www.ijecs.in
International Journal Of Engineering And Computer Science ISSN:2319-7242
Volume 3, Issue 11 November, 2014 Page No. 9024-9034

Three Phase Grid-Tied Single Stage Reconfigurable Solar Converter Controlled By SVPWM Technique

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Abstract-This project addresses a dc/dc converter & dc/ac converter suitable for an energy storage system with an additional function of galvanic isolation. An energy storage device such as an electric double layer capacitor is directly This project addresses a dc/dc converter & dc/ac converter suitable for an energy storage system with an additional function of galvanic isolation. An energy storage device such as an electric double layer capacitor is directly linked to one of the dc buses of the dc/dc converter without any chopper circuit. Nevertheless, the dc/dc converter dc/ac converter can continue operating when the voltage across the energy storage device droops along with its discharge. Theoretical calculation and experimental measurement reveal that power loss and peak current impose limitations on a permissible dc-voltage range. In this project verifies that the dc/dc converter can charge and discharge the capacitor bank properly. Moreover, the dc/dc converter & dc/ac converter can charge the capacitor bank from zero to the rated voltage without any external pre charging circuit.In this project, a new converter called reconfigurable solar converter (RSC) for photovoltaic (PV)-battery application, mainly utility-scale PV-battery application is presented. The major notion of the new converter is to use a single-stage three phase grid-tie solar PV converter to perform dc/ac and dc/dc operations. This converter solution is urging for PV- battery application, since it reduces the number of conversion stages, thereby developing efficiency and reducing cost, weight, and volume. In this project, a combination of analysis and simulation tests is used to show the attractive performance features of the suggested RSC.

I. Introduction

Nowadays, photovoltaic (PV) plants are receiving a very great attention due to their intrinsic ability to directly transform solar energy in electrical energy. Nevertheless, electricity generated from photovoltaic plants can rarely offer immediate response to load demand, as these sources do not deliver a regular supply immediately compatible with consumption needs. In stand-alone PV plants, energy storage (typically based on electrochemical batteries), together with the help of additional generation systems (such as those powered by fuel engines), is on the basis of regularization of PV generation and of full satisfaction of load consumptions.

In grid-linked PV plants – theoretically - energy storage is not essential or useful, due to the availability of the distribution grid that should work as an ideal container of the electrical energy (theoretically, it can work both as an ideal generator and, also, as an ideal load). But, in this last years, an important attention has been devoted to the use of energy storage also in grid-linked PV plants, with the main aim of overcoming some important power quality problems of real distribution grids and for

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 notion evolved from the fact that energy storage combination 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.

II. Reconfigurable Solar Converter

A. Preface

The diagram of the suggested RSC is shown in Fig. 1. The RSC consists of some changes to the usual three-phase PV inverter making PV system. These changes let the RSC to involve the This project p charging task in the usual threephase PV inverter system. Letting that the usual utility-scale PV inverter system contains a three-phase voltage source converter and its related parts, the RSC needs extra cables and mechanical switches, as shown in Fig. 1. Optional inductors are integrated if the ac filter inductance is not sufficient for the charging function.

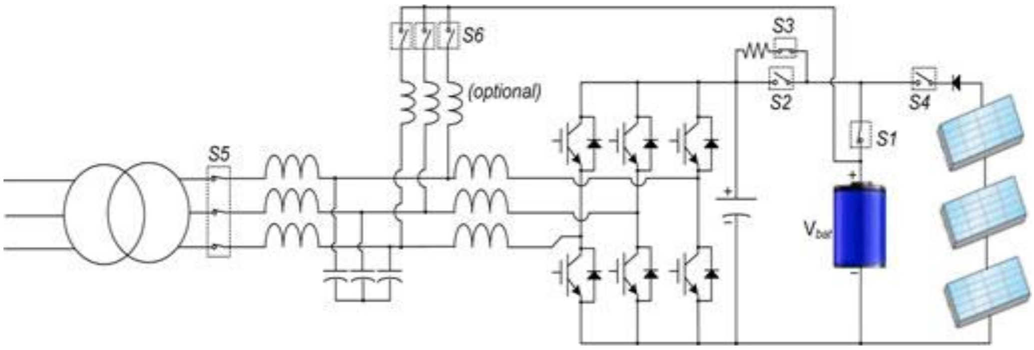


Fig.1. Diagram of the suggested RSC circuit

B. Operation Methods of the RSC

All feasible operation methods for the RSC are shown in Fig. 2. In Method 1, the PV is directly linked to the grid over a dc/ac operation of the converter with prospect of maximum power point tracking (MPPT) monitor and the S1 and S6 switches stay open. In Method 2, the battery is charged with the PV panels over the dc/dc operation of the converter by closing the S6 switch and opening the S5 switch. In this method, the MPPT function is achieved; thus, maximum power is produced from PV. There is an alternative method that both the PV and battery offer the power to the grid by closing the S1 switch. This operation is shown as Method 3. In this method, the dc-link voltage that is the similar to the PV voltage is imposed by the battery voltage; thus, MPPT monitor is not possible. Method 4 represents an operation method that the energy stored in the battery is offerd to the grid. There is another method, Method 5 that the battery is charged from the grid. This method is not shown in Fig. 2.

