A Novel Fuzzy Logic Based Reconfigurable Solar Converter With Grid Connected System

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Abstract:- This paper introduces a novel photovoltaic system is an arrangement of components designed to supply usable electric power using the sun as the power source. The main concept of a new converter, for photovoltaic battery applications, called Reconfigurable Solar Converter (RSC), uses only single-stage three phase grid-tie solar PV converter to perform dc/ac and dc/dc operations overcomes the drawback of conventional converters. In this paper a RSC which uses minimum number of conversion stages which in turn improves the efficiency and reduces the cost, weight and volume has been realized. In this paper fuzzy logic controller is used for controlling the Reconfigurable Solar Converter (RSC) for Photovoltaic (PV)-battery application, particularly utility-scale PV –battery application.

Index terms: Reconfigurable Solar Converter, photo voltaic, fuzzy logic control, grid –tie solar, single-stage inverter cum chopper.

I. INTRODUCTION

Photovoltaic (PV) power supplied to the utility grid is gaining more and more attention nowadays. However, depending on the characteristics of the PV panels, the total output voltage from the PV panels varies greatly due to variation of temperature, irradiation conditions, shading and clouding effects. When even a small portion of a cell, module, or array is shaded, while the remainder is in sunlight, the output falls dramatically. The conventionally used converters in solar systems have many disadvantages such as multiple conversion stages, complex control, less efficient, high cost, bulky, etc. In view of continuity & stability, 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 [1-2].

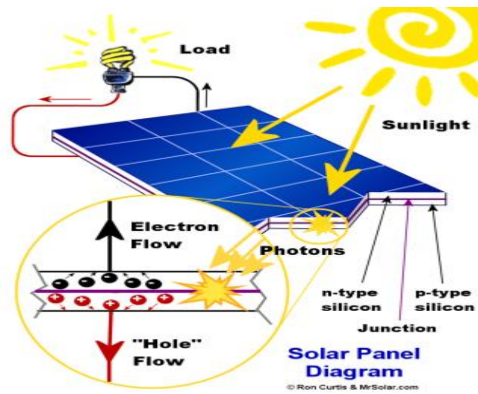

Fig 1. Simple process flow in solar panel

There are different options for integrating energy storage into a Utility-scale solar PV system. Every integration solution has its advantages and disadvantages. Different grouping solutions can be compared with regard to the number of power stages, efficiency, storage system flexibility, control complexity, etc.

The main objective of the system is to design a single-stage inverter cum chopper instead of multistage inverter cum chopper. This proposed single-stage inverter cum chopper (SSICC) performs different operations such as DC-AC & DC-DC in order to interconnect 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. Section II introduces brief description about existing techniques and their problems. In section III and IV we discussed an idea how to generate electrical energy from the solar cell using PV and corresponding modes and controls. In section V, VI gives different control schemes and design considerations and finally section VII and VIII provides simulation results, conclusion followed by its future scope.

II. LITERATURE SURVEY

Literature survey has been carried out on information regarding single stage inverter cum chopper (SSICC) for PV- Battery system [1]–[9].The system described in [7] proposes a hybrid CAES system, where compression and expansion modes are operated under a Maximum Efficiency Point Tracking (MEPT) strategy. The system described in [3]–[7] proposes a two-stage high-frequency power conversion in cascaded configuration with dc link in the middle. The system described in [8]–[11] uses a line-commuted inverter along with

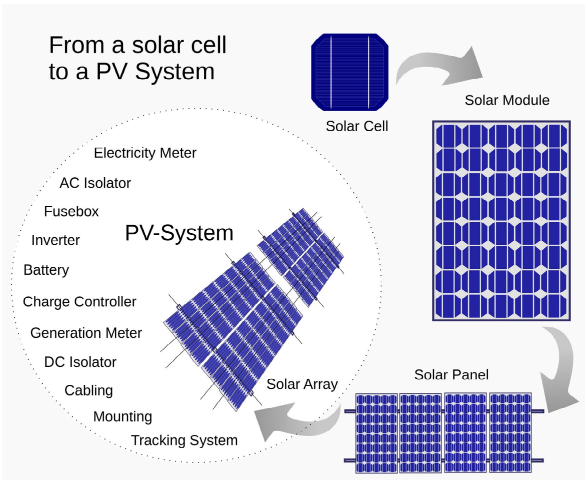

Fig 2. Elements in Electricity generation

an isolated dc–dc stage. Also, many no isolated single-stage boost or buck–boost derived inverter topologies have been developed [2]–

