A New Proposal of Single-Stage Power Conversion System

B.SHIVA KUMAR,RAKESH VAKATI,
PG scholar,PG scholar,
NIT BHOPAL,SPR COLLEGE.

Abstract—This paper introduces a new converter called flexible renewable solar converter (FRSC) for solar-battery application, particularly utility-scale PV-battery application. The main concept of the new converter is to use a single-stage three- phase grid connected solar converter to perform dc/ac and dc/dc operations. This converter solution is appealing for PV-battery application, because it minimizes the number of conversion stages, In this paper, a combination of analysis attractive performance characteristics of the pro- posed FRSC.

I. INTRODUCTION

SOLAR photovoltaic (PV) electricity generation is not avail- able and sometimes less available depending on the time of the day and the weather conditions. Solar PV electricity output is also highly sensitive to shading. 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. From an energy source stand point, a stable energy source and an energy source that can be dispatched at the request are desired. 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 [1]–[3].

This paper introduces a novel single-stage solar converter called flexible renewable solar converter (FFRSC). The basic concept of the FFRSC 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 FRSC 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. Fig. 1 shows different scenarios for the PV- generated power time of use. In case (a), the PV energy is always delivered to the grid and there is basically no need of energy storage. However, for cases (b) and (c), the PV energy should be first stored in the battery and then the battery or both battery and PV supply the load. In cases (b) and (c), integration of the battery has the highest value and the FRSC provides significant benefit over other integration options when there is the time gap between generation and consumption of power.

II. FRSC

A. Introduction

The schematic of the proposed FRSC is presented in Fig. 1. The FRSC has some modifications to the existing three-phase PV inverter system. These modifications allow the FRSC to include the charging function in the existing three- phase PV inverter system. Assuming that the existing utility-scale PVinverter system consists of a three-phase volt- age source converter and its associated components, the FRSC requires additional cables and mechanical switches, as shown in Fig. 2. Optional inductors are included if the ac filter inductance is not enough for the charging purpose.

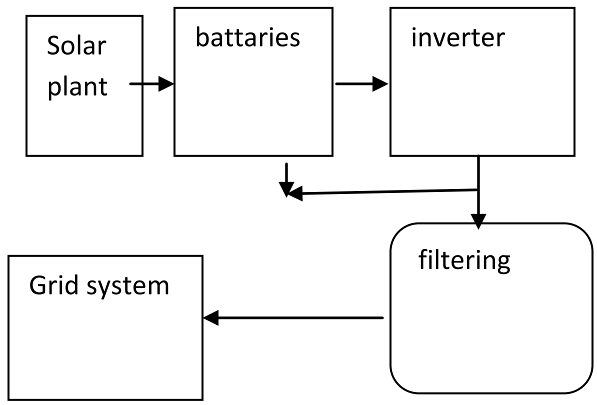

Fig 1. Proposed configuration

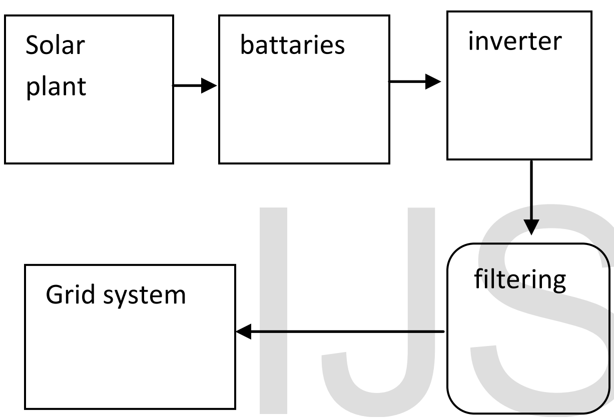

Fig 2. Existing system configuration

B. Operation Modes of the FRSC

All possible operation modes for the FRSC are presented here

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

In Mode 2, the battery is charged with the PV panels through the dc/dc operation of the converter In this mode, the MPPT function is performed; therefore, maximum power is generated from PV.

In Mode 3, There is another mode that both the PV and battery provide the power to the grid.

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

C. System Benefits of Solar PV Power Plant With the FRSC Concept

The FRSC concept provides significant benefits to system plan- ning 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. An example of commercial en- ergy storage solutions is the ABB distributed energy storage (DES) solution that is a complete package up to 4 MW, which is connected to the grids directly and, with its communication ca- pabilities, can be utilized as a mean for peak shifting in solar PV power plants [33]. The FRSC 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 so- lution with the FRSC. Fig. 4 shows examples of the PV energy storage solutions with the FRSC and the current state-of-the-art technology.