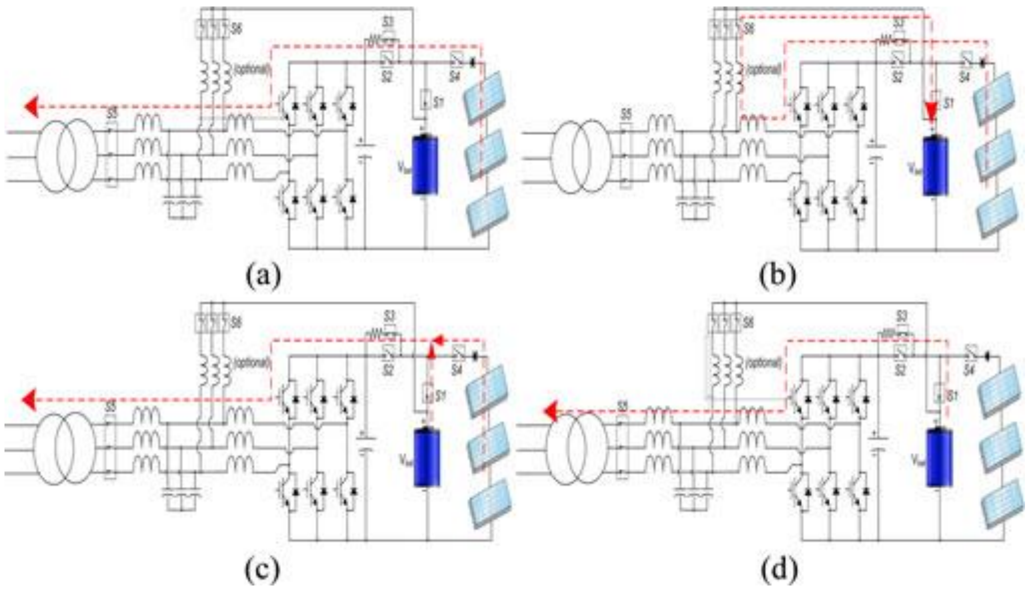


Fig. 2. All operation methods of the RSC. (a) Method 1—PV to grid. (b) Method 2—PV to battery. (c)Method 3—PV/battery to grid. (d)Method 4—battery to grid.

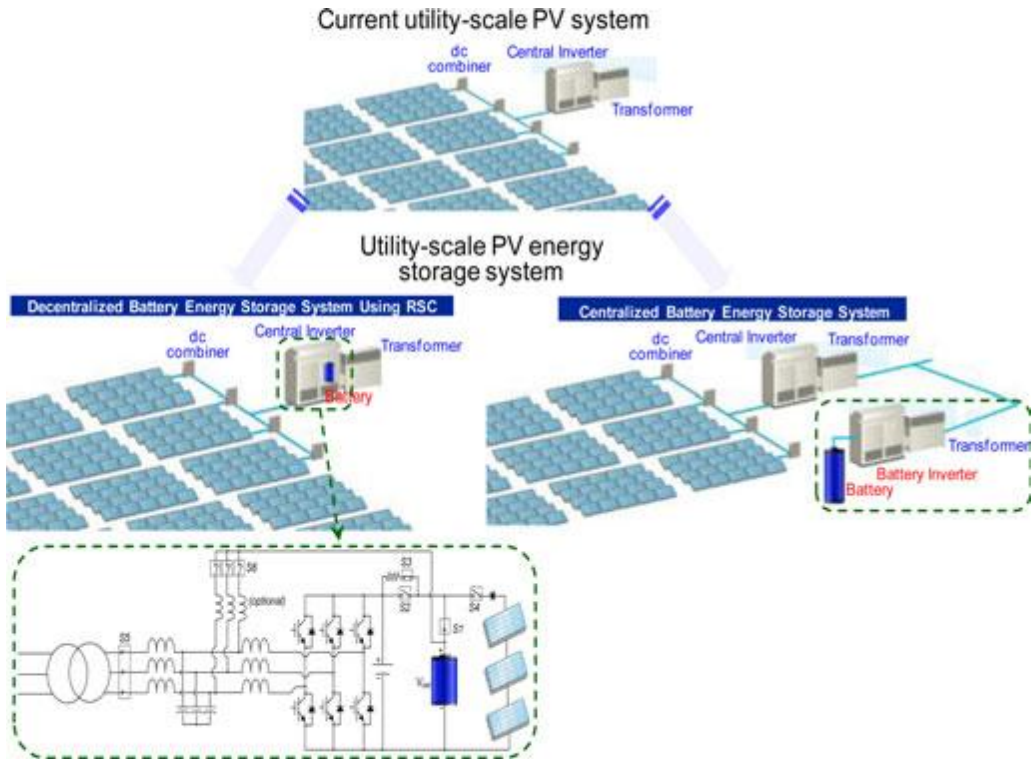


Fig.3. Utility-scale PV-energy storage systems with the RSC and the current state-of-the-art solution

C. System Gains of Solar PV Power Plant With the RSC Method l

The RSC method l offers major gains to system planning of utility-scale solar PV power plants. The current state-of-the-art technology is to combine the energy storage into the ac side of the solar PV system. An example of viable energy storage solutions is the ABB issued energy storage (DES) solution that is a complete package up to 4MW, which is linked to the grids directly and, with its communication means, can be used as a mean for peak shifting in solar PV power plants

[33]. The RSC method l permits not only the system owners to have an flexible ability that assists them to arrange and run the power plant correspondingly although manufacturers to present a cost- aggressive dispersed PV energy storage solution with the RSC. Fig. 3 shows examples of the PV energy storage solutions with the RSC and the current state-of-the-art tools.