[5]. The system described in [6], [7] overcomes the major drawbacks or limitation of input-voltage range and/or requirement of two input sources. The system described in [8] replaces the isolated Dc–dc with non isolated or transformer less dc–dc [8].The system described in [9] uses the transformer less dc–dc stage will be more reliable and cost effective.

III. SOLAR PHOTOVOLTAIC ELECTRICITY GENERATION

Solar photovoltaic (PV) electricity generation is not available 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 standpoint, 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. 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 every integration solution has its advantages and disadvantages[4-5]. Different integration solutions can be compared with regard to the number of power stages, efficiency, storage system flexibility, control complexity, etc.

This paper introduces a novel single-stage solar converter called reconfigurable solar converter (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.

A. BLOCK DIAGRAM OF THE SSICC

The below diagram shows the block diagram of the SSICC .The block diagram consists of following blocks.

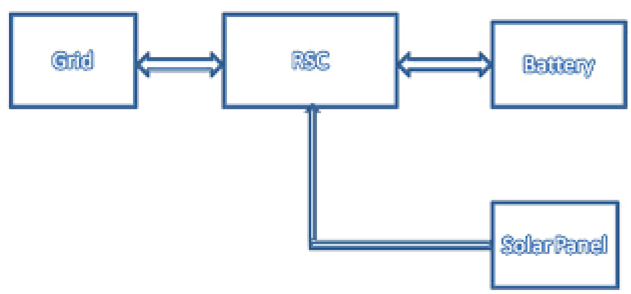

Fig 3. Block diagram of the SSICC

1) Solar cell array

Solar array is the one which converts the solar radiation in to useful DC electrical power. Electricity is directly generated by utilizing solar energy by the photo voltaic process. The direct conversion of solar energy into electrical energy by means of the photovoltaic effect, that is, the conversion of light (or other electromagnetic radiation) into electricity [6].

2) Blocking diode

A Blocking Diode which lets the array – generated power flow only toward the battery or grid. Without a blocking diode the battery would discharge back through the solar array during times of no insulation.

3) Converter

Converter is the one which converts the power from AC to DC or DC to DC or DC to DC. In order to integrate the solar arrays with the batteries there is a requirement for chopper which converts fixed DC to variable DC. Also to integrate solar arrays or batteries to grid there is a need for DC to AC inverter.

4) Battery storage

An electric battery is a device consisting of one or more electrochemical cells that convert stored chemical energy into electrical energy. Each battery consists of a negative electrode material, a positive electrode material, an electrolyte that allows ions to move between the electrodes, and terminals that allow current to flow out of the battery to perform work.

IV. MODES OF OPERATION & CONTROL OF SSICC

This paper explains about different modes of operation, system benefits compared to state of art methods & System control schemes of the proposed system. The system described in [7] proposes a hybrid CAES system, where compression and expansion modes are operated under a Maximum Efficiency Point Tracking (MEPT) strategy[7].

