INTEGRATION OF RENEWABLE ENERGY POWER WITH GRID FOR SMART DG APPLICATIONS

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ABSTRACT

The power demand is ever increasing and the power deficit in developing country like India is a major problem. In order to meet this growing demand power utility has the serious concern about the availability of conventional resources. Hence, the demand for renewable energy resources has gained rapid pace in the present scenario. The paper considered a realistic problem of power utilities and tried to give an alternative to meet the customer's demand during peak load time. In the proposed approach of smart power system for home (SPSH) two different loads as DC and AC load are considered and the results are simulated in MATLAB environment. The synchronization of DC power from solar panel and storage battery has been successfully achieved. The power consumption is met by using battery backup when grid supply is not available. This is to help the consumers to meet their load demand by developing a smart power system for home, and to promote local power generation.

Keyword: - *Solar power generation; grid-tied inverter; storage battery; grid power; AC and DC loads;*

1. INTRODUCTION

Present world is facing major threat of depletion of nonrenewable source of energy like coal, natural gas, petroleum. There will soon be a time when we will face a serious fuel shortage. Therefore, reasonable and effective utilization of resources is an important path which can deal with the global energy crisis. In this scenario, the integration of the sustainable resources in distribution system is gaining a momentum day by day. In deregulation and restructuring of power system, the penetration of distributed resources is usually done at bulk load point. However, for small power generation this could be possible at door step of the individual customers provided that the resources are easily available at economical price and on regular bases. For renewable resources this is possible in case of solar and wind power generation. But wind power neither available regularly nor it is economical to have a generating station at customers end. Also, wind mills cause huge noise which is unbearable and hence it needs to be installed at far away from the residential areas.

Therefore, the solar power is found to be most economical for local generation. The integration of solar systems with the existing grid is the great challenge in designing and implementation of the next generation smart grid. This is due to the fact that in a distributed system where output found changing rapidly, results in many issues for the distribution system operator with a large quantity of load components and the installed photovoltaic devices. However, in order to help integration of the solar power into the grid an additional battery storage system needs to be installed in parallel. This is to optimize the power usage, and it is capable of absorbing and delivering both real and reactive power with sub-second response times. It further helps in mitigating the ramp rate, frequency, and voltage issues in the solar power generation. Also, integration of the energy market makes the solar resource more economical and reliable.

Hill at el. [1] presents an overview of the challenges of integrating solar power to the electricity distribution system. It gives a technical overview of battery energy storage system, and illustrates a variety of modes of operation for battery energy storage system in grid-tied solar application. Wu at el. [2] proposed a seven-level inverter for small capacity grid-connected solar power generation system, configure by a dual-output dc-dc power converters. Here, output voltage of solar panel is converted into two dependent voltage sources, with multiple relationships, using voltage doublers technique. The grid-tied inverter is used as the synchronizer for solar power and the grid power at common voltage and frequency level. However, it is configured by a buck-boost power converter and a full bridge power converter where former is used to generate different level of voltage and, later is switched synchronous with a utility voltage. Martinez at el. [3] presented the fractional modeling of a dc-dc buck-boost converter suitable in solar powered electrical generation system, and designed a fractional controller for the aforesaid switching converter. Although, authors designed and modeled the controller for particular dc-dc converter but they realized that it can be extended to other kind of switching converter as well.

On the other hand, authors in [4] and [5] raised emphasis on the improvement of energy efficiency in solar power generation. In [4], it is observed that with change in solar conditions the extensive use of solar power need to be analyzed in all aspects of lifestyle including moving vehicles. However, in [5] authors proposed several ways to improve the efficiency of solar power generation. For this, author conducted survey and analysis of the proposed methods for improving the efficiency of solar power factor. In the analysis it was found that the maximum power tracking and the storage battery's charging and discharging technology plays an important role for energy efficiency in solar power generation. In addition, the application of complex mechanism of photosynthesis and the condenser are identified as the future research in strengthening the efficiency in solar power generation. Authors in [6]-[8] also reported the approach for the maximum power tracking in their works.