The technical and financial benefits that the FRSC solutionis able to provide are more apparent in larger solar PV power plants. Specifically, a large solar PV power plant using the FRSCs can be controlled more effectively and its power can be dis- patched more economically because of the flexibility of oper- ation. Developing a detailed operation characteristic of a solar PV power plant with the FRSC is beyond the scope of this paper. However, different system controls as shown in Fig. 5 can be proposed based on the requested power from the grid operator. Preq and available generated power form the plant PThese 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 FRSC-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

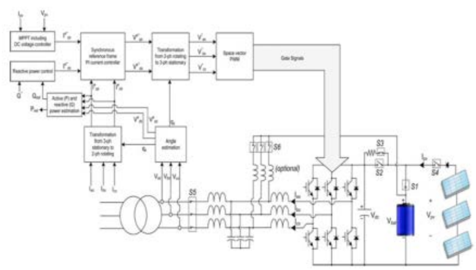

Fig3. Proposed controlling for dc/ac operation

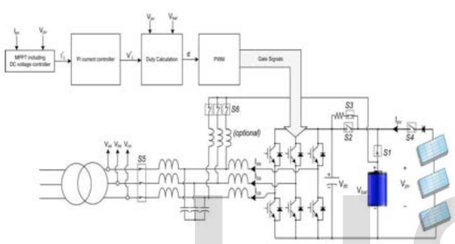

Fig 4. Proposed controlling for dc/dc operation

D. Advantages

Improving efficiency of the conversion system by reducing the number of stages.

Number of converters used in the total converting system was reduces it reducing cost, weight, and volume of the conversion system.

E. Mode Change Control

The basic concept of the FRSC 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 to dc) for PV systems with energy storage, as discussed earlier. Therefore, in addition to the converter control in each mode, the seamless transition be- tween modes is also essential for the FRSC operation. To change a mode, the FRSC must be re-arranged by either disconnecting or connecting components such as the battery through contactors. It is very important to understand the dynamics of the FRSC circuit. Specifically, it is essential to understand the relay re- sponse time such as how long it takes for a relay to completely close or open. Hence, the performance characteristics of all re- lays used in the FRSC circuit must be investigated with their datasheets. All relays used in the FRSC 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 SChgDC in Fig. 8 is investigated during precharging of the inverter capacitors. The captured waveforms are shown in Fig.

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 FRSC mode change control is shownin Fig. 11. This layer consists of fault detection, fault reset, and normal operation. The basic fault detection such as detecting overcurrent and overvoltage 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. In general, shutting down all PWM signals is able to clear the fault. In addition, all relays are forced to be opened. If the system is operating normal, the status of the system will be “Normal Condition.” Once the

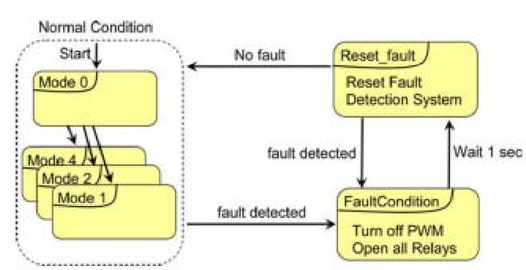

Fig. 5. Highest layer of the FRSC mode change control.

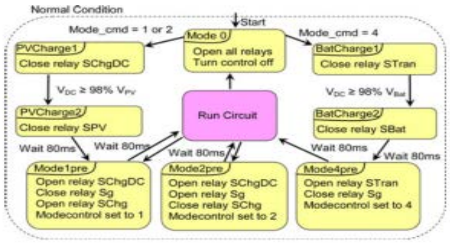

Fig. 6. States inside "Normal Condition."

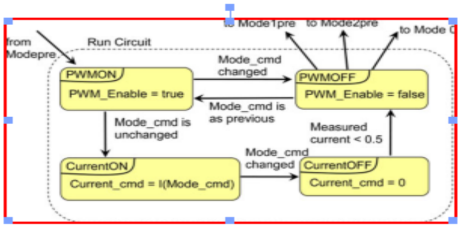

Fig. 7. Control topology inside "Run Circuit."

III. PERFORMANCE ANALASIS

Performance Investigation of the DC/AC Operation Modes

Fig. 8 shows the steady-state performance of dc/ac control in Mode 1. In this test, the voltage on the dc side VDC of the inverter Fig. 15. Different operation modes tested in the lab. Fig. 16. Steady-state performance of dc/ac control in Mode 1. Fig. 9. Steady-state performance of dc /ac control in Mode 4. is set to 200 V. The current reference is set to 5 Apeak for the frequency of 60 Hz. As shown in Fig. 8, a satisfactory steadystate performance is obtained. Fig. 9 shows the steady-state performance of dc/ac control in Mode 4. In the test, the voltage on the dc side VDC of the inverter is 118 V which is the battery voltage. The current reference is set to 3 Apeak for the frequency of 60 Hz. As shown in Fig. 9, the satisfactory dc/ac steady-state performance is obtained. In Fig. 9, the current flowing into the battery is exhibited. The average battery charging current is 1.8 A. The battery charging current has about 0.85 Apk−pk current ripple with the frequency of 60 Hz. C. Performance Investigation of the DC/DC Operation Mode In Mode 2 (PV to battery), the three-phase inverter is used as a dc/dc converter. As explained, initially a coupled threephase inductor is used for the filter inductor to the inverter side. When only phase B is utilized for the dc/dc operation with only either upper or lower three 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 significantly high current ripple in phase B current, as shown in Fig. 18(a). To solve the aforementioned problem,

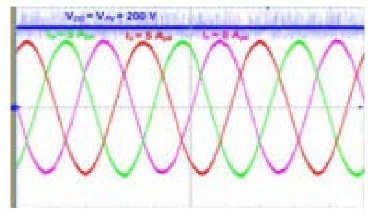

Fig 8. Steady-state performance of dc/ac control in Mode 1.

