VOL. 10, NO. 17, SEPTEMBER 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

AN INVESTIGATION ANALYSIS OF GRID CONNECTED PV SYSTEM USING RECONFIGURABLE SOLAR CONVERTER

T. Sundar[1] and S. Sankar[2]
[1]Department of EIE, SCSVMV University, Kanchipuram, Tamilnadu, India
[2]Department of Electrical and Electronics Engineering, Panimalar Institute of Technology, Chennai, Tamilnadu, India
E-Mail: Sundar_151@yahoo.co.in

ABSTRACT

This paper is used to a new converter called reconfigurable solar converter (RSC) for photovoltaic (PV) system. The new converter is to use a three phase single-stage grid connected solar PV converter to perform dc/ac and dc/dc operations. This converter is likable for PV system, because it minimizes the number of conversion stages, so improving efficiency and reducing cost. The Simulation results are conformed to the theoretical results of the proposed RSC.

Keywords: converter, energy storage, photovoltaic, sim power system.

INTRODUCTION

Solar photovoltaic (PV) electricity generation is not available and sometimes less available depending on the time of the day and the weather conditions [1-3]. The different Scenarios for PV generation and load supply sequence is shown in Figure-1. Solar PV electricity output is also highly sensitive to shading [4, 5]. When even a small portion of a cell, module, or array is shaded, while the remainder is in sunlight, the output falls dramatically. Therefore, solar PV electricity output significantly varies [6, 7]. From an energy source standpoint, a stable energy source and an energy source that can be dispatched at the request are desired.

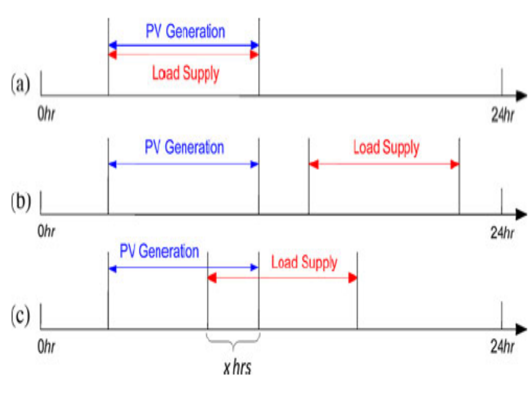

Figure-1. Different scenarios for PV generation and load supply sequence.

As a result, energy storage such as batteries and fuel cells for solar PV systems has drawn significant attention and the demand of energy storage for solar PV systems has been dramatically increased, since, with energy storage, a solar PV system becomes a stable energy source and it can be dispatched at the request, which results in improving the performance and the value of solar PV systems [8]. 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.

PROPOSED METHOD OF RSC

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 RSC concept arose from the fact that energy storage integration for utility-scale solar PV systems makes sense if there is an enough gap or a minimal overlap between the PV energy storage and release time. The Schematic of the proposed RSC Circuit is shown in Figure-2.

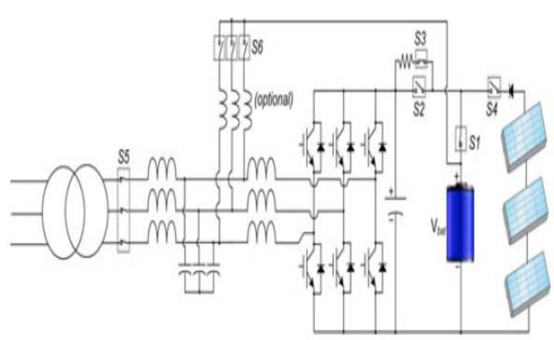

Figure-2. Schematic of the proposed RSC circuit.

VOL. 10, NO. 17, SEPTEMBER 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

Modes of Operations:

Mode 1

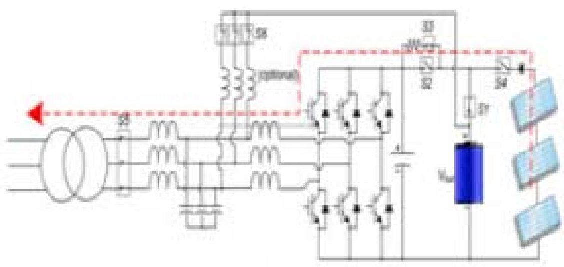

Figure-3. During the Mode 1, the PV is directly connected to the grid through a dc/ac operation of the converter with possibility of maximum power point tracking (MPPT) control and the *S*1 and *S*6 switches remain open.