However, in [9] and [10] an analysis of different load models has been presented. In [9], different static load models are considered for energy efficiency in distribution systems. But in [10] the static load models are further used to develop more realistic load combinations at bulk delivery load point. These loads are found to be changing [11] and with voltage profile. As a result, the load demand keeps on changing with time and system voltage profile at the main grid side of the grid-tied inverter. These further make the approach of maximum power tracking in solar power generation more complicated. In this paper the output of solar panel is synchronized with the grid supply and the two loads; DC load and AC load are used to demonstrate the proposed approach in MA TLAB. In the analysis the DC load is connected to input side of inverter whereas the AC load is connected output side through switching which enables to connect load to grid supply as well.

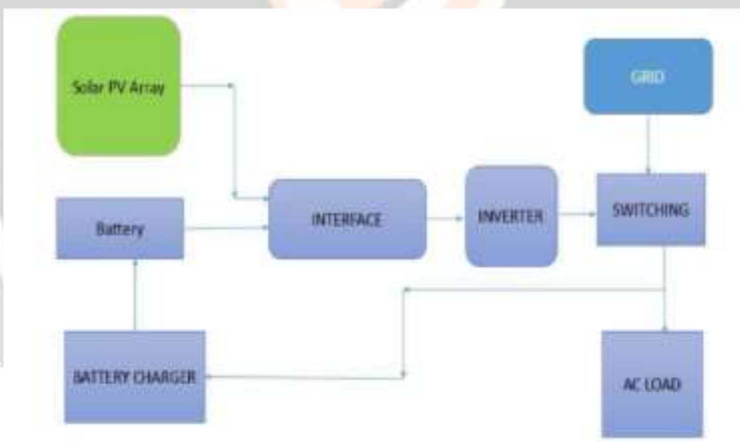

Fig-1: Block diagram of the smart power system for home (SPSH)

2. PV SYSTEM

The word "photovoltaic" combines two terms – "photo" means light and "voltaic" means voltage. A photovoltaic system in this discussion uses photovoltaic cells to directly convert sunlight into electricity.Photovoltaic power generation employs solar panels composed of a number of solar cells containing a photovoltaic material. Materials presently used for photo voltaic include mono crystalline silicon, polycrystalline silicon, amorphous silicon, cadmium telluride, and copper indium gallium solenoid/sulfide. Due to the increased demand for renewable energy sources, the manufacturing of solar cells and photovoltaic arrays has advanced considerably in recent years. Solar photovoltaic is a sustainable energy source where 100 countries are utilizing it. Solar photovoltaic's is now, after hydro and wind power, the third most important renewable energy source in terms of globally installed capacity. Installations may be ground-mounted or built into the roof or walls of a building. (Either building-integrated photovoltaic or simply rooftop)

2.1 PV Cell

A number of solar cells electrically connected to each other and mounted in a single support structure or frame is called a ‘photovoltaic module’. Modules are designed to supply electricity at a certain voltage, such as a common 12 volt system. The current produced is directly dependent on the intensity of light reaching the module. Several modules can be wired together to form an array. Photovoltaic modules and arrays produce direct-current electricity. They can be connected in both series and parallel electrical arrangements to produce any required voltage and current combination.

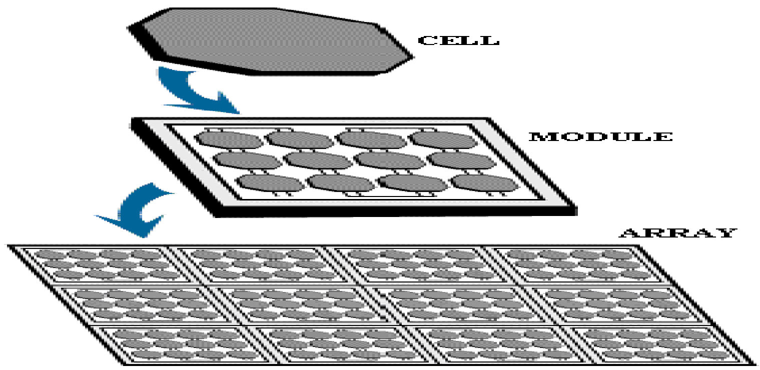

Fig-2:.PV module

2.2 Electrical Connections Of The Cell

The electrical output of a single cell is dependent on the design of the device and the Semi-conductor material(s) chosen, but is usually insufficient for most applications. In order to provide the appropriate quantity of electrical power, a number of cells must be electrically connected. There are two basic connection methods: series connection, in which the top contact of each cell is connected to the back contact of the next cell in the sequence, and parallel connection, in which all the top contacts are connected together, as are all the bottom contacts. In both cases, this results in just two electrical connection points for the group of cells.