The five possible operation modes for the proposed SSICC system are as follows.

a) Mode 1—PV to grid (s1 & s6 switches remain open)

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 this mode S1 and S6 switches remains open keeping all the remaining switches in closed position.

b) Mode 2—PV to battery (s5 & s3 switches remain open)

In Mode 2, the battery is charged from PV panels through the dc/dc operation of the converter .In this mode S5 and S3 switches remains open keeping all the remaining switches in closed position. In this mode, the MPPT function is performed therefore; maximum power is generated from PV.

c) Mode 3—pv/battery to grid (switch s6 switch remains open)

In Mode 3 both the PV and battery provide the power to the grid. In this mode S6 switch remains open keeping all the remaining switches in closed position .In this mode MPPT control is not possible.

d) Mode 4—battery to grid (switch s4 & s6 switches remain open)

In Mode 4 the battery provide the power to the grid Mode 4 represents an operation mode that the energy stored in the battery is delivered to the grid. In this mode S4 & S6 switches remains open keeping all the remaining switches in closed position.

e) *Advantages of single-stage inverter cum chopper (SSICC)*

The single stage inverter cum chopper (SSICC) 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[8].

This 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 single stage converter.

However, different system controls can be proposed based on the requested power from the grid operator specifically, a large solar PV power plant using the single stage converter can be controlled more effectively and its power can be dispatched more economically because of the flexibility of operation. Developing a detailed operation Preq and available generated power form the plant Pgen.

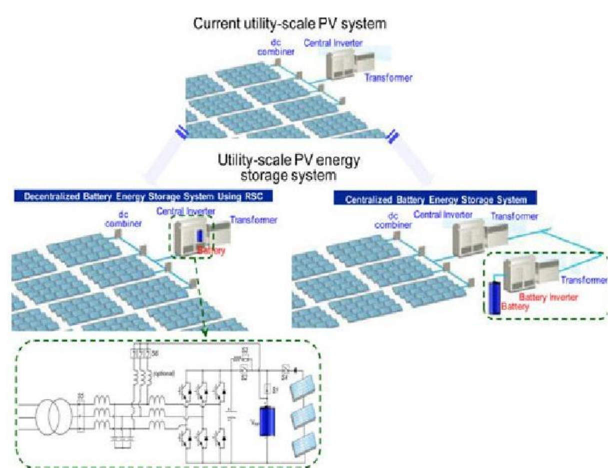

Fig 4. Utility-Scale PV-Energy Storage Systems with the Single Stage Inverter cum Chopper (SSICC) and the Current State-of-the-art Solution

V. SYSTEM CONTROL SCHEMES OF SINGLE STAGE INVERTER CUM CHOPPER (SSICC)

In response to the request of the grid operator, different system control schemes can be realized with the single stage inverter cum chopper (SSICC) based solar PV power plant as follows:

1) *System control 1 for p generated > p demand*

System control 1 will be activated when generated power is greater than the demand. In this control the system operates in mode1 & mode2 such that the PV cells supply the grid & excess amount of power be stored in the batteries.

2) *System control 2 for p generated < p demand*

System control 2 will be activated when generated power is lesser than the demand. In this control the system operates in mode 3 such that the PV cells & batteries supply the grid.

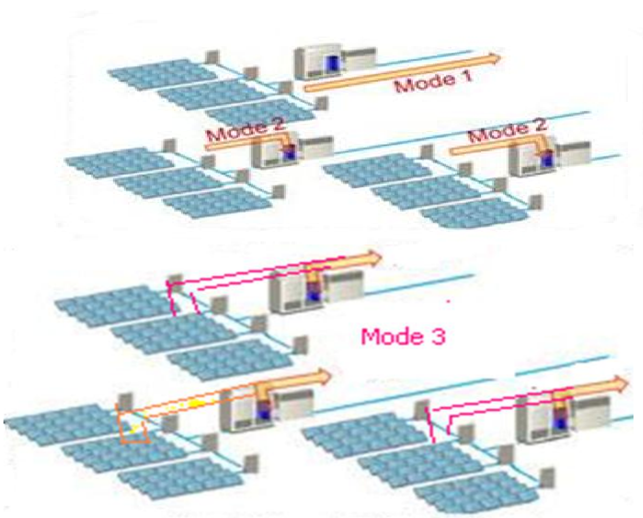

Fig 5. Model for System Control 1 and 2 modes.

3) *System control 3 for p generated = p demand*

System control 3 will be activated when generated power is equal to the demand. In this control the system operates in mode1 such that the PV cells supply the grid.

