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Engineering

DISTRIBUTED GENERATION CONTROL AND ENERGY MANAGEMENT USING HIGH SPEED RECONFIGURABLE CONTROLLER

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ABSTRACT Continuously expanding deployments of Distributed Power Generation system (DPGs) are transforming the conventional centralized power grid into a power distribution network. The modern power grid requires flexible energy utilization but presents challenges in the case of a high penetration degree of renewable energy, among which solar photo voltaic are typical sources. To address the challenging issues and more importantly to leverage the energy generation stringent demands from both utility operators and consumers have been imposed on the DPGs. Furthermore as the core of energy conversion, an energy management technique using Power electronic controller called High Speed Reconfigurable Power Electronic Controller (HSRPEC) is introduced in this paper. Integration of HSRPEC which is a reconfigurable controller that can replace the conventional embedded microcontroller or DSP based controller design for the real time control and monitoring of PV system. An optimized energy management technique to reduce the cost and increase the effectiveness of a PV system is proposed in this paper. It is based on the optimum sizing of the energy storage system, to meet the needs of the system in normal conditions, while in the critical cases; the residential load will be supplied by the micro grid itself. However to extend the battery life and reduces its size , a super capacitor has been combined with batteries, to quickly respond to the short time peak current demand. Furthermore, the proposed algorithm will supervise the battery state of charge (SOC) and satisfy the highest priority load demand under different situation. This can be used in rural areas where it is impossible to draw supply from main grid. It can supply power even though the main grid supply is interrupted due to calamities like flood.

KEYWORDS : Distributed Power Generations, High Speed Reconfigurable Power Electronics Controller, Photo voltaic system, State of Charge, Super Capacitor

1. INTRODUCTION

The motivation behind the use of renewable energy sources is the reduction of CO emissions and improvement of human kind's quality of life. This is especially true in isolated, standalone, small islands where the access to renewable energy sources is the only solution to meet their energy needs. An alternative is the use micro-grid supplied by centralized hybrid systems, where the combination of several natural resources guarantees a steady energy generation. In recent years, a growing interest for micro-grids has been observed in the technical literature[1].

The micro-grid, benign power generation using various renewable energy sources (solar, wind, biomass etc) along with energy storage units has emerged as a reliable power supply. Hence with the implementation of micro-grid, one can access the renewable energy there by reducing the dependency on the main-grid. Moreover, micro-grid can deploy to fill in for an unreliable utility grid, reach new off grid consumers, save money and reduce carbon emissions. Among the renewable energy resources, photovoltaic are prove to be both clean and economical due to new advanced technologies and efficiently. With several solar PV projects coming up under the Jawaharlal Nehru National Solar Mission (JNNSM), the demand for PV cells and modules is expected to increase significantly. Moreover, the capital costs involved in setting up solar PV projects in India, along with the feasible geographical location of the country that enables it to receive around 3,000 hours of sunshine each year, makes solar PV a highly viable option for electricity generation[2]. The daily average solar energy incident over India varies from 4-7 kWh/m^2 with about 2300-3200 sunshine hours per year, depending upon location[3].Even assuming 10% conversion efficiency for PV modules, it will still be thousand times greater than the likely electricity demand in India by the year 2017[4]. Exploitation of the abundant solar energy resources available in our country is therefore, being accorded a high priority by the ministry of New and Renewable Energy. However this paper presents a method to modify the existing system to incorporate renewable resources as a part of energy producing unit so as to provide an uninterruptable power supply.

The key rollers includes solar panel, DC-DC converters, inverter, hybrid energy storage system (battery and super capacitor) and controller (HSRPEC).The output characteristics of PV module depends on the solar isolation, desired temperature and output voltage of PV module. Therefore, maximum power point tracking techniques should be developed in the PV system in order to maximize output power of PV system. Main challenge in the PV system is the limitation in storage capacity which leads to failure in supply at the peak demands. Instead of battery, a hybrid storage system comprises of battery and super capacitor is used which improves the operational range. The battery and super capacitor units act as the energy storage devices and solar PV as the renewable energy source. By using the proposed schemes, it is shown that, the quick fluctuations of load are supplied by the super capacitor pack and the average load demand is taken care by the batteries[5]. Replacing the conventional embedded microcontroller with a SOPC based power electronic controller for real time control and monitoring will reduces the effort required. One of the main advantage of this is it provide faster controller development, reduce the processor obsolesce risk and satisfies minimum time to market criteria. HSRPEC have direct control over the converter and inverter circuit which will help to maintain the voltage at the load as per the requirement.