1. Series Connection

Figure shows the series connection of three individual cells as an example and the resultant group of connected cells is commonly referred to as a series string. The current output of the string is equivalent to the current of a single cell, but the voltage output is increased, being an addition of the voltages from all the cells in the string (i.e. in this case, the voltage output is equal to 3Vcell).

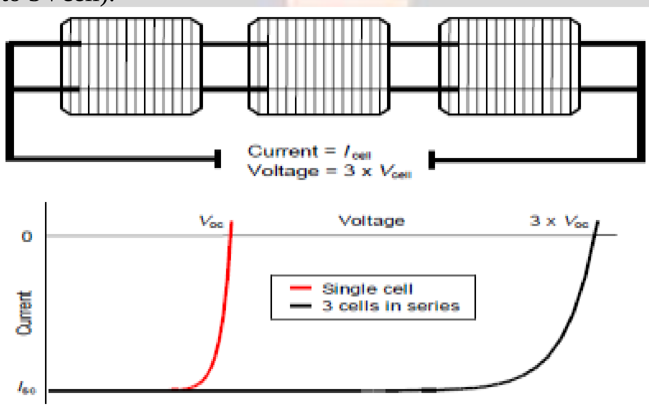

Fig-3:.Series connection of cells, with resulting current–voltage characteristic.

It is important to have well matched cells in the series string, particularly with respect to current. If one cell produces a significantly lower current than the other cells (under the same illumination conditions), then the string will operate at that lower current level and the remaining cells will not be operating at their maximum power points. From the above we can observe some the important points to be noted such as the graphs depicts the linearity of the system.

2. Parallel Connection

Figure shows the parallel connection of three individual cells as an example. In this case, the current from the cell group is equivalent to the addition of the current from each cell (in this case, 3 I cell), but the voltage remains equivalent to that of a single cell. As before, it is important to have the cells well matched in order to gain maximum output, but this time the voltage is the important parameter since all cells must be at the same operating voltage. If the voltage at the maximum power point is substantially different for one of the cells, then this will force all the cells to operate off their maximum power point, with the poorer cell being pushed towards its open-circuit voltage value and the better cells to voltages below the maximum power point voltage. In all cases, the power level will be reduced below the optimum.

2.2 The Photovoltaic Array

A PV array consists of a number of PV modules, mounted in the same plane and electrically connected to give the required electrical output for the application. The PV array can be of any size from a few hundred watts to hundreds of kilowatts, although the larger systems are often divided into several electrically independent sub arrays each feeding into their own power conditioning system.

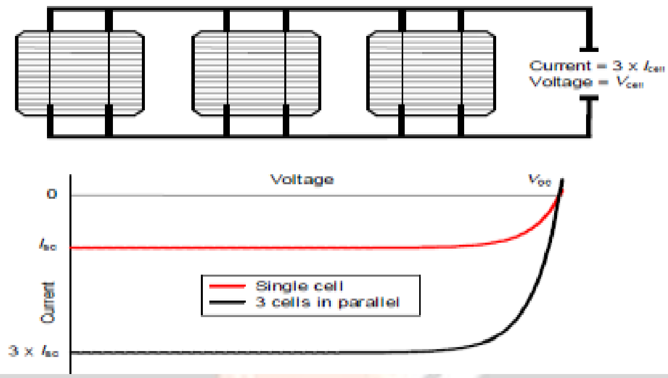

Fig-4:.Parallel connection of cells, with resulting current–voltage characteristic**.**