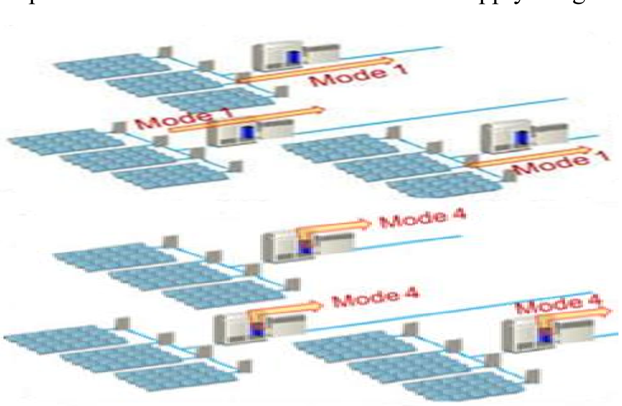

Fig 6.Model for System Control 3 and 4 modes.

4) *System control 4 for p generated = 0*

VI. DESIGN CONSIDERATIONS AND MODIFICATIONS TO CONVENTIONAL INVERTER

One of the most important requirements of the paper 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 single stage converter 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 single stage converter circuit.

A. *MAXIMUM POWER POINT TRACKING*

Maximum power point tracking, frequently referred to as MPPT, is an electronic system that operates the Photovoltaic (PV) modules in a manner that allows the modules to produce all the power they capable of. MPPT is not a mechanical tracking system that physically moves the modules to make them point more directly at the sun. Since the power output of a PV array varies according to the sunlight conditions, atmospheric conditions, including cloud cover local surface reflectivity and temperature. So MPPT is necessary in order to extract the maximum power from the array at all times. MPPT is a fully electronic system that varies the electrical operating point of the modules so that the modules are able to deliver maximum available power.

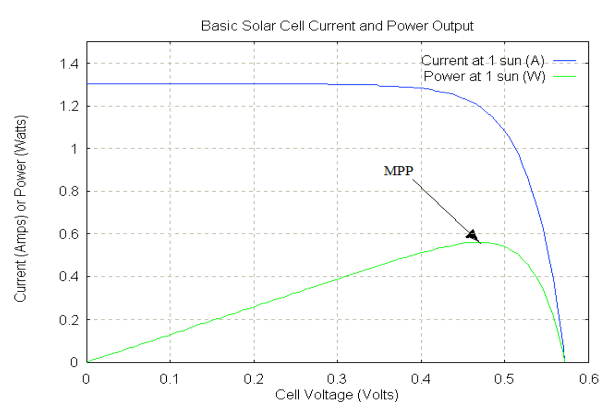

Fig.7.1 PV Module Power/Voltage/Current Characteristics

i) System configuration

The system configuration for the topic is as shown. Here the PV array is a combination of series and parallel solar cells. This array develops the power from the solar energy directly and it will be changes by depending up on the temperature and solar irradiances. So we are controlling this to maintain maximum power at output side we are boosting the voltage by controlling the current of array with the use of PI controller. The relevant circuit is as shown. After we are getting the maximum power we are applying to the utility grid.

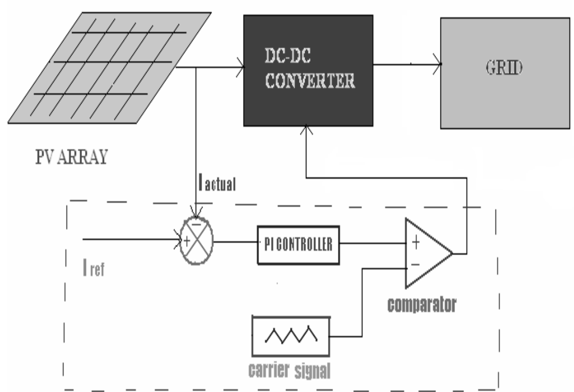

Fig 7.2 System Configuration of PV System

Different algorithms help to track the peak power point of the solar pv module automatically. The various algorithms used are.