Mode 2

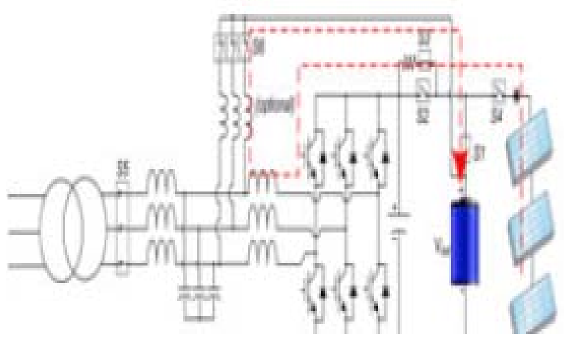

Figure-4. During the Mode 2, the battery is charged with the PV panels through the dc/dc operation of the converter by closing the *S*6 switch and opening the *S*5 switch.

Mode 3

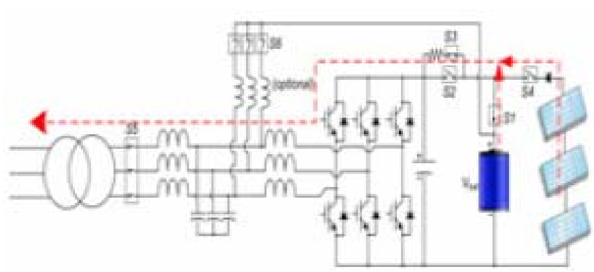

Figure-5. During the Mode3, both the PV and battery provide the power to the grid by closing the *S*1 switch.

Mode 4

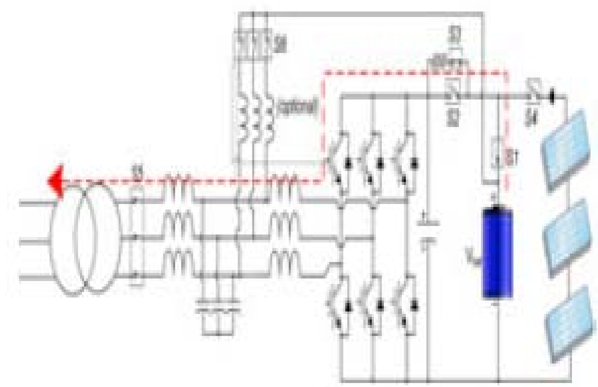

Figure-6. During the Mode4 represents an operation mode that the energy stored in the battery is delivered to the grid.

SOLAR PV POWER PLANT WITH THE RSC CONCEPT

The RSC concept provides significant benefits to system planning of utility-scale solar PV power plants. The current state of- the-art technology is to integrate the energy storage into the ac side of the solar PV system. The RSC concept allows not only the system owners to possess an expandable asset that helps them to plan and operate the power plant accordingly but also manufacturers to offer a cost competitive decentralized PV energy storage solution with the RSC. The PV 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 can be proposed based on the requested power from the grid operator Preq and available generated power form the plant Pgen. These two values being results of an optimization problem (such as unit commitment methods) serve as variables to control the solar PV power plant accordingly.

In other words, in response to the request of the grid operator, different system control schemes can be realized with the RSC-based solar PV power plant as follows:

1) system control 1 for Pgen > Preq;
2) system control 2 for Pgen < Preq;
3) system control 3 for Pgen = Preq;

VOL. 10, NO. 17, SEPTEMBER 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

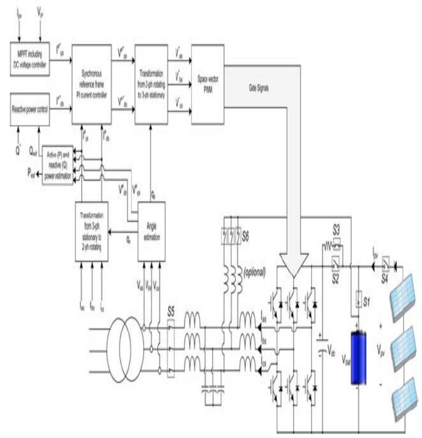

Figure-7. Overall control block diagram of the RSC in the dc/ac operation.

