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Reconfigurable Solar Converter: A Single-Stage Power Conversion PV-Battery System and a Comparison between MPPT Techniques

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Abstract--This paper introduces a new converter called reconfigurable solar converter (RSC) for photovoltaic (PV)-battery application, particularly utility-scale PV-battery application. Maximum Power Point Tracking (MPPT) algorithms are important in PV systems because it reduces the PV array cost by reducing the number of PV panels required to achieve the desired output power. This paper presents comparative simulation study of two important MPPT algorithms specifically perturb and observe and incremental conductance. These algorithms are widely used because of its low-cost and ease of realization. Some important parameters such as voltage, current and power output for each different combination have been traced for both algorithms. Matlab simulink tool box has been used for performance evaluation by a 70W photovoltaic (PV) array.

***Keywords**:* Converter, energy storage, photovoltaic (PV), solar.

1. Introduction

Photovoltaic (PV) generation represents currently one of the most promising sources of renewable green energy. Due to the environmental and economic benefits, PV generation is preferred over other renewable energy sources, since they are clean, inexhaustible and require little maintenance. PV cells generate electric power by directly converting solar energy to electrical energy. PV panels and arrays, generate DC power that has to be converted to AC at standard power frequency in order to feed the loads. Therefore PV systems require interfacing power converters between the PV arrays and the grid. Photovoltaic-generated energy can be delivered to power system networks through grid-connected inverters. One significant problem in PV systems is the probable mismatch between the operating characteristics of the load and the PV array. The system's operating point is at the intersection of the I-V curves of the PV array and load, when a PV array is directly connected to a load. The Maximum Power Point (MPP) of PV array is not attained most of the time. This problem is overcome by using an MPPT which maintains the PV array's operating point at the MPP. The occurrence of MPP in the I-V plane is not known priory; therefore it is calculated using a model of the PV array and measurements of irradiance and array temperature. Calculating these measurements are often too expensive and the required parameters for the PV array model are not known adequately. Thus, the MPPT continuously searches for MPP. There are several MPPT continuously searches algorithms that have been proposed which uses different characteristics of solar panels and the location of the MPP [1].

There are different options for integrating energy storage into a utility-scale solar PV system. Specifically, energy storage can be integrated into the either ac or dc side of the solar PV power conversion systems which may consist of multiple conversion stages [4]. Every integration solution has its advantages and disadvantages. Different integration solutions can be compared with regard to the number of power stages, efficiency, storage system flexibility, control complexity, etc.

To extract the maximum power from the solar PV module and transfer that power to the load, a MPPT is used. A dc/dc converter (step up/step down) transfers maximum power from the solar PV module to the load and it acts as an interface between the load and the module. Maximum power is transferred by varying the load impedance as seen by the source and matching it at the peak power of it when the duty cycle is changed. In order to maintain PV array's operating at its MPP, different MPPT techniques are required. In the literature many MPPT techniques are proposed such as, the Perturb and Observe (P&O) method, Incremental Conductance (IC) method, Fuzzy Logic Method etc. Of these, the two most popular MPPT techniques (Perturb and Observe (P&O) and Incremental Conductance methods) are studied [2].

The paper has been organized in the following manner. The proposed RSC circuit, system benefits and different modes of operation discussed in section 2. Control of RSC is introduced in section 3. The basic principle of PV cell and the

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characteristics of PV array are discussed in section 4. Section 5 presents the P&O and In C MPPT algorithms in detail. The simulation results of PV array, MPPT algorithms and their comparison are discussed in section 6. Last section concludes with the scope for further work.

2. RSC

2.1 Introduction

The schematic of the proposed RSC circuit is presented in Fig.1.

