10)$$

$$\begin{bmatrix} L_g & 0 \\ 0 & C_h \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_g \\ v_{ch} \end{bmatrix} = \begin{bmatrix} -R_{Lg} & -1 \\ 1 & 0 \end{bmatrix} \begin{bmatrix} i_g \\ v_{ch} \end{bmatrix} + \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix} \begin{bmatrix} i_{con} \\ v_g \end{bmatrix} \quad (11)$$

The state space average model of DC-AC inverter is illustrated below

$$\frac{d}{dt} \begin{bmatrix} \hat{i}_g \\ \hat{v}_{ch} \end{bmatrix} = \begin{bmatrix} -\frac{R_{Lg}}{L} & \frac{-D'}{L_g} \\ \frac{D'}{C_h} & 0 \end{bmatrix} \begin{bmatrix} \hat{i}_g \\ \hat{v}_{ch} \end{bmatrix} + \begin{bmatrix} 0 & \frac{1}{L_g} & \frac{v_{ch}}{L_g} \\ \frac{-1}{C_h} & 0 & \frac{i_g}{C_h} \end{bmatrix} \begin{bmatrix} \hat{i}_{con} \\ \hat{v}_g \\ \hat{d} \end{bmatrix} \quad (12)$$

$$\begin{bmatrix} \hat{i}_g \\ \hat{v}_{ch} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \hat{i}_g \\ \hat{v}_{ch} \end{bmatrix} + \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \hat{i}_{con} \\ \hat{v}_g \\ \hat{d} \end{bmatrix} \quad (13)$$

TABLE I: Switching state of single phase DC-AC inverter

S_1	S_2	S_3	S_4	V_a	V_b	V_{ab}
ON	OFF	OFF	ON	$V_s/2$	$-V_s/2$	V_s
OFF	ON	ON	OFF	$V_s/2$	$V_s/2$	$-V_s$
ON	OFF	ON	OFF	$V_s/2$	$-V_s/2$	0
OFF	ON	OFF	ON	$-V_s/2$	$V_s/2$	0

The small signal AC model of single phase inverter is shown in Eq. (14) and Eq.(15) respectively.

$$\frac{\hat{i}_L}{\hat{d}}(s) = \frac{(C_l C_h R_B V_{ch})s^2 + (C_l R_B D' I_L + C_h V_{ch})s + D' I_L}{(C_l C_h L_a R_B)s^3 + (C_l C_h R_L R_B + C_h L_a)s^2 + (C_h R_L + C_h R_B + C_l D'^2 R_B)s + D'^2} \quad (14)$$

$$\frac{\hat{v}_{ch}}{\hat{d}}(s) = \frac{(C_l R_B L_a I_L)s^2 + (C_l R_L R_B I_L + C_l R_B D' V_{ch} + I_L L_a)s + R_L I_L - D' V_{ch}}{(C_l C_h R_B V_{ch})s^2 + (C_l R_B D' I_L + C_h V_{ch})s + D' I_L} \quad (15)$$

The transfer function of LC filter is represented as

$$F(s) = \frac{1}{1 + L_f s + L_f C_f s^2} \quad (16)$$

VII. SIMULATION RESULTS

This section presents simulation results of 600W grid connected PV system. The system parameters are summarized below.

TABLE II: Parameters of the system

Voltage of single PV cell	19 V
Voltage of 6 PV cell	119.7 V
Power of 6 PV cell	592.6 W
Current of PV cell	4.95 A
DC-link voltage	340 V
Power of boost converter	570.2 W
Efficiency of boost converter	96.21
Reference current for inverter	3.94 A
Voltage of inverter	120 V
Inverter current	5 A
Efficiency of inverter	95.26
THD of load current	4.53%

Different characteristics of PV cell are simulated in this paper. Voltage and current of PV cell are plotted with varying irradiance level. The V-I characteristics of PV cell with varying irradiance is shown in Figure 6.

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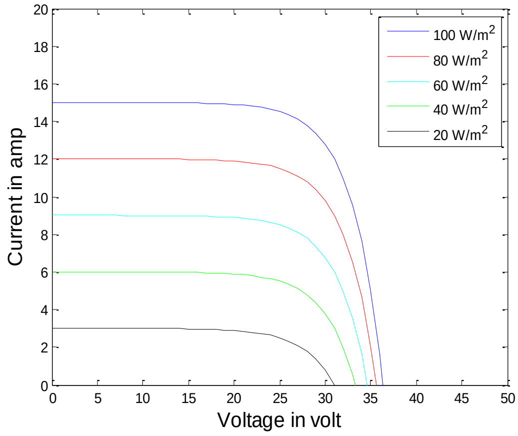

Fig. 6. Voltage and current characterisitcs of PV cell

The power and voltage of PV cell i.e P-V characteristics of PV cell with varying irradiance level is shown in Figure 7. Power and current of PV cell i.e P-I characterisitics of PV cell with varying irradiance level is shown in Figure 8.