3. PROPOSED SYSTEM FRT ANALYS

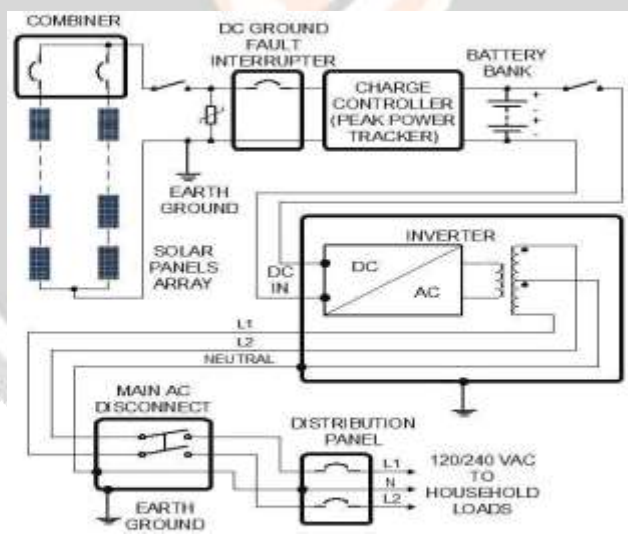

Fig.5. Schematic of an OFF-grid PV System with DC Loads

Currently in India, most of the PV systems are installed in rural areas which have very little chance of getting connected to the national grid within 5-10 years. Due to this reason; off-grid SHSs are the most popular renewable energy application which has maximum growth rate for many years in India. Over the span of three years more than 16,000 solar home systems have been financed through 2,000 bank branches particularly in rural areas of south India where the grid does not yet extend. The total installed capacity of renewable source in India is 973.13MW out of which off grid solar system has capacity of 159.77MW [12]

Typical configuration of a rural off-grid PV system in India is shown in Fig 1. To achieve the aim of having 20GW energy from solar sources, we need to grab every opportunity of increasing up. If we closely track the technology trend of developed countries in this regard, we can find 90% of the European PV systems are Grid-connected [13]. Following the world trend of grid-tied PV market, cities like Delhi, Chandigarh, and Mumbai etc. have high potential to use the solar energy through grid-tied PV systems. Configuration of a typical grid-tied PV system is given in Fig 5.

3.1 PROPOSED GRID-TIED PV SYSTEM

A grid-tied PV system without storage has been suggested to give power on-site electrical loads; serve energy to the grid when the grid power is available and backup the on-site critical load when the grid power is unavailable and sunlight is available.

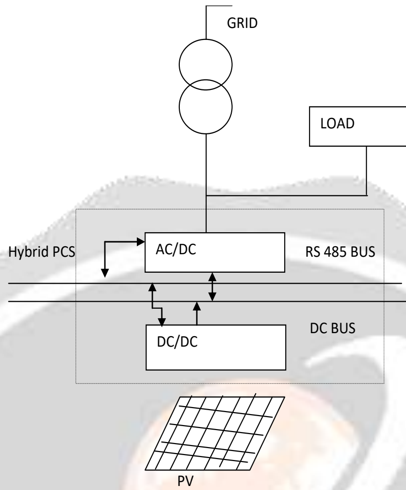

Fig.6. Schematic of Grid-tied PV System

A. Configuration

The system consists of PV arrays, a step-up dc–dc converter, a grid-tie inverter (GTI), controller (microcontroller) and an automatic AC transfer switch. PV arrays change solar energy into electric energy. The output voltage level of PV arrays is very low so we use a step-up dc–dc converter that boosts the array voltage to a higher level. The GTI inverts the DC power produced by the PV array into AC power with the desired voltage and power quality as required by utility grid. The controller sends a signal to transfer switch which changes supply source and also chooses serving loads according to available power. In standard condition, the system will feed energy to the grid; if the PV array output and grid power both are available and grid power. To sell energy back to Distribution Company we can utilize net metering facility. But when the utility grid power is not available or when the synchronization is not possible due to lower voltage level or lower frequency level, the system automatically disconnects the grid by using an anti-islanding system. In this circumstance, existing battery less grid-tied PV systems do not provide to any loads. But in our considered design, when sun light is available, it will supply some loads during the grid failure. This feature is indispensible considering the grid load shedding condition in India especially in summer season when power requirement is very high.

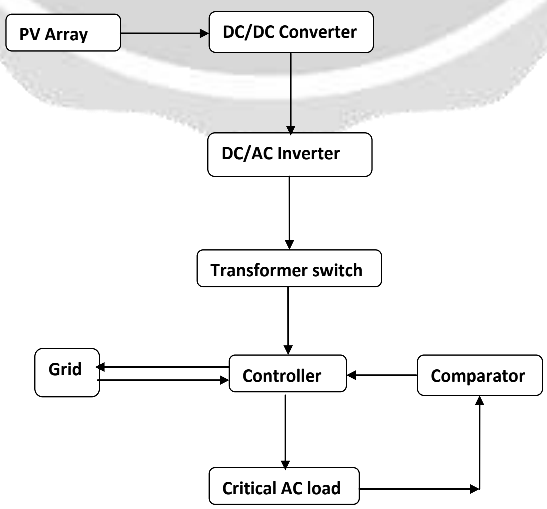

Fig.7. Configuration of Proposed Grid-tied System

B .Grid-tie Inverter

The basic element of Grid-tied PV system is the GTI which regulates the voltage and current which comes from solar panels and also ensures that power supply is in phase with the available grid power. On AC side, it keeps the sinusoidal output synchronized to the grid frequency (nominally 50Hz in India).