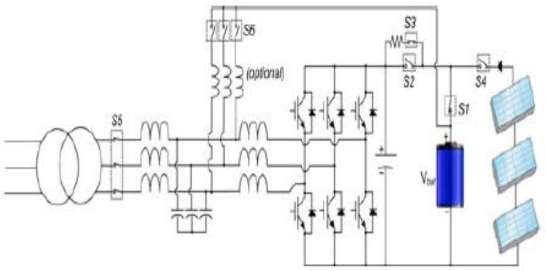

Fig.1 Schematic of the proposed RSC circuit

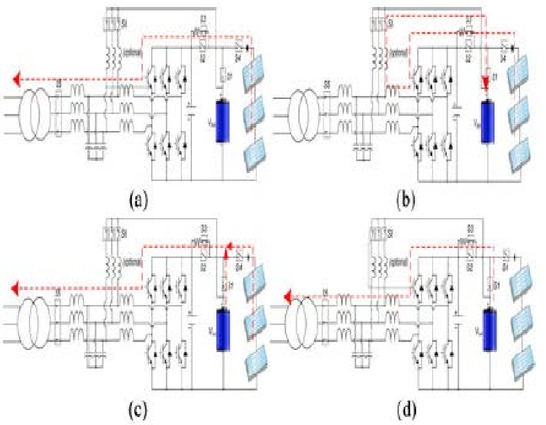

Fig.2 All operation modes of the RSC (a) Mode 1 PV to grid (b) Mode 2 PV to battery (c) Mode 3 PV/battery to grid (d) Mode 4 battery to grid

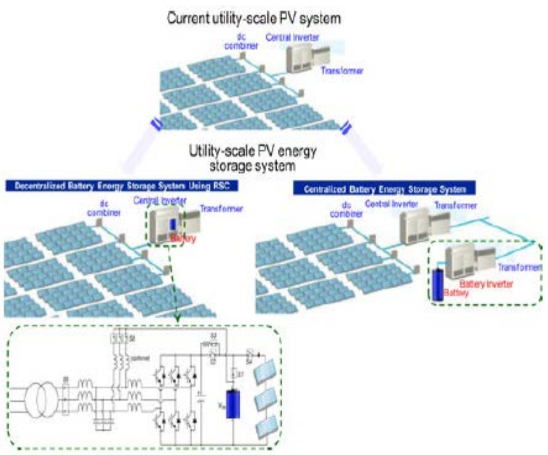

Fig.3 Utility-scale PV-energy storage systems with the RSC and the current state-of-the-art solution

The RSC has some modifications to the conventional three-phase PV inverter system. These modifications allow the RSC to include the charging function in the conventional three phase PV inverter system. Assuming that the conventional utility-scale PV inverter system consists of a three-phase voltage source converter and its associated components, the RSC requires additional cables and mechanical switches, as shown in Fig.1.

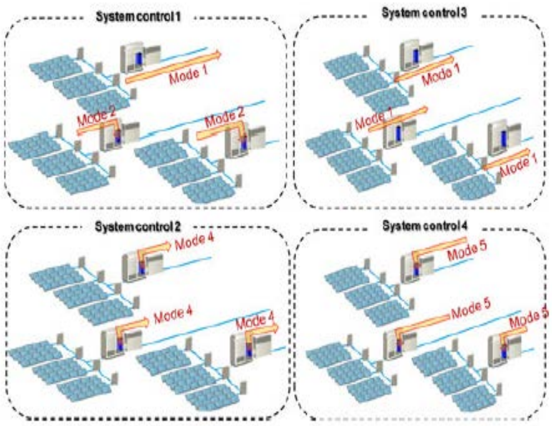

Fig.4 Example of different system operation modes of a RSC-based solar PV power plant

2.2 Operation Modes of the RSC

All possible operation modes for the RSC are presented in Fig.2. In Mode 1, the PV is directly connected to the grid through a dc/ac operation of the converter with possibility of maximum power point tracking (MPPT) control and the *S*1 and *S*6 switches remain open. In Mode 2, the battery is charged with the PV panels through the dc/dc operation of the converter by closing the *S*6 switch and opening the *S*5 switch. In this mode, the MPPT function is performed; therefore, maximum power is generated from PV. There is another mode that both the PV and battery provide the power to the grid by closing the *S*1 switch. This operation is shown as Mode 3. In this mode, the dc-link voltage that is the same as the PV voltage is enforced by the battery voltage; therefore, MPPT control is not possible. Mode 4 represents an operation mode that the energy stored in the battery is delivered to the grid. There is another mode, Mode 5 that the battery is charged from the grid. This mode is not shown in Fig.2.