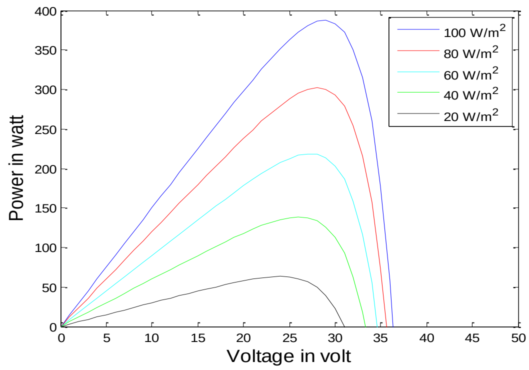

Fig. 7. Voltage and Power characterisitcs of PV cell

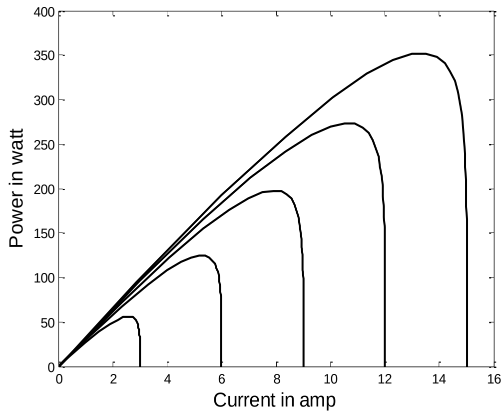

Fig. 8. Power and current characterisitcs of PV cell

Each PV array provides 19.7V DC output under normal condition. To increase the source voltage, 6 PV arrays are connected in parallel. So the output voltage of PV cell is increased up to 119.7V DC. The PV cell voltage is then stepped up to a certain level. A boost converter is used for this purpose. The boost converter steps up the voltage and provides 340V DC output. The efficiency of boost converter is 95.2% as the power of boost converter is 570W. Figure 9 shows the voltage of boost converter. Figure 10 shows the voltage and current of single phase DC-AC inverter.

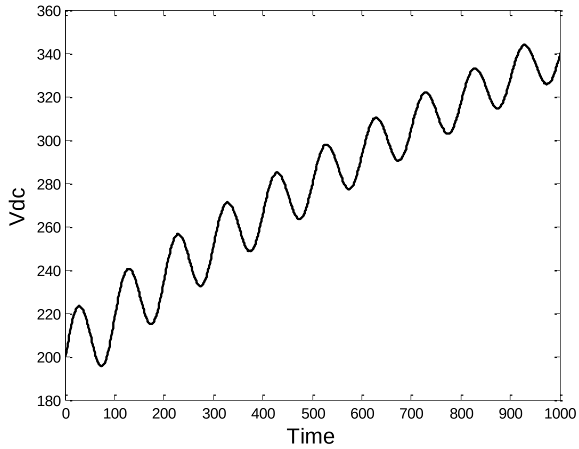

Fig. 9. Output voltage of boost converter

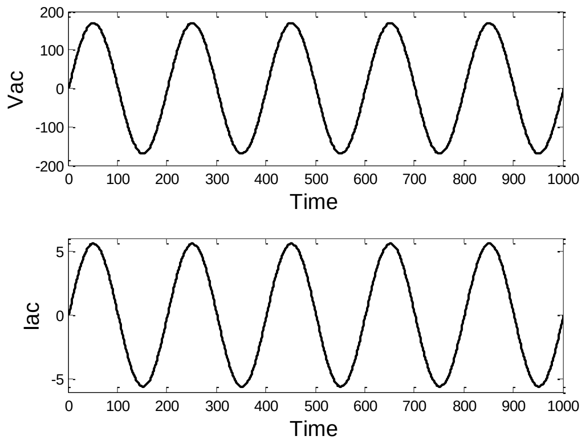

Fig. 10. Output voltage and current of DC-AC inverter

For power quality constraints, the total harmonic distortion (THD) of the voltage and current should be with in a limit of 5% according to IEEE-519 standard. Figure 11 shows the current THD of the system which is under the 5% boundary condition.