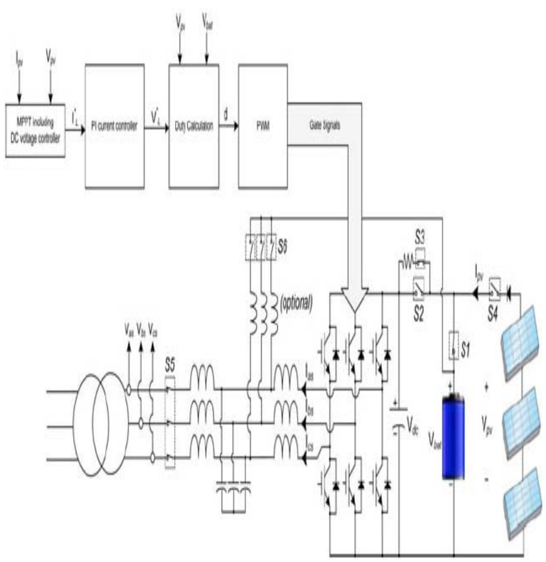

Figure-8. Overall control block diagram of the RSC in the dc/dc operation.

One of the most important requirements of the project is that a new power conversion solution for PV-battery systems must have minimal complexity and modifications to the conventional three-phase solar PV converter system. Therefore, it is necessary to investigate how a three-phase dc/ac converter operates as a dc/dc converter and what modifications should be made. It is common to use a LCL filter for a high-power three-phase PV converter and the RSC in the dc/dc operation is expected to use the inductors already available in the LCL filter. There are basically two types of inductors, coupled three-phase inductor and three single-phase inductors that can be utilized in the RSC circuit. Using all three phases of the coupled three-phase inductor in the dc/dc operation causes a significant drop in the inductance value due to inductor core saturation. The reduction in inductance value requires inserting additional inductors for the dc/dc operation which has been marked as "optional" in Figure-8. To avoid extra inductors, only one phase can perform the–dc/dc operation. However, when only one phase, for instance phase B, is utilized for the dc/dc operation with only either upper or lower three insulated-gate bipolar transistors (IGBTs) are turned OFF as complementary switching, the circulating current occurs in phases A and C through filter capacitors, the coupled inductor, and switches, resulting in high current ripple in phase B current.

To prevent the circulating current in the dc/dc operation, the following two solutions are proposed;

1) All unused upper and lower IGBTs must be turned OFF;
2) The coupled inductor is replaced by three single-phase inductors.

While the first solution with a coupled inductor is straightforward, using three single-phase inductors makes it possible to use all three phase legs for the dc/dc operation. There are two methods to utilize all three phase legs for the dc/dc operation:

1) Synchronous operation;
2) Interleaving operation.

To overcome the aforementioned problem associated with the synchronous operation, phases B and C can be shifted by applying a phase offset. For the interleaving operation using three phase legs, phases B and C are shifted by 120◦ and 240◦, respectively. The inductor current control in interleaving operation requires a different inductor current sampling scheme In general, for digital control of a dc/dc converter; the inductor current is sampled at either the beginning or center point of PWM to capture the average current that is free from switching noises. For two phase interleaving that two phases are 180◦ apart, there is no need to modify the sampling scheme, since the average inductor currents for both phases can be obtained with the conventional sampling scheme.

However, for three-phase interleaving, a modified sampling scheme is required to measure the average currents for all three phases. Therefore, the sampling points for phases B and C must be shifted by 120◦ and 240◦, respectively which may imply that computation required inductor current control for each phase should be done asynchronously. Using the interleaving operation reduces the ripples on the charging current flowing into the battery. Therefore, the filter capacitance value can be reduced significantly.