Overall this paper gives an insight into an efficient energy production and control. Micro-grids have two modes of operation, namely, grid-interactive and islanding modes [6]. During islanding mode, the main objective of the storage is to maintain the energy balance. During grid-interactive mode, the aim is to prevent the propagation of the renewable source intermittency and load fluctuations to the utility grid [7]. This technology can be used for an individual home or a group of home or can be implemented in a locality to form micro-grid. Using the above control strategy each home can get power from their daily requirements from the micro-grid. If micro-grid fails they can get connect with utility. Thus a uninterrupted power can be maintained within the available resources.

2. CONVENTIONAL TOPOLOGY AND PROPOSED TOPOLOGY

Photovoltaic PV system are solar energy supply systems which supply power directly to an end user. The efficiency of the PV system mainly depends on the power electronic conversion and its controlling scheme. The voltage and current available at the terminal of PV device may directly fed to small loads such as lighting system and DC motors. For more sophisticated applications it required electronic converts to process the electricity from the PV device regulation and controlling purposes.

One task of power electronic conversion is to continuosly adapt the system such that it can draw the maximum power from the PV panels regardless of weather or load conditions. And also at the same time, an efficient storage unit should also be designed to meet the load demands at the peak time. The conventional PV system are not much advanced in its controlling areas and storage capacity. Typical conventional block diagram is shown in the fig 1

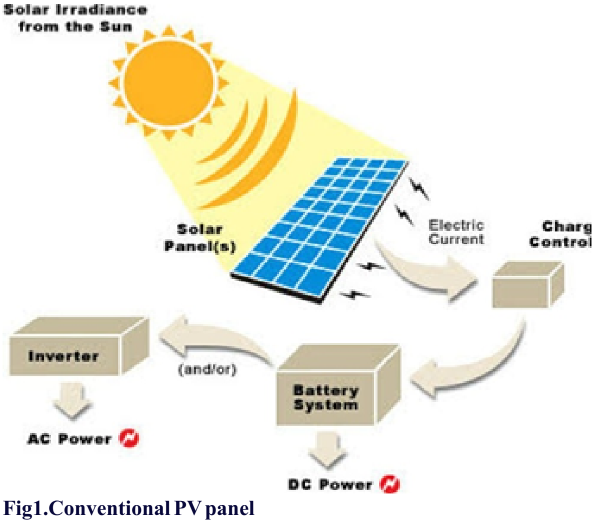


Fig1.Conventional PV panel

But the main problem in this system is seasonal availability of sunlight and capacity of storage system. This paper proposes advanced distribution generation system which comprises hybrid storage system and advanced controller. Hybrid storage system which was the combination of battery and super capacitor is used[5]. Proposed block diagram is shown in fig2.

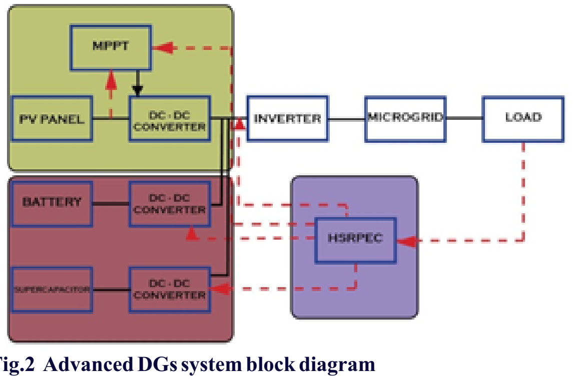


Fig.2 Advanced DGs system block diagram

Four modes of operation of the proposed system are:

MODE 1: Operation is assumed to be day time, ie; solar insolation is greater than 80%. Due to the availability of sunlight high amount of energy can be produced. Hence PV feed the load requirement(both priority and non-priority loads).The excess amount of energy produced is used to charge battery and supercapacitor.

MODE 2: In this mode ,the amount of solar insolation is about 60%-80%. During this time the generated power is used to meet the load and to charge the supercapacitor.

MODE 3: Only about 25-60% of solar insolation is available. PV and supercapacitor together meet the load requirement. The rate of discharge of supercapacitor during this mode depends upon the peak demand at that time.

MODE 4: This mode is assumed to be night time, since no sunlight is available or amount of solar insolation available is less than 25%.The load requirement will be taken over by supercapacitor and battery.The peak demand will be met by the supercapacitor.

PV PANEL

Photovoltaic(PV) system directly converts sunlight into electricity. The basic device of a PV system is the PV cell. Cells may be grouped to form panels or arrays[8].The amount of power generated by a solar cells is determined by the light falling which in turn is determined by the weather and time of day.The capacity of the solar PV array depends 90% energy consumption of the building on and the shade- free roof top area available.