A. Perturb and observe.

B. Incremental Conductance.

C. Parasitic Capacitance.

D. Voltage Based Peak Power Tracking.

E. Current Based peak power Tracking.

ii) *Flow chart*

The Flowchart of Short-circuit current MPPT is shown below

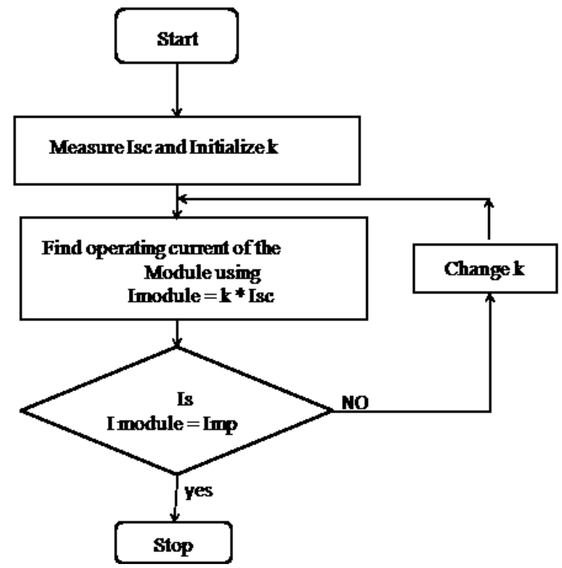

Fig 7.3 Flow Chart For the Short-Circuit Method

iii) Fuzzy Logic Controller

Developing fuzzy logic controller is cheaper than developing model based or other controller with comparable performance. Fuzzy logic controllers are more robust than PID controllers because they can cover much wider range of operating conditions. These are customizable. We can use Fuzzy Logic Toolbox software with MATLAB technical computing software as a tool for solving problems with fuzzy logic. Fuzzy logic is a fascinating area of research because it does a good job of trading off between significance and precision—something that humans have been managing for a very long time.

VII. SIMULATION/EXPERIMENTAL RESULTS

Any logic circuit, or control system for a dynamic system can be built by using standard building blocks available in Simulink Libraries. Various toolboxes for different techniques, such as Fuzzy Logic, Neural Networks, dsp, Statistics etc. are available with Simulink, which enhance the processing power of the tool. The main advantage is the availability of templates / building blocks, which avoid the necessity of typing code for small mathematical processes.

The converter circuit topology is designed to be compatible with a given load to achieve maximum power transfer from the solar arrays. The power will be maximum for along the variations of temperature and solar irradiance in the PV array which is giving to input to DC-DC converter. In this paper we explained the model of PVA and the DC-DC converter that is boost converter and its output characteristics and we observed that the designed DC-DC converters successfully followed the variations of solar irradiation. The maximum power point tracking is controls their respective voltage, current waves. Here the power is maintaining maximum value. And similarly the boost converter which is boosting the voltage is also under the control of the MPPT.

A. *MPPT block for DC–DC operation*

The figure 6.1 shows the simulink model of MPPT controller block for DC-DC operation.

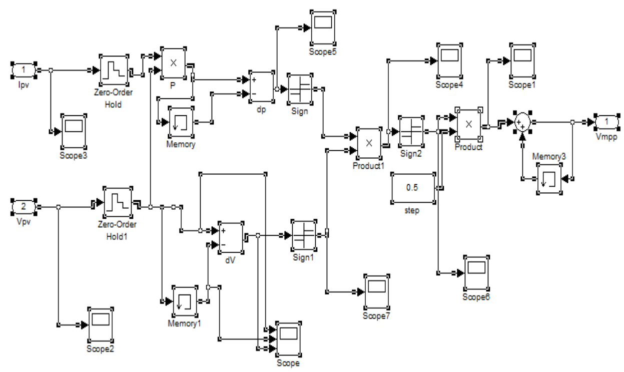

Fig 8.1 Simulink Model of MPPT

Controller Block For DC-DC Operation

Initial measured PV array voltage, PV array current are calculated power as P1and stored in the memory. After few minutes again measured PV array voltage, PV array current are calculated as P2 and compared the previous power (P2) and present power(P1) as stored in the memory and generate the error signal .That error signal will generate a duty cycle. That duty cycle will control the boost converter operation. If P2-P1=0 the error signal will be zero therefore PV array will be observed at maximum power point .If P2>P1 the error signal will be positive and increased duty cycle to meet the increased load. If P2<P1 the error signal will be negative and decreased duty cycle to meet the reduced load. The cycle will be repeated continually.