MODE CHANGE CONTROL

The basic concept of the RSC is to use a single power electronics circuit to perform different operation modes such as PV to grid (dc to ac) and PV to battery (dc

VOL. 10, NO. 17, SEPTEMBER 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

to dc) for PV systems with energy storage, as discussed earlier. Therefore, in addition to the converter control in each mode, the seamless transition between modes is also essential for the RSC operation. To change a mode, the RSC must be reconfigured by either disconnecting or connecting components such as the battery through contactors. It is very important to understand the dynamics of the RSC circuit. Specifically, it is essential to understand the relay response time such as how long it takes for a relay to completely close or open. Hence, the performance characteristics of all relays used in the RSC circuit must be investigated with their datasheets. All relays used in the RSC circuit have a maximum operating time equal to or smaller than 50 ms. All switching, which occur during mode change, are done under zero or nearly zero current, except fault cases. To verify the operating time given in the datasheet of the relays, a test for one of the relays used is made. The operating time of the relay used for DC .The relay signal inside the DSP is captured through a D/A converter. It takes 240 μs until the signal reaches a value, 12 V that is high enough to trigger the relay switching. Once the operating voltage is applied to the relay, it takes 20 ms until the current starts flowing through the relay. In other words, it takes 20 ms for the relay to be fully closed. The measured relay operating time of 20 ms is only half of the value given in the datasheet. For all relays used in the circuit, 80 ms is used as the relay switching transient time for both closing and releasing. The highest layer of the RSC mode change control is shown in Figure. This layer consists of fault detection, fault reset, and normal operation. The basic fault detection such as detecting over current and over voltage and fault management like turning off PWM signals are implemented inside the converter control executed in the inner most control loop. In this way, fast fault detection and protection are possible.

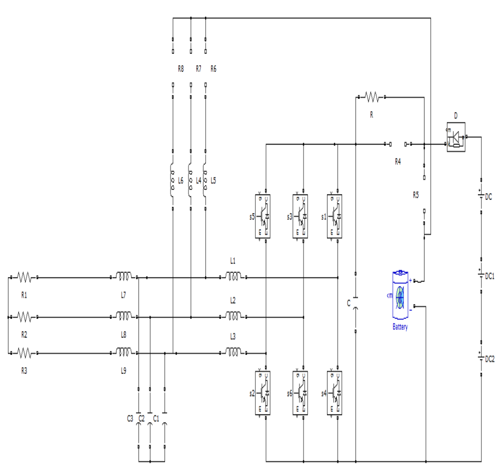

Figure-9. Proposed circuit diagram for mode 1.

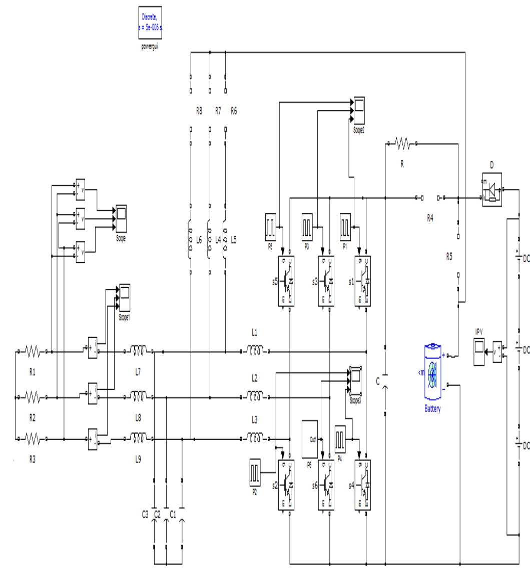

Figure-10. Simulated diagram for the proposed circuit (mode1).

The input voltage for the proposed circuit (mode 1) is 420V as shown in Figure-11. The triggering pulse (S1, S3, S5) for the proposed circuit (mode 1) as shown in Figure-12. The triggering pulse (S2, S4, S6) for the proposed circuit (mode 1) as shown in Figure-13. The simulated triggering pulse as shown in Figure-14 and Figure-15.

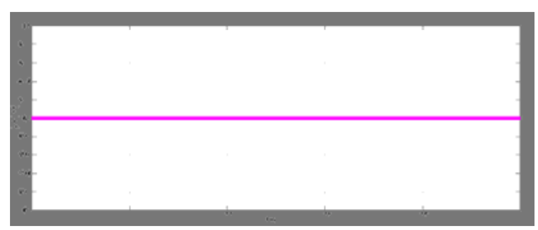

Figure-11. The simulated input voltage for the proposed circuit (mode 1).