2.3 System Benefits of Solar PV Power Plant with the RSC Concept

The RSC concept provides significant benefits to system planning of utility-scale solar PV power plants. Fig.3 shows examples of the PV

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energy storage solutions with the RSC and the current state-of-the-art technology. The technical and financial benefits that the RSC solution is able to provide are more apparent in larger solar PV power plants. Specifically, a large solar PV power plant using the RSCs can be controlled more effectively and its power can be dispatched more economically because of the flexibility of operation. Developing a detailed operation characteristic of a solar PV power plant with the RSC is beyond the scope of this paper. However, different system controls as shown in Fig.4 can be proposed based on the requested power from the grid operator *P*req and available generated power form the plant *P*gen. RSC-based solar PV power plant as follows:

1) system control 1 for *P*gen > *P*req;
2) system control 2 for *P*gen < *P*req;
3) system control 3 for *P*gen = *P*req;
4) system control 4 for charging from the grid (Operation Mode 5).

3. RSC CONTROL

The RSC Control in 4 ways in brief

1. Control of the RSC in the DC/AC Operation Modes (Modes 1, 3, 4, and 5)
2. Control of the RSC in the DC/DC Operation Mode (Mode 2)
3. Design Considerations and Modifications to the
4. Conventional Three-Phase PV Converter Mode Change Control.

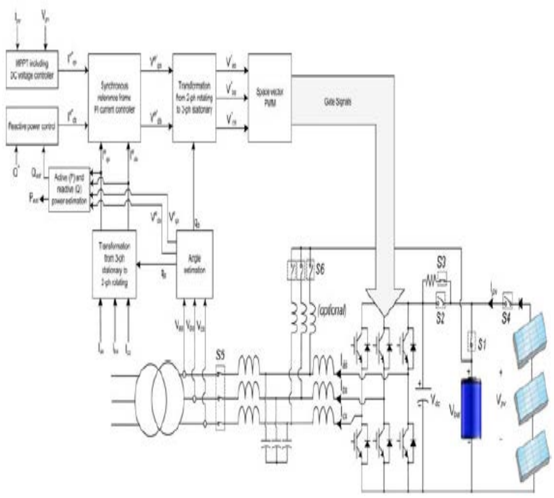

Fig.5 Overall control block diagram of the RSC in the dc/ac operation

The RSC dc/ac operation is used for delivering power from PV to grid (mode1), battery to grid (mode3), PV and battery to grid (mode4), and grid to battery (mode5). The overall control block diagram of the RSC in dc/ac operation is shown in Fig.5.

The RSC dc/dc operation is used for delivering the maximum power from the PV to the battery (mode2). The overall control block diagram of the RSC in dc/dc operation is shown in Fig.6.

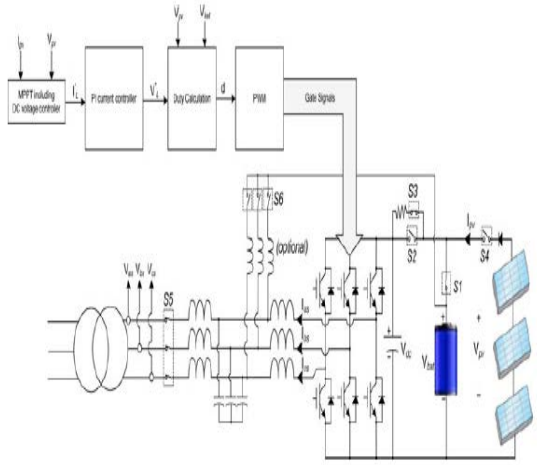

Fig.6 Overall control block diagram of the RSC in the dc/dc operation

4. PV array Characteristics

The use of single diode equivalent electric circuit makes it possible to model the characteristics of a PV cell. The mathematical model of a photovoltaic cell can be developed using MATLAB simulink toolbox. The basic equation from the theory of semiconductors that mathematically describes the I-V characteristic of the Ideal photovoltaic cell is given by