B. *Simulation circuit for DC-AC operation mode*

The figure 6.2shows the simulink model of MPPT controller block for DC-DC operation. Initial measured PV array voltage, PV array current are calculated power as P1and stored in the memory. After few minutes again measured PV array voltage, PV array current are calculated as P2 and compared the previous power (P2) and present power(P1) as stored in the memory and generate the error signal .That error signal will generate a duty cycle. That duty cycle will control the boost converter operation. If P2-P1=0 the error signal will be zero therefore PV array will be observed at maximum power point .If P2>P1 the error signal will be positive and increased duty cycle to meet the increased load. If P2<P1 the error signal will be negative and decreased duty cycle to meet the reduced load. The cycle will be repeated continually.

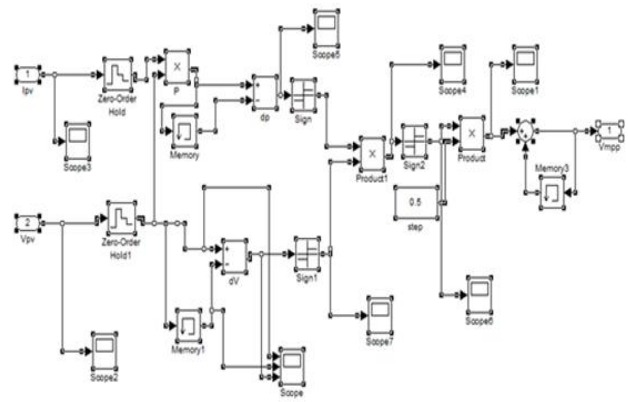

Fig 8.2 Simulink Model of MPPT Controller Block For DC-AC Operation

C. *Controller blocks for DC-AC operation*

The fig 6.12 shows simulink model of controller block for DC-AC operation. The main function of the PLL first it will generate some value and it will store in memory and next time it will measure the value is same it will generate the same duty cycle if the value is changed it will store that changed value in the memory for that it will generate the duty cycle.

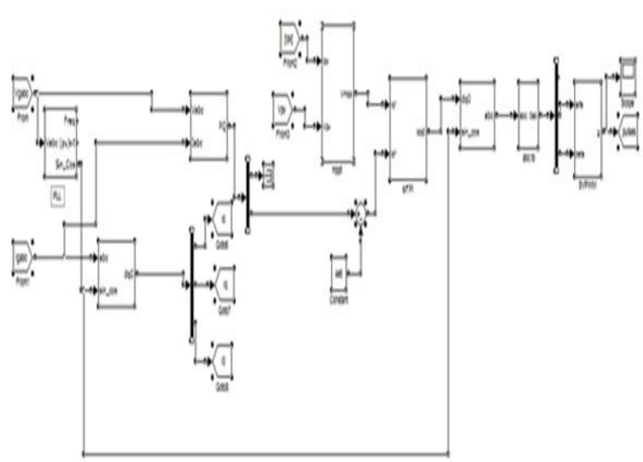

Fig 8.3 Simulink Model of Controller Block For DC-AC Operation

D. *Fuzzy Logic Controller Block for DC-DC operation*

The figure 6.14 shows the simulink model of FLC block for DC-DC operation. The main function of a PI controller if there is any errors in the steady state currents it will decrease it and send to the pulse width modulation. The main function of the pulse width modulation to compare the reference signal and carrier signal to generate the duty cycle.