The voltage of the inverter output should be variable and it needs to be higher than the grid voltage to supply the current to the utility grid [14]. Fig 4 shows the schematic of a grid-tied inverter. The operating principle of a grid-tied inverter with three power stages has been illustrated. In first stage, the DC input voltage is stepped up by the boost converter and a combination of inductor L1, MOSFET Q1, diode D1 and capacitor C2. The inverter offers a galvanic isolation between input and the output. We can use a step-up transformer TX1, instead of the first stage (boost converter). In this case, to provide isolation in the second stage, a high frequency transformer is used. This stage is basically a pulse-width modulator DC-DC converter. The output voltage must be higher than the peak of the utility grid AC voltage. For example, 230 V, AC service voltage, requires the DC link greater than 230*√2= 325V. In the third conversion stage, DC is changed into AC by using a full bridge converter, which consists of IGBT Q6-Q9 and LC-filter L3, C4. Output LC-filter reduces harmonics to produce a sine-wave voltage.

Typical modern GTIs have a constant unity power factor which means its output voltage and current are completely lined up and its phase angle is within 1 degree of the AC power grid. The GTI has an on board computer which will sense the current waveform of grid and provides an output voltage to correspond with the grid. In addition, when the grid is down, the GTI will provide AC output synchronized with pre-defined references.

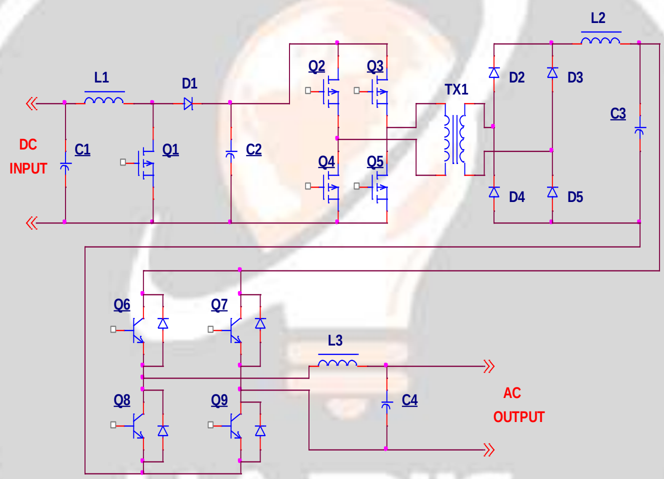

Fig.8. Schematic of a Grid-tied Inverter

3.2 CONTROL SCHEME

Fig. 9 illustrates the scheme of control for proposed system. It consists of three parts (i). PV converter control

PV arrays, a step-up dc–dc converter, a grid-tie inverter (GTI) and an automatic AC transfer switch with a controller (microcontroller). The output power of a PV array depends on the voltage level where it operates under a given condition of cell-surface temperature and irradiance. For better efficiency, a PV array should operate almost at the peak point of the $V-P$ curve. A variety of Maximum Power Point Tracking (MPPT) techniques have been discussed in [15] and [16]. The MPPT block senses the PV array current I_{PV} and array voltage V_{PV} and returns the array voltage command. The PV converter controls the array voltage V_{PV} at the reference voltage V^*_{PV} commanded by the MPPT controller and boosts the voltage to the level of desired dc voltage. Error between the ordered and real voltage is processed through the voltage controller into the ordered current I^*_{PV}, which is compared with the array current I_{PV}.