$$I = I_{pvcell} - I_d \quad (1)$$

Where,

$$I_d = I_{0cell}[\exp(qv/\alpha kT)-1] \quad (2)$$

Therefore

$$I = I_{pvcell} - I_{0cell}[\exp(qv/\alpha kT)-1] \quad (3)$$

Where, 'I_{PVCell}' is the current generated by the incident light (it is directly proportional to the Sun irradiation), I_d is the diode equation, Io, cell' is the reverse saturation or leakage current of the diode, 'q' is the electron charge [1.60217646* 10−19C], k is the Boltzmann constant [1.3806503 *10−23J/K], 'T' is the temperature of the *p-n* junction, and 'a' is the diode ideality constant. Fig.7 shows the equivalent circuit of ideal PV cell.

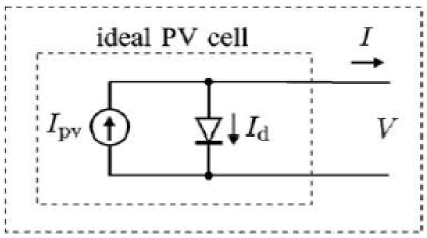

Fig.7 Equivalent circuit of ideal PV cell

Practical arrays are composed of several connected PV cells and the observation of the

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characteristics at the terminals of the PV array requires the inclusion of additional parameters (as shown in Fig.8) to the basic equation:

$I = I_{pv}-I_o[\exp(V+IR_s/V_t\alpha)-1]-(V+IR_s/R_p)$ (4)

Where $V_t = N_skT/q$ is the thermal voltage of the array with 'N_s' cells are connected in series. Cells connected in parallel increases the current and cells connected in series provide greater output voltages. *V* and *I* are the terminal voltage and current. The equivalent circuit of ideal PV cell with the series resistance (Rs) and parallel resistance (Rp) is shown in Fig.8.

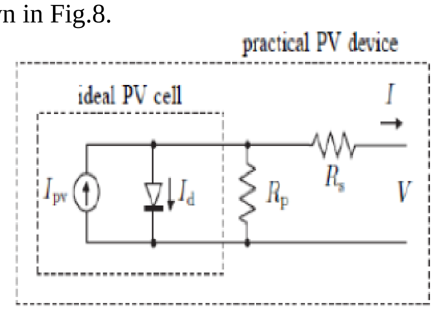

Fig.8 Equivalent circuit of ideal PV cell with Rp and Rs.

For a good solar cell, the series resistance (Rs), should be very small and the shunt (parallel) resistance (Rp), should be very large. For commercial solar cells (Rp) is much greater than the forward resistance of a diode. The I-V curve is shown in Fig.9. The curve has three important parameters namely open circuit voltage (Voc), short circuit current (Isc) and maximum power point (MPP). In this model single diode equivalent circuit is considered. The I-V characteristic of the photovoltaic device depends on the internal characteristics of the device and on external influences such as irradiation level and the temperature.