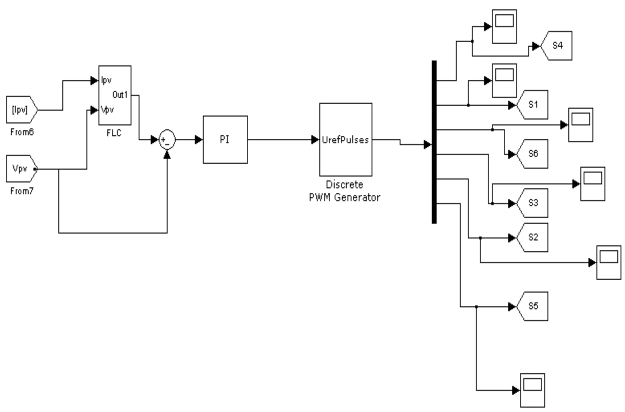

Fig 8.4 Simulink Model of FLC Block For DC-DC Operation

E. *Simulation outputs in DC- DC mode*

i) *PV Output Voltage for DC-DC Converters ion*

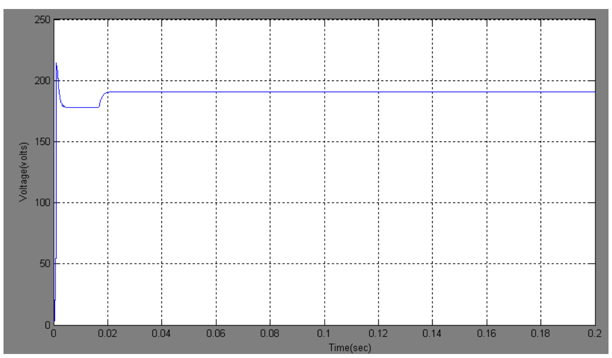

Fig 8.5 PV Output Voltage for DC-DC Converters ion

The above figure 6.18 shows the IPV voltage in the DC-DC mode of operation. The inputs of the PV cell are temperature, irradiance. In this simulation circuit maximum irradiance is 800 meter per second, temperature 25 degrees centigrade the resultant voltage is 180V.

ii) *PV Output Current for DC-DC Converters ion*

The above figure 6.19 shows the PV current in the DC-DC mode of operation. The inputs of the PV cell are temperature, irradiance. In this simulation circuit maximum irradiance is 800 meter per second, temperature 25 degrees centigrade the maximum current is 8.2 A.