The technical and financial gains that the RSC solution is able to offer are more apparent in larger solar PV power plants. Specially, a large

solar PV power plant using the RSCs can be monitored more efficiently and its power can be dispatched more economically since of the flexibility of operation. Developing a full operation characteristic of a solar PV power plant with the RSC is further than the scope of this project. But, different system monitors as shown in Fig. 4 can be suggested based on the requested power from the grid operator *P*req and available generated power form the plant *P*gen. These two values being results of an optimization problem (such as unit commitment methods) serve as variables to monitor the solar PV power plant accordingly. In other words, in response to the request of the grid operator, different system monitor plans can be realized with the RSC-based solar PV power plant as follows:

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

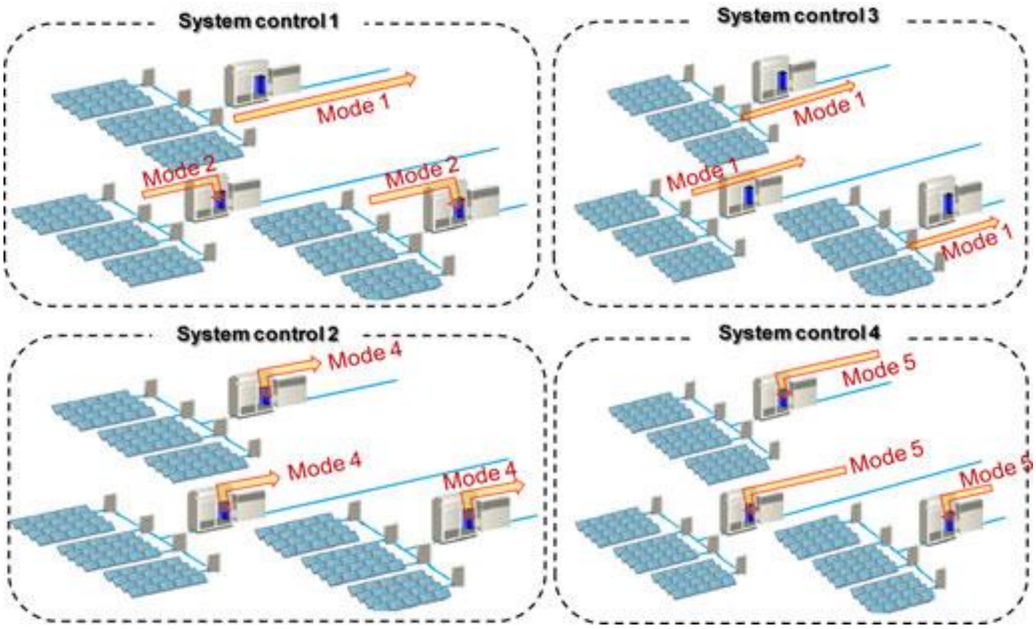


Fig.4. Example of different system operation methods of a RSC-based solar PV power plant

III. RSC MONITOR

A. Monitor of the RSC in the DC/AC Operation Methods (Methods 1, 3, 4, and 5)

The dc/ac operation of the RSC is used for delivering power from PV to grid, battery to grid, PV and battery to grid, and grid to battery. The RSC performs the MPPT algorithm to deliver maximum power from the PV to the grid. Like the usual PV inverter control, the RSC control is implemented in the synchronous reference frame. The synchronous reference frame proportional-integral current monitor is employed. In a reference frame rotating synchronously with the fundamental excitation, the fundamental excitation signals are transformed into dc signals. As a result, the current regulator forming the innermost loop of the monitor system is able to regulate ac currents over a wide frequency range with high bandwidth and zero steady-state error.

For the pulse width modulation (PWM) scheme, the usual space vector PWM scheme is used.

Fig. 5 presents the overall monitor block diagram of the RSC in the dc/ac operation. For the dc/ac operation with the battery, the RSC monitor should be matched with the battery management system (BMS), which is not shown in Fig. 5.