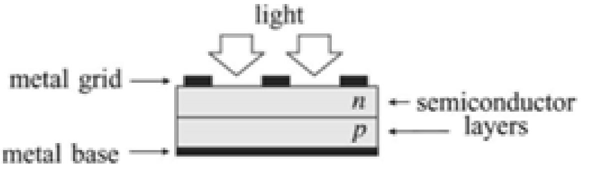


Fig.3 Basic structure of PV cell

Solar cells have relatively low conversion efficiency and the improvement of overall system efficiency is an important design factor: in the area of PV systems. This can be partly achieved by using high-efficiency intermediate converters with maximum power point controllers (MPPT). Tracking the maximum power point (MPP) of a photovoltaic (PV) array is usually an essential part of a PV system. As such, many MPP tracking (MPPT) methods have been developed and implemented. The overall simplicity and efficiency of PV system depends on the MPPT technique employed[9].

In this proposed system, the sunlight is incident on the solar panel or module, and then the dc voltage is produced. This voltage is fed into the interleaved boost converter for step up the dc voltage. The Controller is used for generating the control signals to turn on/off of the power switches present in the converter circuit to get the desired output voltage. The output voltage of the DC-DC converter is given to the filter circuit for regulating the dc voltage. This regulated dc output is given to the dc load.

3. DC-DC CONVERTER

Switched mode DC-DC converter converts unregulated DC input voltage into regulated DC output voltage at a specified voltage level. Switching power supplies offer much more efficiency and power density compare to linear power supplies. Basic converters that step up or step down voltage input contains elements like transistors, diodes, capacitor and inductors. Three basic converter topologies exist, they are buck (step-down), boost (step-up) and buck-boost (step-up or step-down)[10]. In our proposed design boost topology is used because its free wheeling diode can be used for blocking reverse current and it efficiently amplify PV arrays output voltage into higher level. Converters are controlled by pulse width modulation (PWM) duty cycle since the output of converter being determined by state of transistor switch. Thus optimum load impedance of PV module is achieved by varying duty cycle.

4. INVERTER

Power inverter is an electronic device or circuitry that changes direct current to alternating current. Inverter doesn't produce any power, the power is provided by the dc source. Inverter power circuit design contains a pair of two parallel MOSFET gates .Control circuit combines an analog circuit which is used to produce switching signal for inverter power circuit. The inverter requires four switching signals since it has four MOSFET switches. To create four signals an AND operation is performed between two sets of square wave signals and the SPWM. The four sets of switching signals can be categorized in two groups. The first group contains MOSFETs Q1 & Q2 while the second group contains MOSFETs Q3 & Q4. The switching circuit is illustrated in Fig.3. When Q2 is turned ON, Q1 is switched with SPWM signal and both Q3, Q4 are turned OFF. This creates positive output voltage at inverter. For negative part of output voltage Q1 and Q2 are forced to be OFF and Q4 is ON while Q3 is switched by SPWM.

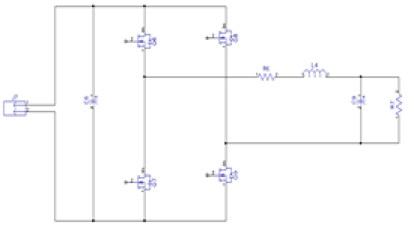


Fig.4 Switching circuit of inverter

5. HYBRID STORAGE SYSTEM

Optimal active hybrid system topology is used to connect the battery and super-capacitor in one combination for reducing the size of battery and capacitor banks and it increases the battery life. Battery banks are ables to store high energy density and release it over a long time. Super capacitor has high power density, it is capable to charge very fast and release large quantity of power in short period. A bidirectional buck-boost converter is used to store and recover energy from the storage system. During buck mode when the battery starts saving power and while the boost mode used for injecting power to the AC load or to the grid.

A super-capacitor is a high-capacity capacitor with capacitance values much higher than other capacitors that bridge the gap between bridge the gap between electrolytic capacitors and rechargeable batteries. They typically store 10 to 100 times more energy per unit volume or mass than electrolytic capacitors, can accept and deliver charge much faster than batteries, and tolerate many more charge and discharge cycles than rechargeable batteries. Hence this combination improves the operating range of the PV system.

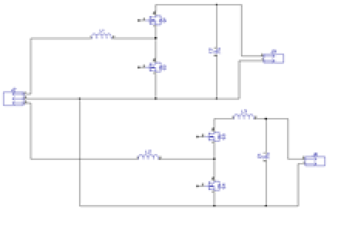


Fig.5 Switching circuit of storage system

6. HSRPEC

HSRPEC is used to provide a reconfigurable controller architecture which replaced the conventional embedded micro controller for Power Electronics system real-time control and monitoring. The basic controller building blocks for such a system will be integrated in hardware and software into a programmable system like FPGA. In this scheme, the user can implement a controller for a specific application with minimum efforts than required in conventional processor hardware and its software development. It reduce the processor obsolesce risk and satisfies minimum time to market criteria. The SOPC methodology developed for PE applications explores the idea of using control blocks as hardware IPs (designed in HDL as custom Ips), which is faster and reusable than its equivalent software implementation. These IPs either can be used as peripheral of a soft/ hard CPU core or as standalone IPs. The IPs with soft/hard CPU cores can be invoked from the application software project using the custom functions/instructions developed, which are easily understandable by the PE system developer.