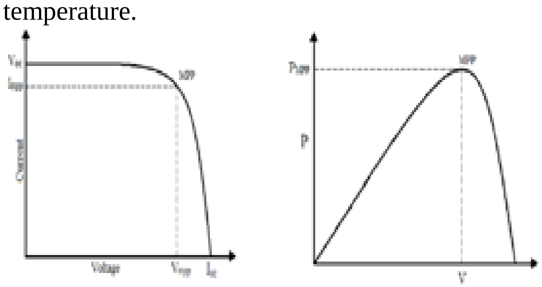

Fig.9 I-V and P-V characteristics of PV cell

5. MPPT ALGORITHMS

5.1 Perturb and Observe (P&O) Algorithm

A slight perturbation is introduced in this algorithm. The perturbation causes the power of the solar module to change continuously. If the power increases due to the perturbation then the perturbation is continued in the same direction. The power at the next instant decreases after the peak power is reached, and after that the perturbation reverses. The algorithm oscillates around the peak point when the steady state is reached. The perturbation size is kept very small in order to keep the power variation small [1]. The algorithm can be easily understood by the following flow chart which is shown in Fig.10.

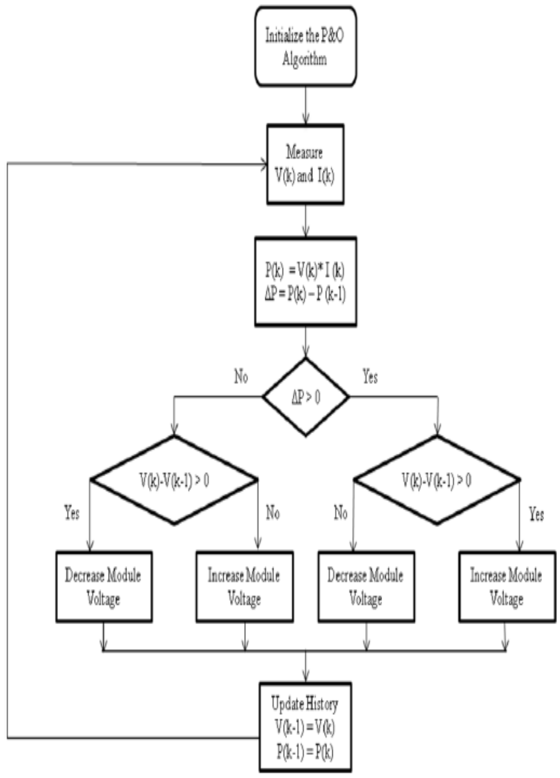

Fig.10 Perturb and Observe Algorithm

5.2 Incremental Conductance (IC) Algorithm

Incremental Conductance (IC) method overcomes the disadvantage of the perturb and observe method in tracking the peak power under fast varying atmospheric condition [2]. The disadvantage of this algorithm is that it is more complex when compared to P&O. The algorithm can be easily understood by the following flow chart which is shown in Fig.11.

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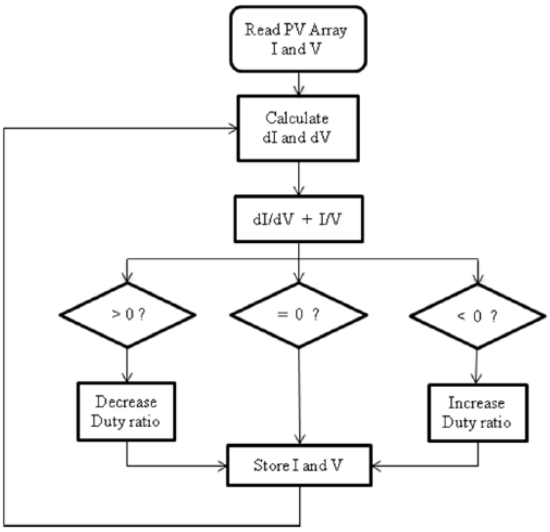

Fig.11 Incremental Conductance Algorithms

6. SIMULATION RESULTS

The simulation circuit of proposed RSC circuit is shown in Fig.12. The simulation circuit of perturb and observe MPPT method is shown in Fig.13. The simulation circuit of Incremental Conductance MPPT method is shown in Fig.14.