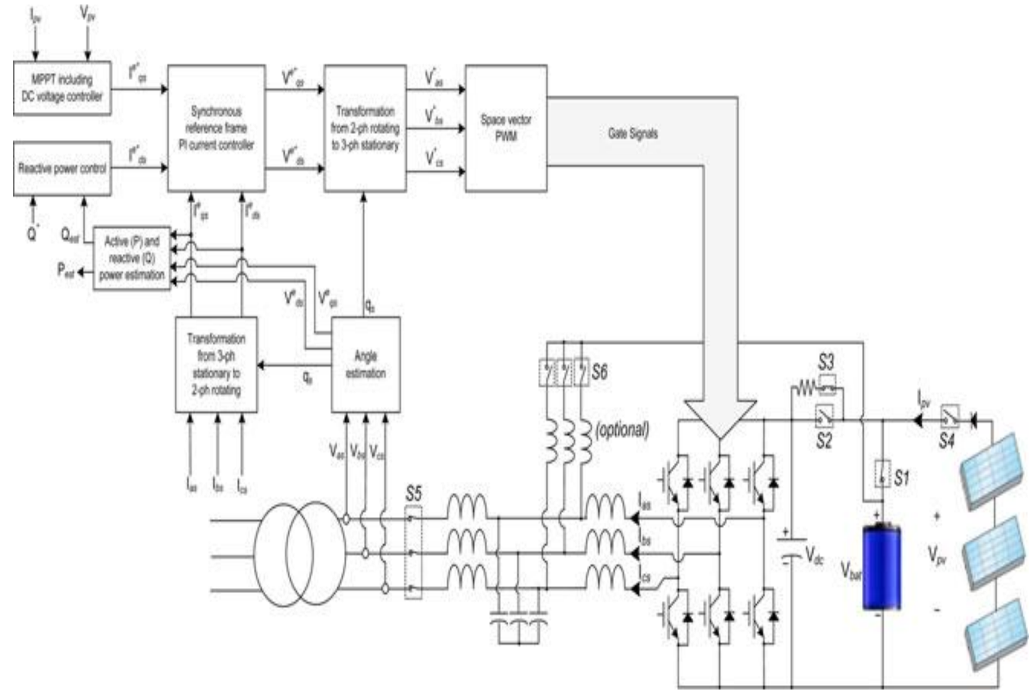


Fig.5. Overall control block diagram of the RSC in the dc/ac operation

B. Monitor of the RSC in the DC/DC Operation Method (Method 2)

The dc/dc operation of the RSC is also used for delivering the maximum power from the PV to the battery. The RSC in the dc/dc operation is a boost converter that monitors the current flowing into the battery. In this research, Li-ion battery has been selected for the PV-battery systems. Li-ion batteries need a stable current, stable voltage type of charging algorithm. In other words, a Li-ion battery should be charged at a set current level until it achieves its final voltage. At the last voltage, the charging process should switch over to the stable voltage method, and offer the current essential to possess the battery at this final voltage. Thus, the dc/dc converter performing charging process must be able of offering stable monitor for maintaining either current or voltage at a stable value, depending on the state of the battery. Typically, a few percent capacity losses happen by not performing stable voltage charging. But, it is not uncommon only to use stable current charging to simplify the charging monitor and process. The latter has been used to charge the battery. Thus, from the monitor point of view, it is just sufficient to monitor only the inductor current. Like the dc/ac operation, the RSC performs the MPPT algorithm to convey maximum power from the PV to the battery in the dc/dc operation. Fig. 6 shows the overall monitor block diagram of the RSC in the dc/dc operation. In this method, the RSC monitor should be managed with the BMS, which is not shown.

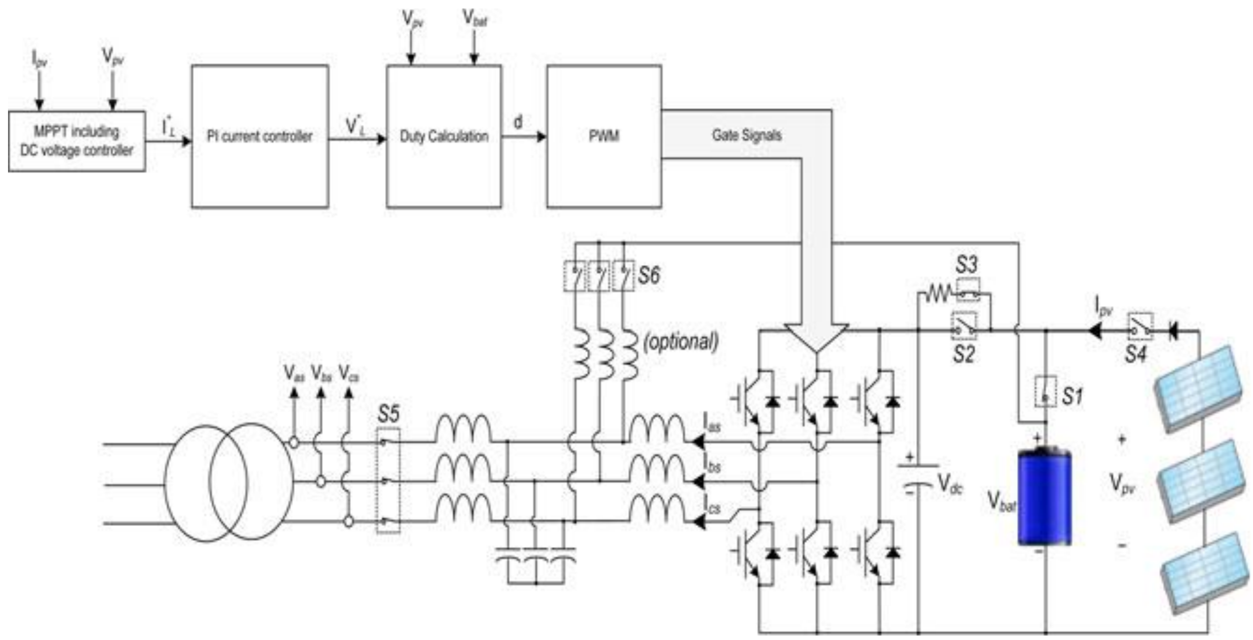


Fig.6. Overall monitor block diagram of the RSC in the dc/dc operation

C. Strategy Issues and Changes to the Usual Three-Phase PV Converter

One of the most vital conditions of the project is that a new power conversion solution for PV-battery systems must consist least difficulty and changes to the usual three-phase solar PV converter system. Thus, it is essential to explore how a three-phase dc/ac converter works as a dc/dc converter and what changes should be made. It is widespread to use a *LCL* filter for a high-power three-phase PV converter and the RSC in the dc/dc operation is probable to use the inductors already existing in the *LCL* filter. There are chiefly two types of inductors, coupled three-phase inductor and three single-phase inductors that can be used in the RSC circuit. Using all three phases of the coupled three-phase inductor in the dc/dc operation affects a major drop in the inductance value due to inductor core saturation. The reduction in inductance value needs inserting additional inductors for the dc/dc operation which has been marked as “optional” in Fig. 1. To shun extra inductors, only one phase can do the–dc/dc operation. But, when only one phase, for example phase B, is used for the dc/dc operation with only either upper or lower three insulated-gate bipolar transistors (IGBTs) are turned OFF as balancing switching, the flowing current occurs in phases A and C through filter capacitors, the coupled inductor, and switches, ensuing in radically high current ripple in phase B current.

To stop the flowing current in the dc/dc operation, the following two solutions are suggested; 1) all unemployed upper and lower IGBTs must be turned OFF; 2) the coupled inductor is exchanged by three single-phase inductors.

Whereas the primary 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 use all three phase legs for the dc/dc operation:

1) synchronous operation;

2) interleaving operation.