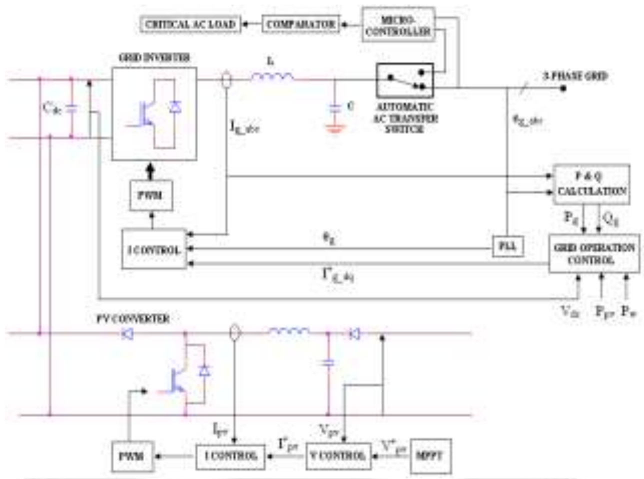

Fig.9. Schematic Control for Grid-tied PV System

(ii). GTI control

Basic concept of GTI control is to obtain the maximum power from varying sun irradiation and minimize the rating of the inverter by regulating reactive power generation. Below a specific solar irradiation, real power from the PV system is controlled to obtain the maximum power from changeable sun irradiation to supply either on-site electrical loads, or to supply power to the grid when the PV system output and sufficient sun light are available. But, when the grid fails for load shedding, or voltage level and frequency level goes down beyond usual limits the inverter stops output initially for few seconds, and then the transfer switch moves to inverter only mode and finally the inverter starts to give output to the critical on-site loads(approximately 30% of installed capacity of solar plant) with own pre-defined references until the grid is come back.

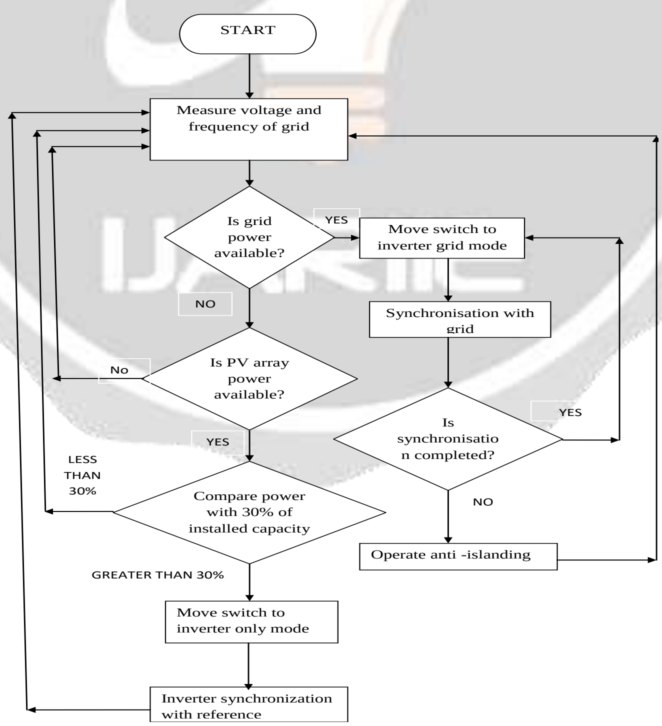

Fig.10. Flow Chart of Control Scheme

(iii). Anti-islanding control

The condition where a GTI continues to supply power to the grid in the duration of blackout is called islanding. Due to the technical requirements as mention in IEEE 1547, to avoid the condition, inverter will detect the voltage and frequency of the grid. If voltage and frequency are less than set values, the inverter will switch OFF. In addition a new complicated active detection scheme is necessary to decrease the non-detection zone. So the inverter will use a variety of methods to efficiently push and pull a little on the grid voltage and frequency. When the grid is available, this small push-and-pull has no effect. However, if the inverter is the only source supporting an islanding grid, it will rapidly push the voltage and frequency outside the inverter's acceptable window of operation, triggering the inverter to shut down. But the problem is that in India power crisis is severe. Hence, the grid shuts down its feeders many a time during a day and existing battery less inverter remains OFF even though power is available in PV array until the grid would come back and it would run again. In our design we used an automatic transfer switch with a control circuit. When power will not available in grid, the control circuit will send a command to transfer switch and transfer switch will be activated in inverter only mode. In this mode, the inverter will reactivate the output transistors to continue supplying power to loads wired into the critical load panel which is separately connected from the grid. In this way, when the grid goes down and the inverter is sending power only to the critical load panel, PV power is not allowed energizing from the utility lines. Fig. 6 presents the complete flow chart of our planned control scheme.Fig.6.

4. SIMULATION RESULTS AND ANALYSIS

This section deals with simulation of the proposed circuit in different conditions.