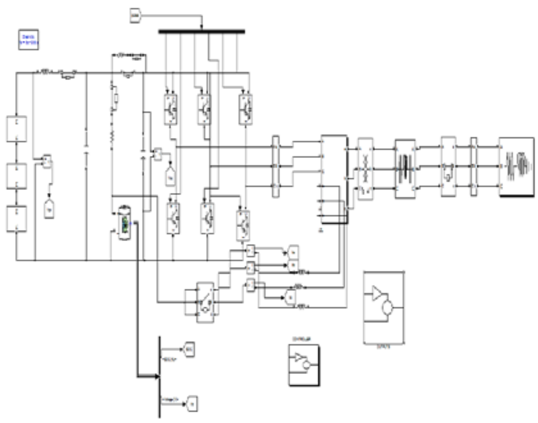

Fig.12 Simulation Circuit of RSC

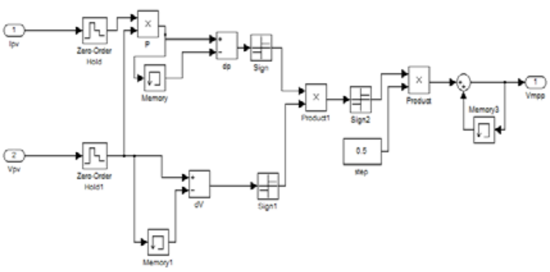

Fig.13 P&O MPPT

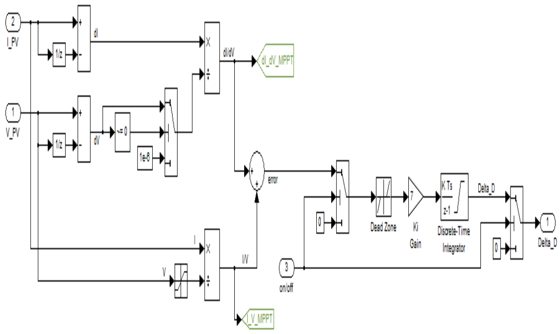

Fig.14 Incremental Conductance MPPT

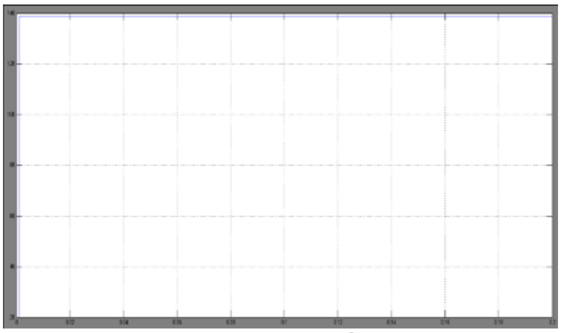

Fig.15 PV output Voltage

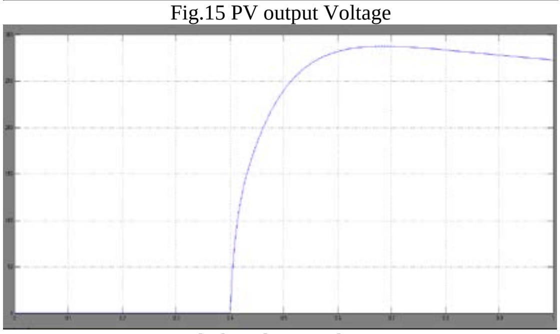

Fig.16 DC link Voltage with P&O MPPT

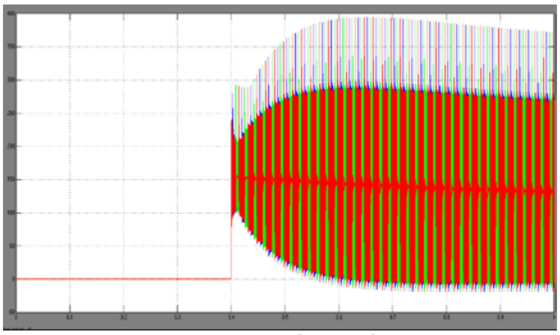

Fig.17 Inverter Output Voltage with P&O MPPT

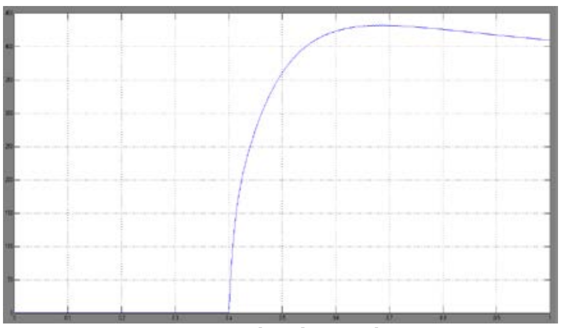

Fig.18 DC Link Voltage with INC

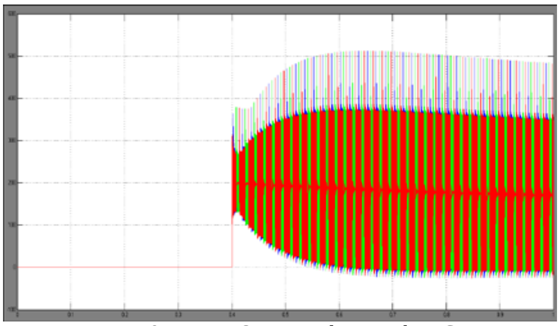
Fig.19 Inverter Output Voltage with INC

Fig.15 shows the output voltage of PV. The DC link voltage with P&O MPPT method is shown in Fig.16. The DC link voltage with Incremental Conductance MPPT method is shown in Fig.18. By comparing Fig.16&Fig.18, the DC link voltage is high with INC MPPT method. Fig.17 shows the inverter output voltage with P&O MPPT method. Fig.19 shows the inverter output voltage with INC MPPT method. By comparing Fig.17&Fig.19, the inverter output voltage is high with INC MPPT method.

7. CONCLUSION

This paper introduced a new converter called RSC for PV-battery application, particularly utility-scale PV-battery application. The basic concept of the RSC is to use a single power conversion system to perform different operation modes such as PV to grid (dc to ac), PV to battery (dc to dc), battery to grid (dc to ac), and battery/PV to grid (dc to ac) for solar PV systems with energy storage. The proposed solution requires minimal complexity