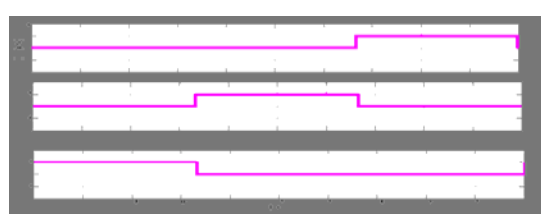

Figure-12. The simulated triggering pulse (S1, S3, S5) for the proposed circuit (mode 1).

VOL. 10, NO. 17, SEPTEMBER 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

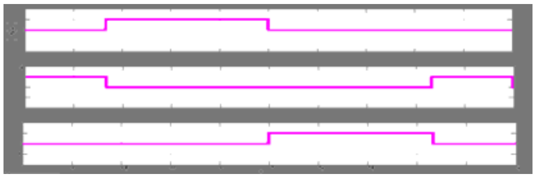

Figure-13. The simulated triggering pulse (S2, S4, S6) for the proposed circuit (mode 1).

The three phase output voltage for the proposed circuit (mode 1) is 500V as shown in Figure-14. The three phase output current for the proposed circuit (mode 1) is 1Amp as shown in Figure-15.

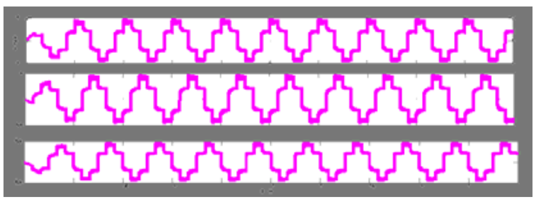

Figure-14. The simulated three phase output voltage for the proposed circuit (mode 1).

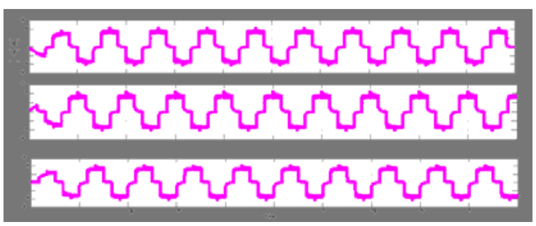

Figure-15. The simulated three phase output current for the proposed circuit (mode 1).

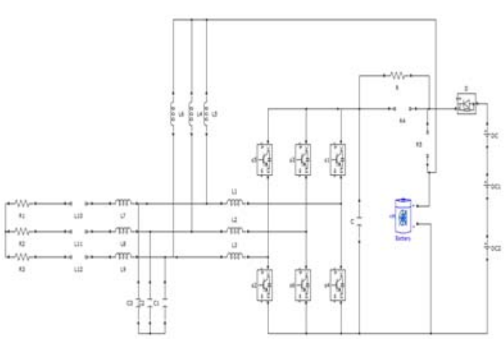

Figure-16. Proposed circuit diagram for mode 2.

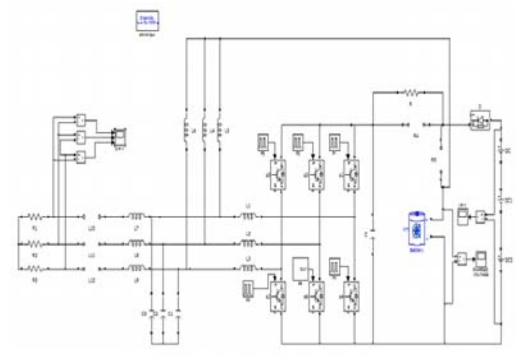

Figure-17. The simulated diagram for the proposed circuit (mode2).

The input voltage for the proposed circuit (mode 2) is 420V as shown in Figure-18. The charged voltage for the proposed circuit (mode 2) is 55V as shown in Figure-19.

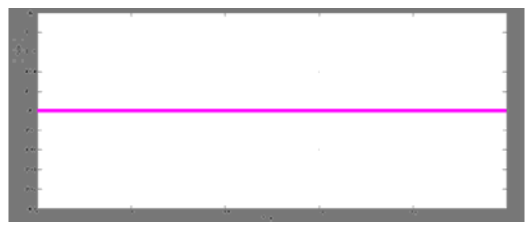

Figure-18. The simulated input voltage for the Proposed circuit (mode 2).