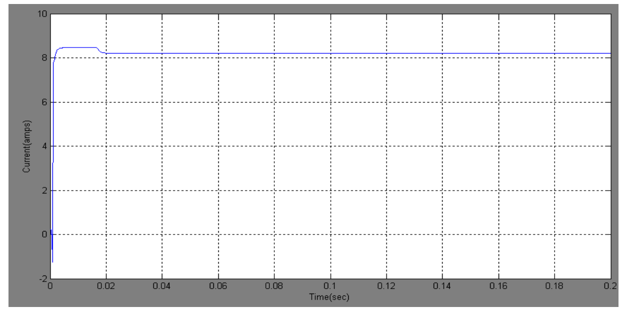

Fig 8.6 PV Output Current for DC-DC Converters ion

iii) *PV Output Power for DC-DC Converters ion*

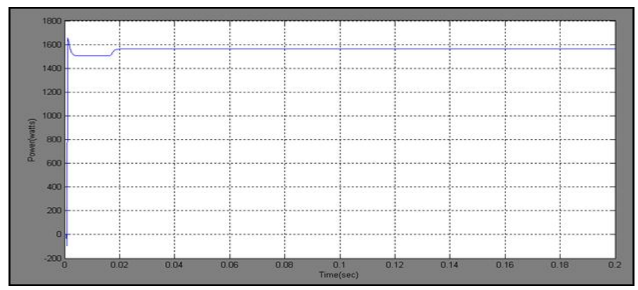

Fig 8.7 PV Output Power for DC-DC Converters ion

iv) *Battery State of charge mode (SOC) (DC-DC)*

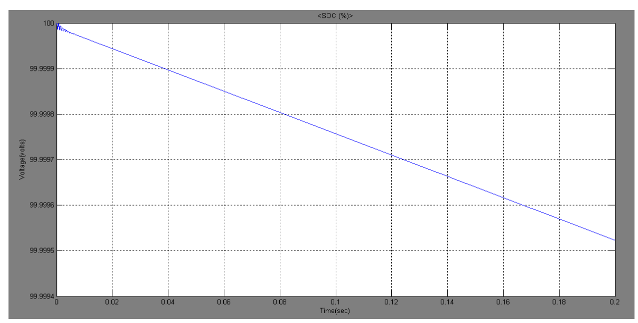

Fig 8.8 Battery State of charge mode (SOC) (DC-DC)

v) *Voltage across Battery (DC-DC)*

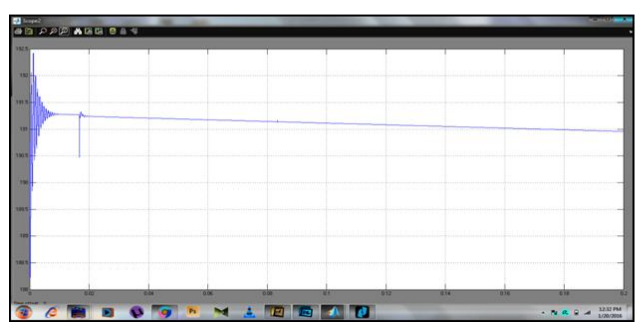

Fig 8.9 Voltage across Battery (DC-DC)

F. Simulation out puts in DC-AC Conversation

i) *The Voltage across the Grid (DC– AC)*

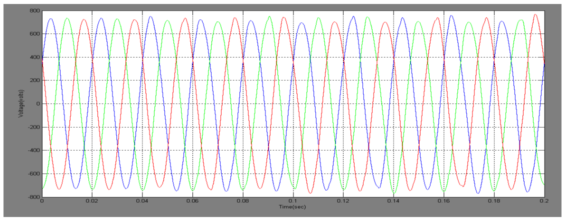

Fig 9.0 Voltage across the Grid (DC– AC)

The above figure 6.23 shows the voltage across in the DC-AC mode of operation. The inputs of the PV cell are temperature, irradiance. In this simulation circuit maximum irradiance is 800 meter per second, temperature 25 degrees centigrade the output is nearly 650V.

ii) *The Current across Grid in DC-AC Converters ion*

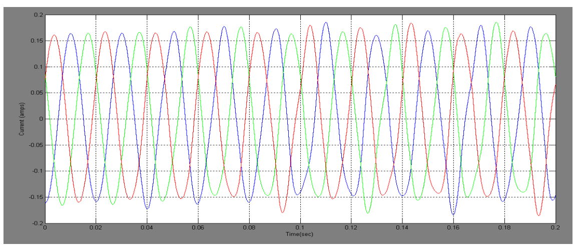

Fig 9.2 Current across Grid (DC – AC)

The above figure 6.24 shows the current across the grid in the DC-AC mode of operation. The inputs of the PV cell are temperature, irradiance. In this simulation circuit maximum irradiance is 800 meter per second, temperature 25 degrees centigrade the resultant current nearly 0.16 A.

VIII. CONCLUSION & FUTURE SCOPE

The single stage inverter cum chopper for PV- battery application works efficiently for generating the required output. The SSICC power conversion system performs different operating 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) in different control strategies for solar PV systems with energy storage. Results for various inputs shown in the above figures confirm that the system is solution for PV-battery power conversion systems. The 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 applications because it minimizes the number of conversion stages, thereby improving efficiency, reducing cost, weight and volume.

Although this paper focuses on three-phase application, the main concept can also be applied to single-phase application. The solution is also capable of providing potential benefits to other intermittent energy sources including wind energy. The solution requires minimal complexity and modifications to the conventional three-phase solar PV converters for PV-battery systems.

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