and modifications to the conventional three-phase solar PV converters for PV-battery systems. In this paper a mathematical model of a 70W photovoltaic panel has been developed using MATLAB Simulink. This model is used for the maximum power point tracking algorithms. The P&O and Incremental conductance MPPT algorithms are discussed and their simulation results are presented. It is proved that Incremental conductance method has better performance than P&O algorithm. These algorithms improve the dynamics and steady state performance of the photovoltaic system as well as it improves the efficiency of the dc-dc converter system.

REFERENCES

[1] Trishan Esram, and Patrick L. Chapman, “Comparison of Photovoltaic Array Maximum PowerPoint Tracking Techniques,” *IEEE Transactions on Energy Conversion, 22 (2)*, 2007, 439-449.

[2] Hairul Nissah Zainudin, Saad Mekhilef, “Comparison Study of Maximum Power Point Tracker Techniques for PV Systems,” *Proc. 14th International Middle East Power Systems Conference (MEPCON10)*, Cairo University, Egypt, 2010, 750-755.

[3] U.S. Department of Energy, “Solar energy grid integration systems-energy storage (SEGIS-ES),” May 2008.

[4] J. H. Enslin and D. B. Snyman, “Combined low-cost, high efficient inverter, peak power tracker and regulator for PV applications,” *IEEE Trans. Power Electron*., vol. 6, no. 1, pp. 73–82, Jan. 1991.

[5] F. Liu, *et al.*, “A variable step size INC MPPT method for PV systems,” *IEEE Transactions on Industrial Electronics*, vol. 55, pp. 2622-2628, Jul 2008.