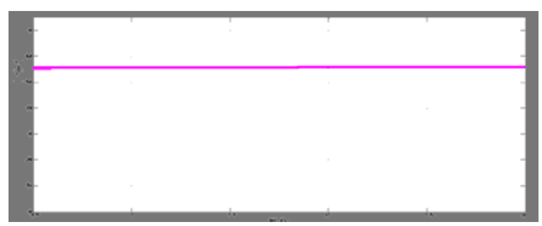

Figure-19. The simulated charged voltage for the proposed circuit (mode 2).

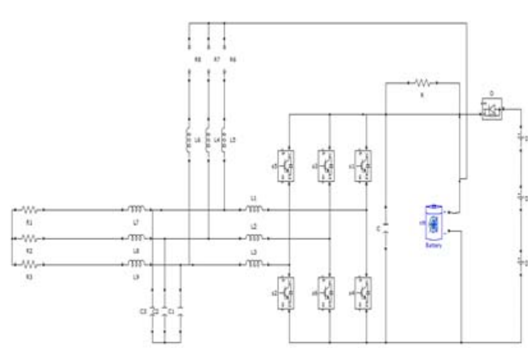

Figure-20. Proposed circuit diagram for mode 3.

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

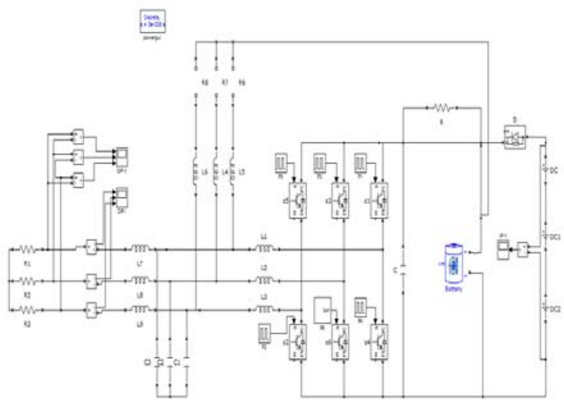

Figure-21. The simulated diagram for the proposed circuit (mode3).

The input voltage for the proposed circuit (mode 3) is 420V as shown in Figure-22. The output voltage for the proposed circuit (mode 3) is 505V as shown in Figure-23. The output current for the proposed circuit (mode 3) is 1.1 Amp as shown in Figure-24.

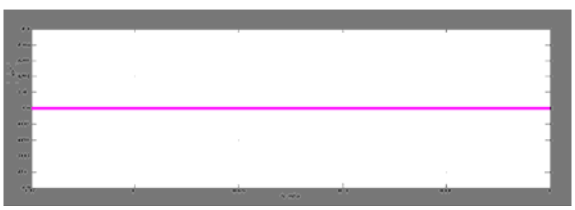

Figure-22. The simulated input voltage for the proposed circuit (mode 3).

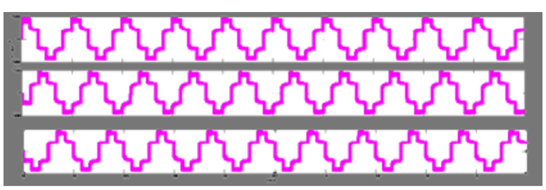

Figure-23. The simulated output voltage for the proposed circuit (mode 3).

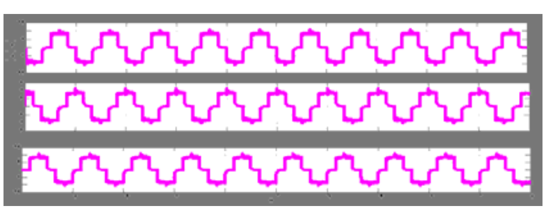

Figure-24. The simulated output current for the proposed circuit (mode 3).