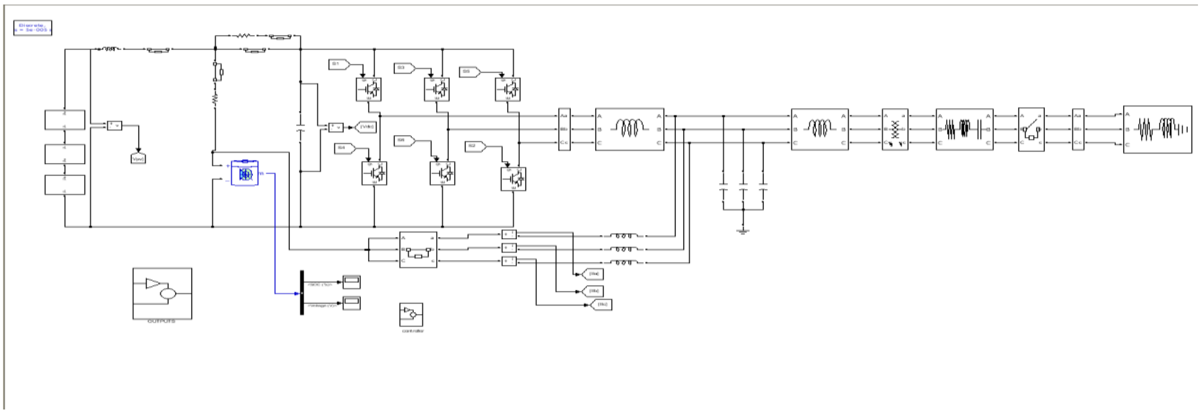
In the primary solution, all three phase legs can work synchronously with their own current control. In this task, the battery can be charged with a higher current compared to the case with one-phase dc/dc operation. This leads to a faster charging time due to higher charging current capability. But, each phase operates with higher current ripples. Higher ripple current flowing into the battery and capacitor can have negative results on the lifetime of the battery and capacitors.

To beat the aforementioned problem associated with the synchronous operation, phases B and C can be moved by applying a phase offset. For the interleaving operation using three phase legs, phases B and C are moved by 120◦ and 240◦, respectively. The inductor current control in interleaving operation needs a different inductor current sampling scheme, as shown in Fig. 9. Generally, for digital control of a dc/dc converter, the inductor current is tested at either the beginning or center point of PWM to confine the average current that is unbound from switching noises. For two phase interleaving that two phases are 180◦ apart, there is no need to change the sampling scheme, since the average inductor currents for both phases can be attained with the usual sampling scheme.

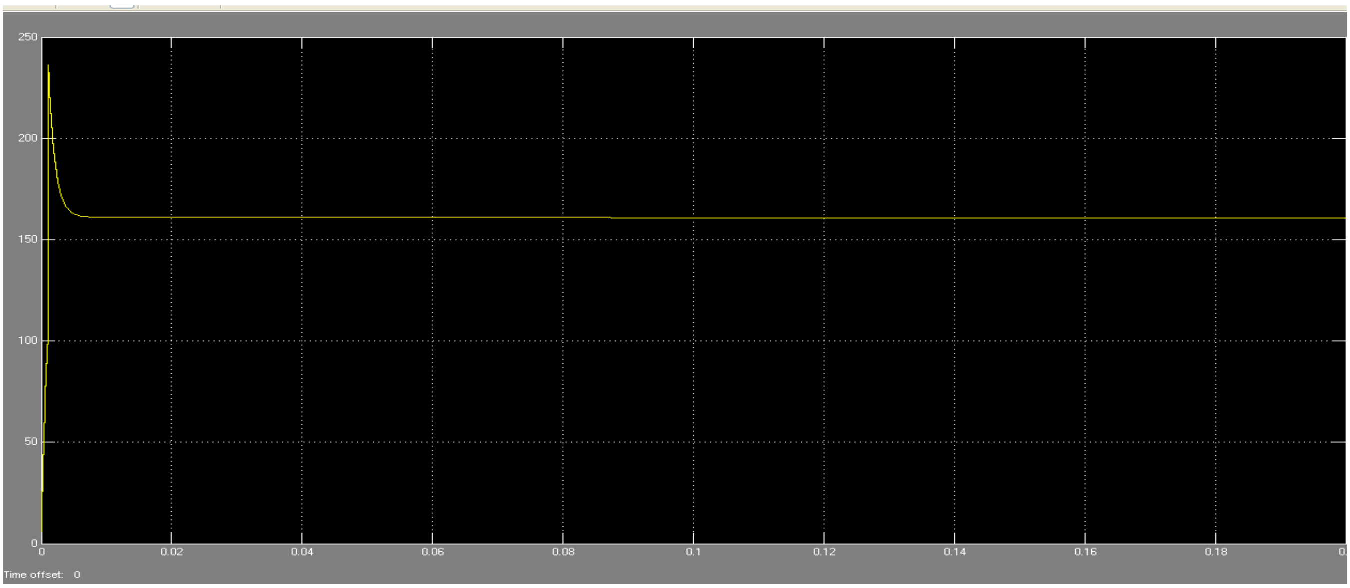
But, for three-phase interleaving, a changed sampling scheme is needed to compute the average currents for all three phases. Thus, the sampling points for phases B and C must be moved by 120◦ and 240◦, respectively, which may entail that computation needed inductor current control for each phase should be done asynchronously. Using the interleaving operation reduces the ripples on the charging current flowing into the battery. Thus, the filter capacitance value can be decreased considerably.