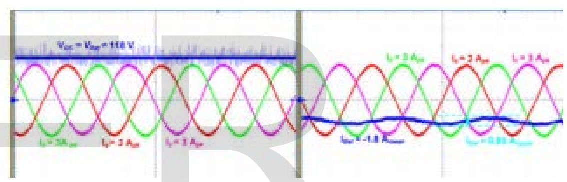

Fig 9.Steady-state performance of dc /ac control in Mode 4.

as explained, two solutions are proposed. First, the switches unused are turned off and consequently the phase current presents much lower ripple as shown in Fig. 9. The average current in phase B is now 5 A with a ripple of 5 Apk−pk while the current in phases A and C remains zero. This means no circulating current. The second solution is to use three single-phase inductors in the RSC circuit. As expected with single-phase operation in this mode, the circulating current is vanished automatically. The result of the test is presented in Fig. 18(c) showing that the current in the other phases remains zero while the battery is charged. Fig. 19 shows the current going into the battery for the test shown in Fig. 9. The average phase B current is 5 A and the average battery current is also 5 A. The phase B ripple is 5 Apk−pk and the battery current ripple is 1.4 Apk−pk . The capacitor ripple current is about 4.2

Apk−pk . Using three single-phase inductors enables the FRSC to use all three phase legs in the dc/dc operation. As discussed earlier, there are two methods to utilize all three phase legs for the dc/dc operation. In the first approach, all three phase-legs operate synchronously with their own current controls. The sum of all three phase currents is 5 A, which means that each phase carries one-third of it. Therefore, it is possible to charge the battery with even a higher current, which leads to a faster charging time. However, each phase current shows the current ripple of 5 Apk−pk · The battery current has the current ripple of 4 Apk−pk and the capacitor current shows the current ripple Fig. 20. Steady-state performance of the FRSC with three-phase synchronous operation in the dc/dc mode (Mode2). Fig. 21. Steady-state performance of the RSC with three-phase interleaved operation in the dc/dc mode (Mode2). of 12 Apk−pk which is almost three times as high as the ripple current of the battery charging using a single phase leg. Higher ripple current flowing into the battery and capacitor can have negative effects on the lifetime of the battery and capacitors

IV. CONCLUSION

This paper introduced a new converter called FRSC for PV-battery application, particularly utility-scale PV-battery application. The basic concept of the FRSC 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. Test results have been presented to verify the concept of the RSC and to demonstrate the attractive performance characteristics of the FRSC. These results confirm that the FRSC is an optimal solution for PV-battery power conversion systemsAlthough this paper focuses on three-phase application, the main concept can be applied to single-phase application. The proposed solution is also capable of providing potential benefits to other intermittent energy sources including wind energy.

V. REFERENCES

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

[2] D. Bundestag, “Gesetz zur Neuregelung des Rechts der erneuerbaren Energien im Strombereich und zur Anderung damit zusammenh ¨ angender ¨ Vorschriften,” Bundesgesetzblatt, 2008.

[3] 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.

[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] 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.

[6] 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.

[7] 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.

[8] 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.

[9] N. Benavidas and P. Chapman, "Power budgeting of a multiple-input buckboost converter," IEEE Trans. Power Electron., vol. 20, no. 6, pp. 1303– 1309, Nov. 2005.

[10] 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.

[11] S. J. Chiang, K. T. Chang, and C. Y. Yen, "Residential photovoltaic energy storage system," IEEE Trans. Ind. Electron., vol. 45, no. 3, pp. 385–394, Jun. 1998.

[12] Z. Zhao, M. Xu, Q. Chen, J. Lai, and Y. Cho, "Derivation, analysis, and implementation of a boost-buck converter-based high-efficiency PV inverter," IEEE Trans. Power Electron., vol. 27, no. 3, pp. 1304–1313, Mar. 2012.

[13] C. Ho, H. Breuninger, S. Pettersson, G. Escobar, L. Serpa, and A. Coccia, "Practical design and implementation procedure of an interleaved boost converter using SiC diodes for PV applications," IEEE Trans. Power Electron., vol. 27, no. 6, pp. 2835–2845, Jun. 2012.

[14] 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.

[15] 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.

[16] S. Jain and V. Agarwal, "An integrated hybrid power supply for distributed generation application fed by non conventional energy sources," IEEE Trans. Energy Convers., vol. 23, no. 2, pp. 622–631, Jun. 2008.

[17] 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.

[18] 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.