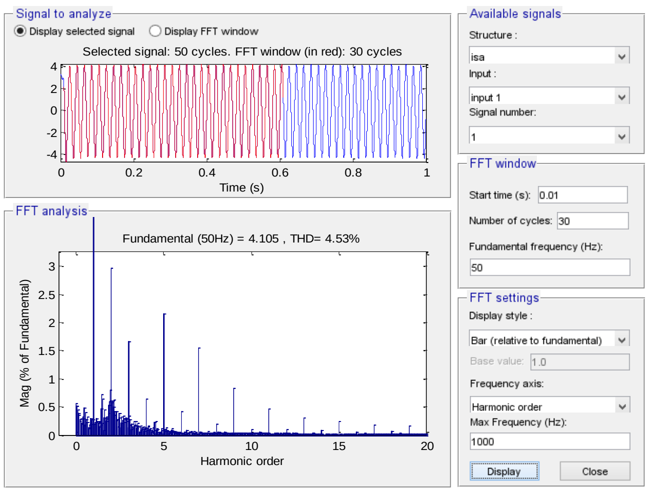

Fig. 11. Total harmonic distortion (THD) of load current of DC-AC inverter

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VIII. CONCLUSIONS

This paper provides the design of 600W grid connected PV array setup. The grid connected setup comprises of 6 standalone PV cell connected in parallel, DC-DC boost converter, single phase DC-AC inverter and LC filter. Voltage control method and current control method is used to control the DC-DC converter and DC-AC inverter. Simulation analysis is carried out and functionality of each and every sub module and sub system is tested and all the system are working in satisfactory condition with high efficiency.

REFERENCES

1. Bidyadhar Subudhi, Raseswari Pradhan, "A comparative study on maximum power point tracking techniques for photovolatic power systems," IEEE Transactions on Sustainable Energy, vol. 4, no. 1, 2013, pp. 89-98.
2. Boualem Bendib, Hocine Belmili, Fateh Krim, "A survey of the most used MPPT methods: Conventional and advanced algorithms applied for photovolatic systems," Renewable and Sustianable Energy Reviews, vol. 45, May 2015, pp. 637-648.
3. Hegazy Rezk, Ali M. Eltamaly, "A comparative comparision of different MPPT techniques for photovoltaic systems," Solar Energy, vol. 112, Feb 2015, pp. 1-15.
4. Giovanni Petrone, Giovanni Spagnuolo, and Massimo Vitelli, "An Analog Technique for Distributed MPPT PV Applications," IEEE Transactions on Industial Electronics, Vol. 59, No. 12, Dec 2012, pp. 4713-4722.
5. Hiren Patel and Vivek Agarwal, "MPPT Scheme for a PV-Fed Single-Phase Single-Stage Grid-Connected Inverter Operating in CCM With Only One Current Sensor," IEEE Transactions on Energy Conversion, vol. 24, no. 1, Mar 2009, pp. 256-263.
6. Raseswari Pradhan, Bidyadhar Subudhi, "Design and real-time implementation of a new auto-tuned adaptive MPPT control for a photovoltaic system," International Journal of Electric Power and Energy Systems, vol. 64, Jan 2015, pp. 792-803.
7. Venkata Ratnam Kolluru, Kamalakanta Mahapatra and Bidyadhar Subudhi, "Development and Implementation of Control Algorithms For a Photovoltaic System," in Proc. IEEE Students Conf. Engineering and Systems, 2013, pp. 1-5.
8. Kinattingal Sundareswaran, Sankar Peddapati, and Sankaran Palani, "MPPT of PV Systems Under Partial Shaded Conditions Through a Colony of Flashing Fireflies," IEEE Transactions on Energy Conversion, vol. 29, no. 2, June 2014, pp. 463-471.
9. Subhransu Padhee, Umesh Chandra Pati, Kamalakanta Mahapatra, "Investigation on transient response of fuel cell power conditioning unit during rapid load changes," in Proc. IEEE Conf. Computational Intelligence and Communication Technology, 2015, pp. 482-487.
10. Kanhu Charan Bhuyan, Rajesh Kumar Patjoshi, Subhransu Padhee, Kamalakanta Mahapatra, "Solid oxide fuel cell with DC-DC converter system: Control and grid interfacing," WSEAS Transactions on Systems and Control, 9, 2014, pp. 247-254.
11. Kanhu Charan Bhuyan, Sumit Sao and Kamalakanta Mahapatra, "An FPGA based controller for a SOFC DC-DC power system," Advances in Power Electronics, 2013.
12. Kanhu Charan Bhuyan, Subhransu Padhee, Rajesh Kumar Patjoshi, Kamalakanta Mahapatra, "Hysteresis Control of Power Conditioning Unit for Fuel Cell Distributed Generation System," International Journal of Electrical, Computer, Electronics and Communication Engineering, vol. 8, issue 7, 2014, pp. 1143-1148.
13. Dong-Yub Hyun, Chang-Soon Lim, Rae-Young Kim, Dong-Seok Hyun, "Average modeling and control of a single phase grid connected two stage inverter for battery application" Proc. IEEE IECON,Vienna,Austria,pp.487-492, 2013

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