IV. Results

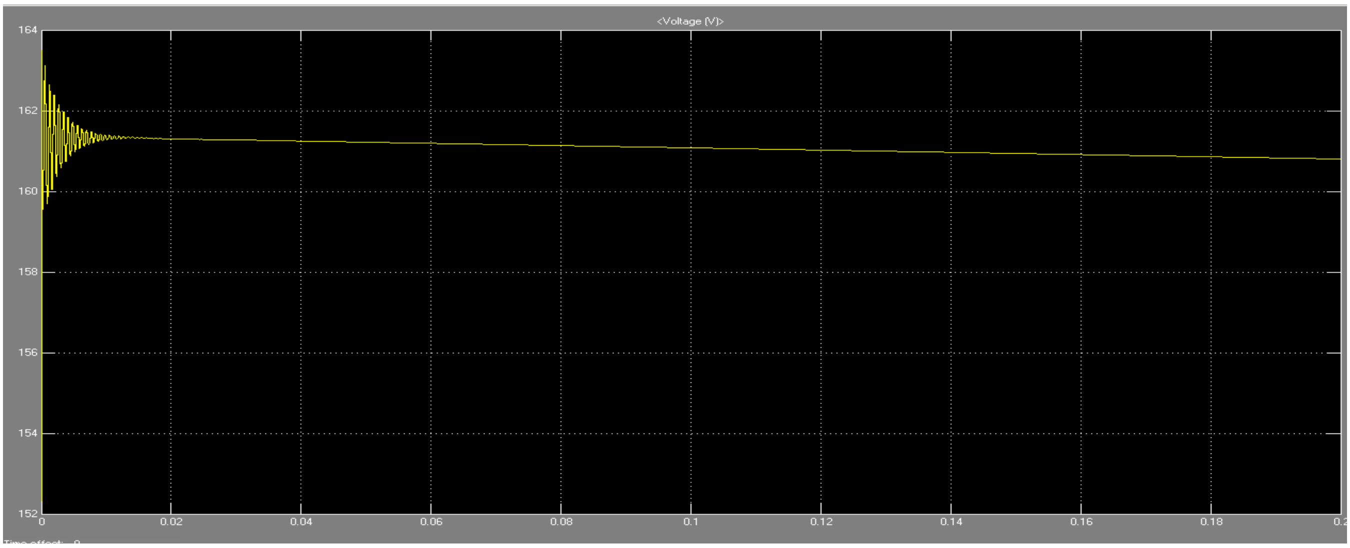
DC to AC



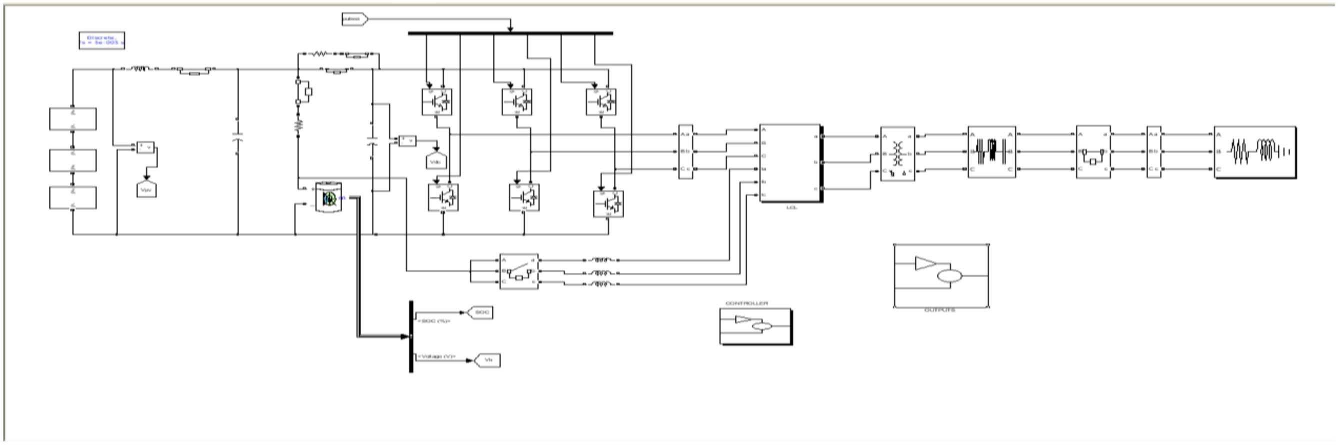
PV voltage



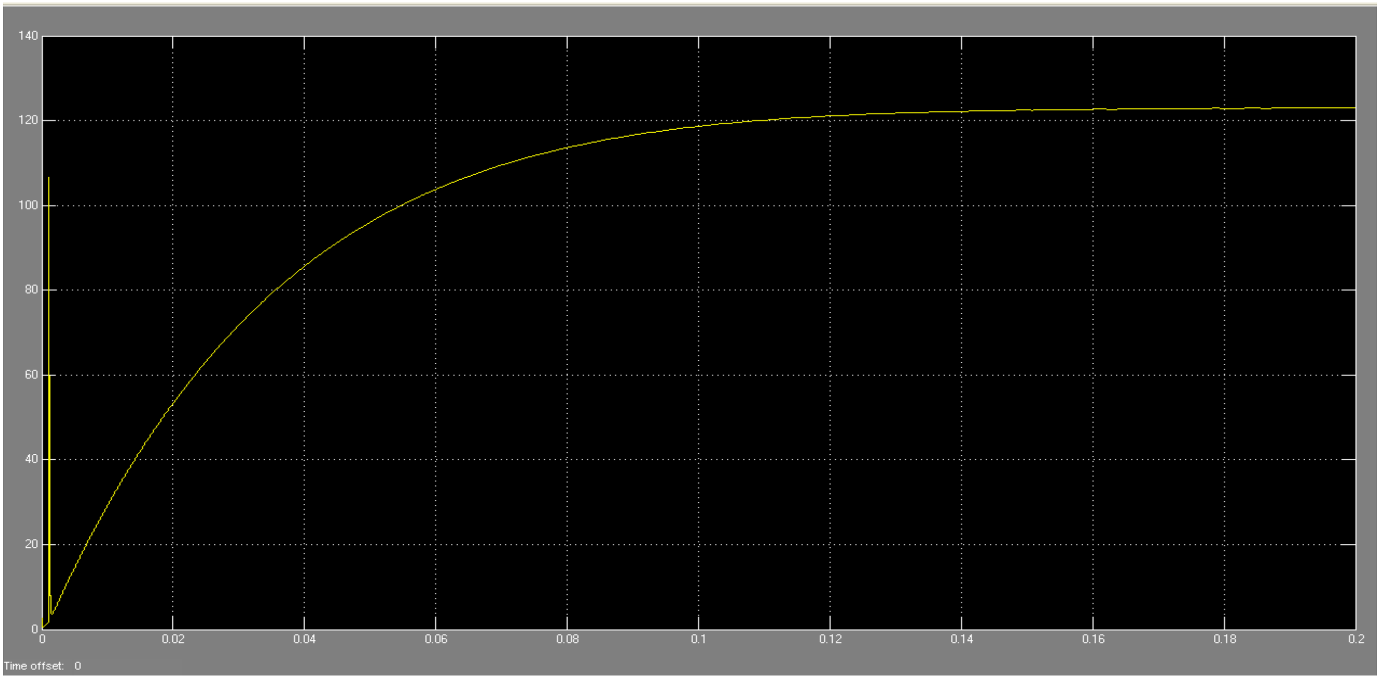
Battery Voltage



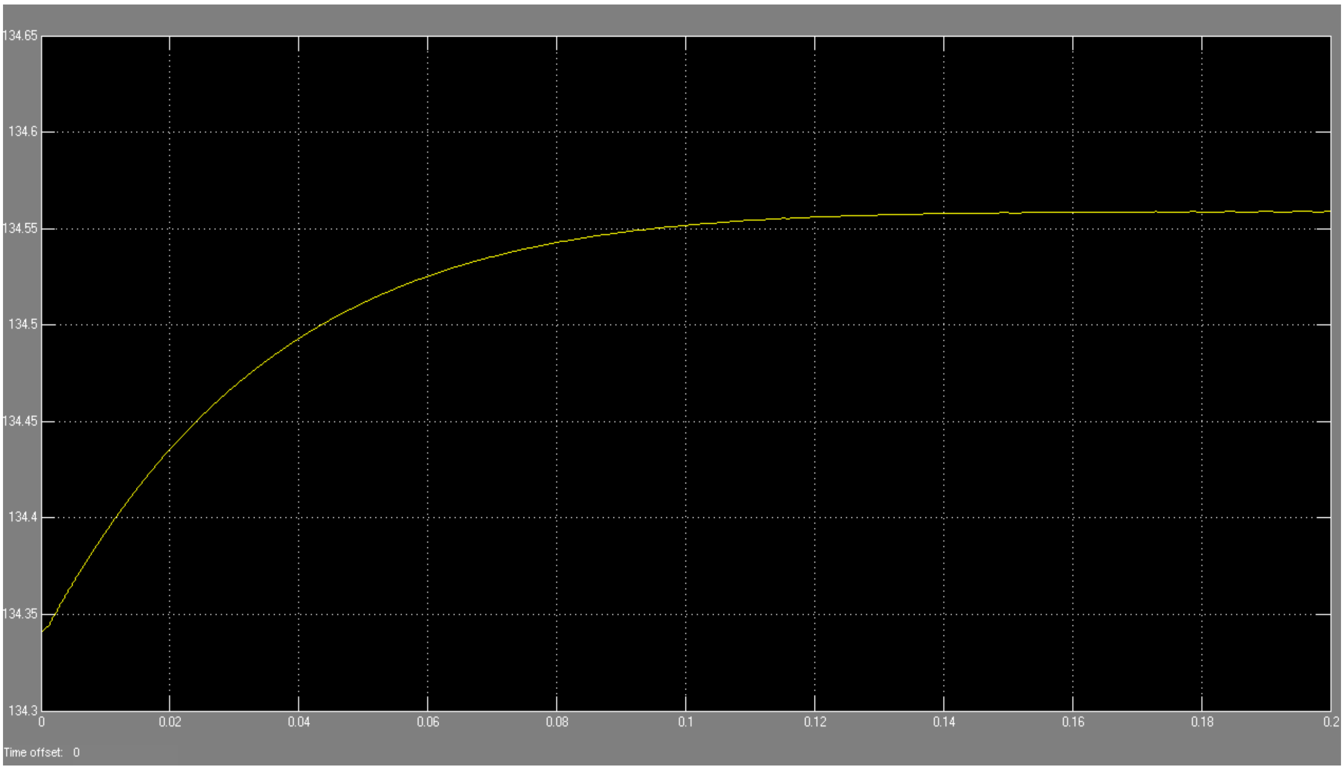
DC TO AC



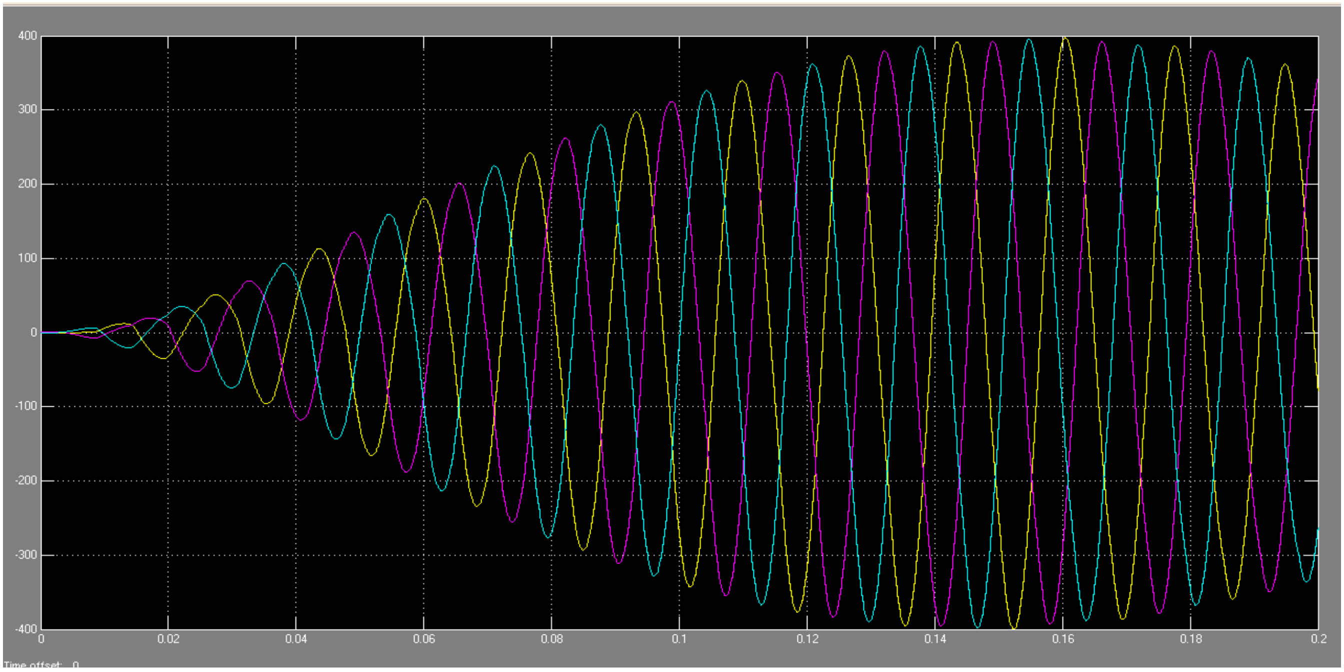
PV Voltage



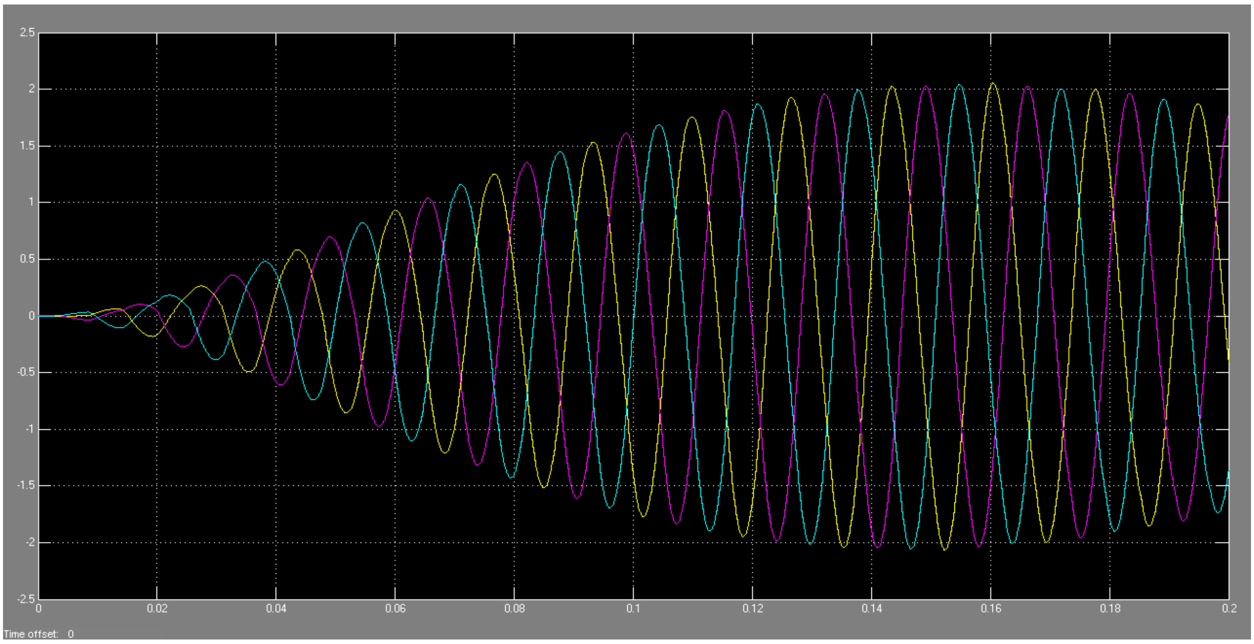
Battery Voltage:



Grid Voltage:



Grid Current



V. Conclusion

A passive MPPT technique, to be utilized mostly in large grid-connected PV plants, has been introduced and discussed; it is essentially based on the energy storage capabilities of batteries that are proposed to be put in parallel to a proper number of PV sub-fields, so as to be used in a distributed manner. If well designed in their location, in their nominal voltage value and in their capacity, batteries can naturally catch the MPP of each PV sub-field, also compensating for critical unbalanced solar irradiation conditions.

Furthermore, the presence of an energy storage system can make more and more attractive grid-connected PV plants, due to some important additional capabilities not commons of currently conceived grid-connected PV plants, as: a more great availability in favour of the AC power grid; a significant reduction of unfavourable requests of occasional peaks of load power demand; the possibility to substitute other expensive (and often not renouncing) apparatus for utility grid power quality improvements, as UPS and active filters; the possibility to be integrable with other different renewable resources, with minor expenses and with great economical advantages.

Finally, a conspicuous number of batteries distributed on board to a single PV module could be on the basis of the development of AC PV modules, to be directly connected to LV distribution grids and characterized by high quality of AC voltage, high efficiency and high availability.

Simulation results have been presented to verify the concept of the RSC and to demonstrate the attractive performance characteristics of the RSC. These results confirm that the RSC is an optimal solution for PV-battery power conversion systems.

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