[6] M. Bragard, N. Soltau, R. W. De Doncker, and A. Schiemgel, “Design and implementation of a 5 kW photovoltaic system with Li-ion battery and additional dc/dc converter,” in *Proc. IEEE Energy Convers. Congr. Expo.*, 2010, pp. 2944–2949.

[7] P. Barrade, S.Delalay, and A. Rufer, “Direct connection of supercapacitors to photovoltaic panels with on-off maximum power point tracking,” *IEEE Trans. Sustainable Energy*, vol. 3, no. 2, pp. 283–294, Apr. 2012.

[8] M. Bragard, N. Soltau, R. W. De Doncker, and A. Schmiegel, “Design and implementation of a 5 kW PV system with Li-ion battery and additional dc/dc converter,” in *Proc. IEEE Energy Convers. Congr. Expo.*, 2010, pp. 2944–2949.

[9] F. Ding, P. Li, B. Huang, F. Gao, C. Ding, and C. Wang, “Modeling and Simulation of grid connected hybrid PV/battery distributed generation system,” in *Proc. China Int. Conf. Electr. Distrib.*, 2010, pp. 1–10.

[10] J. Jung and A. Kwasinski, “A multiple input SEPIC with bidirectional input for modular distributed generation and energy storage integration,” in *Proc. IEEE Appl. Power Electron. Conf. Expo.*, Mar. 2011, pp. 28–34.

[11] L. Ma, K. Sun, R. Teodorescu, J. M. Guerrero, and X. Jin, “An integrated multifunction dc/dc converter for PV generation system,” in *Proc. IEEE Int. Symp. Ind. Electron.*, Jul. 2010, pp. 2205–2210.

[12] I. Sefa and S. Ozdemir, “Multifunctional interleaved boost converter for PV systems,” in *Proc. IEEE Int. Symp. Ind. Electron.*, Jul. 2010, pp. 951– 956.

[13]S. Liu,X. Zhang, H. Guo, and J. Xie, “Multiport DC/DC converter for stand -alone PV lighting system with battery storage,” in *Proc. IEEE Int. Conf. Electr. Control Eng.*, Jun. 2010, pp. 3894–3897.

[14] Y. Hu, J. Tatler, and Z. Chen, “A bidirectional DC/DC power electronic converter for an energy storage device in an autonomous power system,” in *Proc. IEEE Power Electron. Motion Control Conf.*, Aug. 2004, pp. 171– 176.

ISSN 2348 – 7968

[15] J. Wang, C. Wang, and F. Hong, "New topology of dc/dc converter for battery discharging circuit in PV system," in *Proc. 9th IEEE Int. Conf. Electron. Meas. Instrum.*, 2009, pp. 1-136–1-139.
[16] R. Carbone, "Grid connected PV systems with energy storage," in *Proc. Int. Conf. Clean Electr. Power*, Jun. 2009, pp. 760–767.
[17] S. A. Zabalwi, G. Mandic, and A. Nasiri, "Utilizing energy storage with PV for residential and commercial use," in *Proc. IEEE Ind. Electron. Conf.*, Nov. 2008, pp. 1045–1050.
[18] S. Jain and V. Agarwal," Comparison of the performance of maximum power point tracking schemes applied to single-stage grid-connected photovoltaic systems," *IET Electr. Power Appl.*, 2007, 1, (5), pp. 753–762.
[19] Nicola Femia, Giovanni Petrone, Giovanni Spagnuolo and Massimo Vitelli (2005) "Optimization of Perturb and Observe Maximum Power point Tracking Method," *IEEE transaction on power electronics*, vol.20, no.4.
[20] H. Konishi, T. Iwato, and M. Kudou, "Development of large-scale power conditioning system in Hokuto mega-solar project," in *Proc. Int. Power Electron. Conf.*, 2010, pp. 1975–1979.
[21] H. Ertl, J. W. Kolar, and F. Zach, "A novel multicell dc-ac converter for applications in renewable energy systems," *IEEE Trans. Ind. Electron.*, vol. 49, no. 5, pp. 1048–1057,
Oct. 2002

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