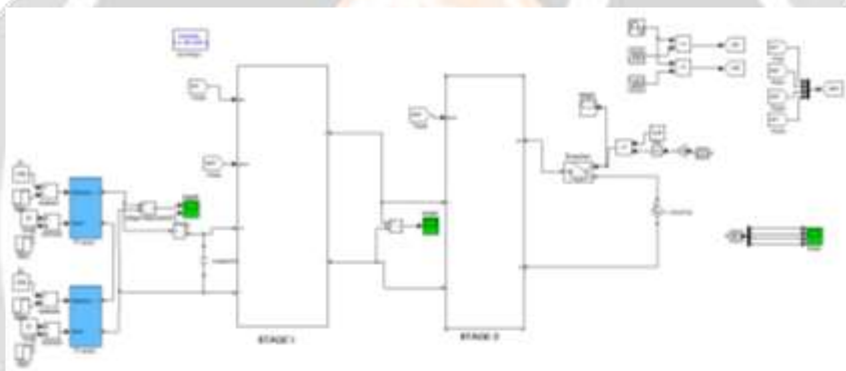

Fig.11. simulation diagram of proposed system

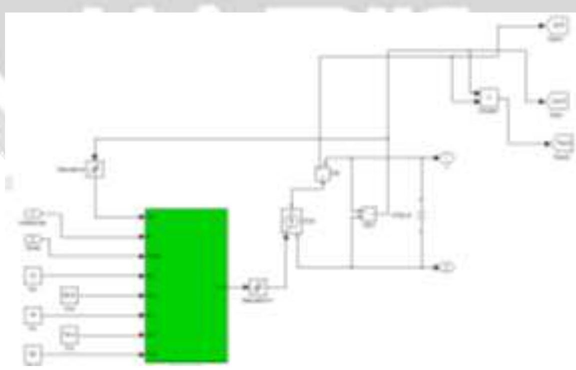

Fig.12. Solar PV system equivalent diagram using MATLAB

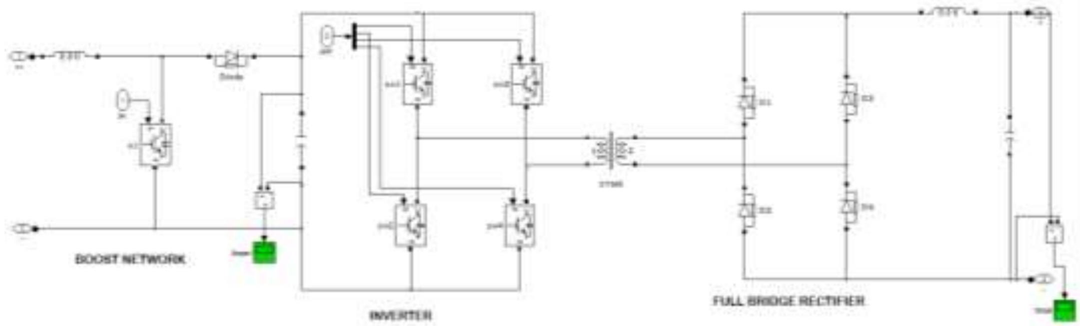

Fig.13. DC-DC converter design using MATLAB

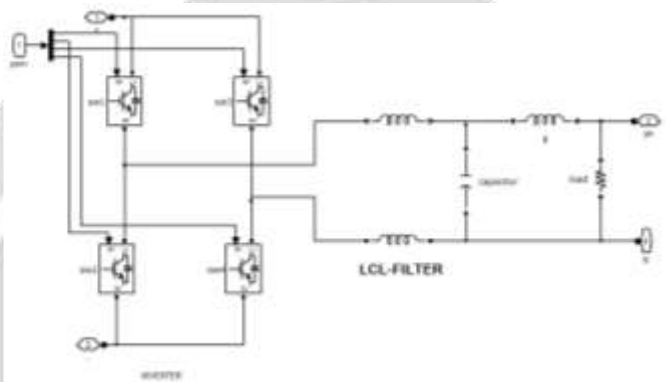

Fig.14. proposed inverter using MATLAB

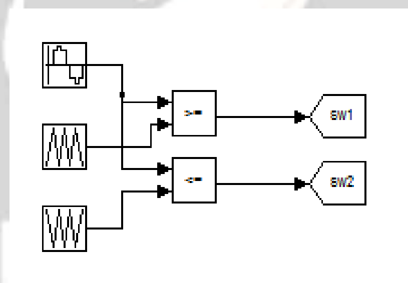

Fig.15. pwm pulses generated for inverter using MATLAB

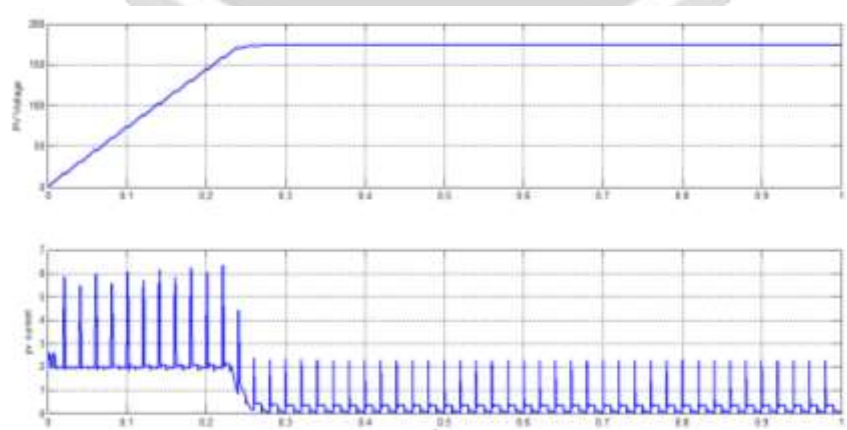

Fig.16. Solar PV system generated voltage and current

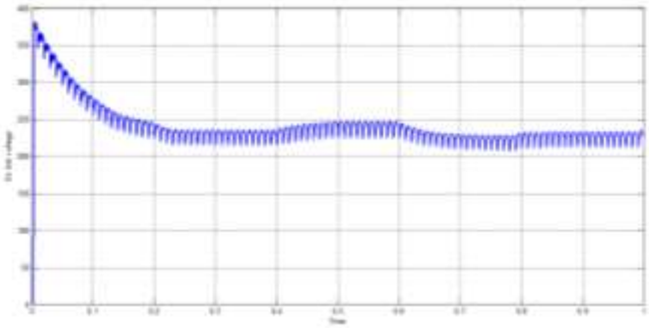

Fig.17. Voltage across the common DC-link

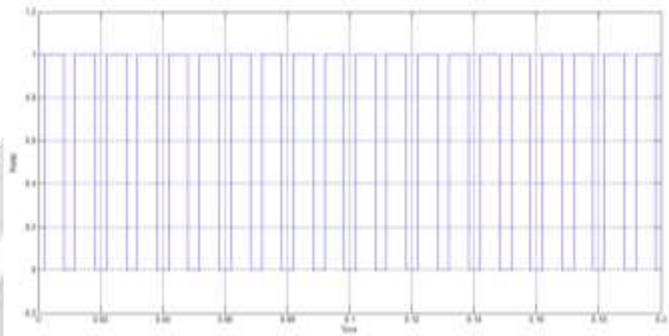

Fig.18. PWM pulses for proposed inverter

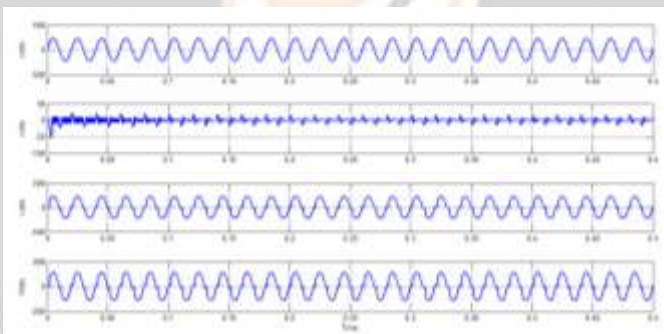

Fig.19. (a) Voltage of grid. (b) Current of grid (c). Voltage injected into grid (d) current flowing into grid

4. CONCLUSION

In this paper a smart power system for home is simulated in MAT LAB environment. This is to help the consumers to meet their load demand by local power generation. The SPSH increases the system efficiency when load demand becomes more than the generation capacity. The synchronization of DC power from solar cell and battery has been successfully achieved, and the grid power is managed separately. However, optimization of the power usage from solar panel, battery and the grid supply needs to be considered in future works. Also, the efficiency of solar PV array could be another consideration for obtaining better results.

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