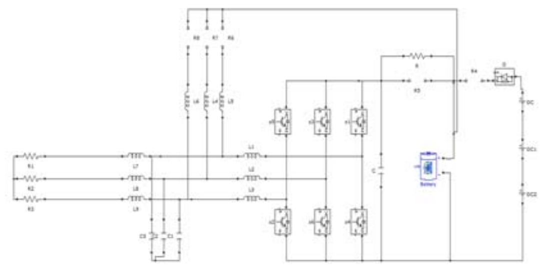

Figure-25. Proposed circuit diagram for mode 4.

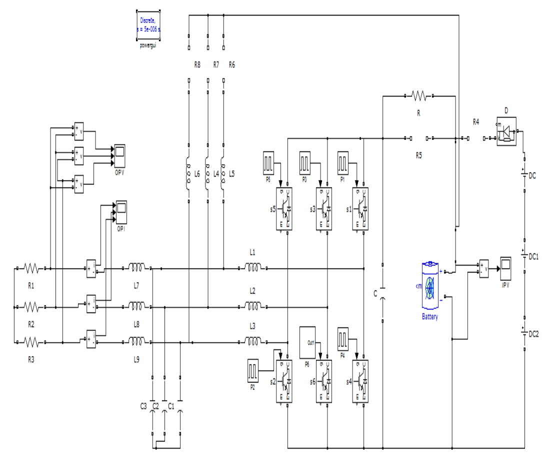

Figure-26. The simulated diagram for the proposed circuit (mode4).

The battery input voltage for the proposed circuit (mode 4) is 130V as shown in Figure-27. The output voltage for the proposed circuit (mode 4) is 150V as shown in Figure-28. The output Current for the proposed circuit (mode 4) is 0.4 Amp as shown in Figure-29.

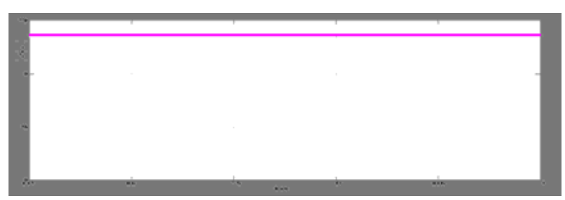

Figure-27. The simulated battery input voltage for the proposed circuit (mode 4).

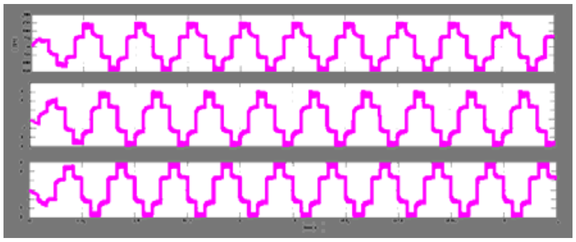

Figure-28. The simulated output voltage for the proposed circuit (mode 4).

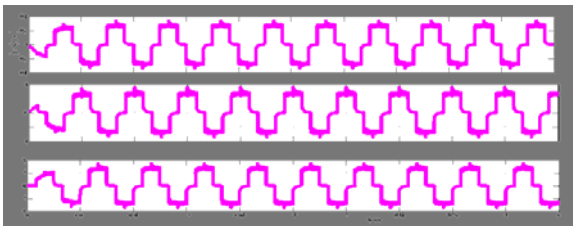

Figure-29. The simulated output current for the proposed circuit (mode 4).

CONCLUSIONS

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. Therefore, the solution is very attractive for PV-battery application, because it minimizes the number of conversion stages, thereby improving efficiency and reducing cost, weight, and volume. The disadvantage of this system is that it has limited voltage range.

REFERENCES

[1] D. Bundestag, “Gesetz zur Neuregelung des Rechts der erneuerbaren Energien im Strombereich und zur A¨ nderung damit zusammenha¨ngender Vorschriften,” Bundesgesetzblatt, 2008.

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

[3] C. Zhao, S. D. Round, and J. W. Kolar, “An isolated three-port bidirectional dc/dc converter with decoupled power flow management,” IEEE Trans. Power Electron., vol. 23, no. 5, pp. 2443-2453, Sep. 2008.

[4] 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.

[5] 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.

[6] 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.

[7] W. Li, J. Xiao, Y. Zhao, and X. He, “PWM plus phase angle shift control scheme for combined multiport dc/dc converters,” IEEE Trans. Power Electron. vol. 27, no. 3, pp. 1479-1489, Mar. 2012.

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