7. RESULT AND DISCUSSIONS

8.1 PV array modeling

Equivalent circuit of a solar cell that can be treated us a current source, a diode, a parallel resistor expressing in terms of leakage current and also consisting of a series resistor describing an internal resistance which helps the current to flow. Diode which represents dark current.

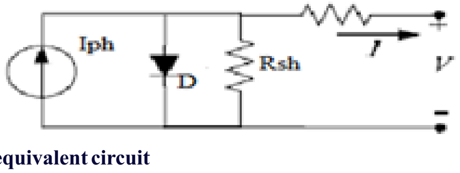


Fig.6 equivalent circuit

$$I = I_{ph} - Ir\left[e^{\frac{q(V+IRs)}{nkT}} - 1\right] - \frac{V + IR_s}{R_p} \quad (1)$$

Where
Iph is the photoelectric current
Is is the cell saturation dark current
Tc is the cell working temperature
A is ideal factor
Rsh is the shunt resistance
Rs is the series resistance

The photo electric current mainly depends on solar isolation and cell's normal working temperature on a particular area which is related by

$$I_{ph} = [I_{sc} + k_1(T_c - T_{ref})]H \quad (2)$$

Basically cell saturation current varies with that of temperature us

$$I_S = I_{RS}\left(\frac{T_c}{T_{ref}}\right)^3 e\left[\left(\frac{qE_g(T_c - T_{ref})}{T_{ref}T_c K A}\right)\right] \quad (3)$$

A pv array is a group of cells that are connected in series or parallel to get the required output such as an equivalent circuit is shown in figure

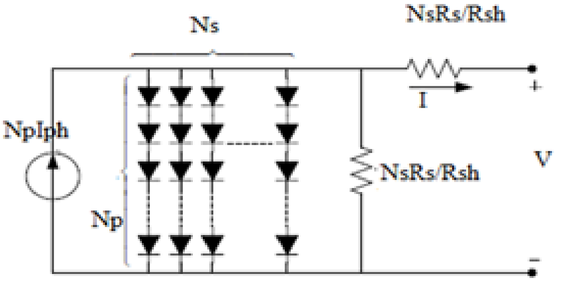


Fig.7 Equivalent circuit of a number of solar cells in series and parallel

$$I = N_p I_{ph} - N_p I_s\left[e^{\frac{q(V/Ns + IRs/Np)}{kTnA}} - 1\right] - \frac{N_p V/N_s + IR_s}{R_{sh}} \quad (4)$$

A solar cell is modeled based on equivalent circuit

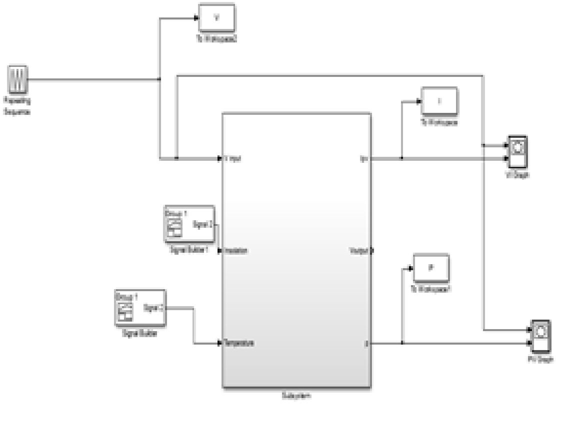
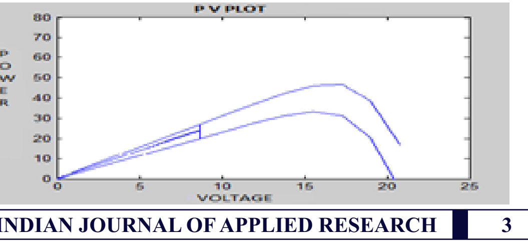


Fig 8. Masked PV model

The nonlinear nature of PV cell is apparent as shown in the Fig. 9, i.e., the output current and power of PV cell depend on the cell's terminal operating voltage and temperature, and solar isolation as well. The developed model is simulated for different solar isolation level and for different temperature. The figures shows that with increase of working temperature, the short circuit current of the PV cell increases, whereas the maximum power output decreases. In as much as the increase in the output current is much less than the decrease in the voltage, the net power decreases at high temperatures.



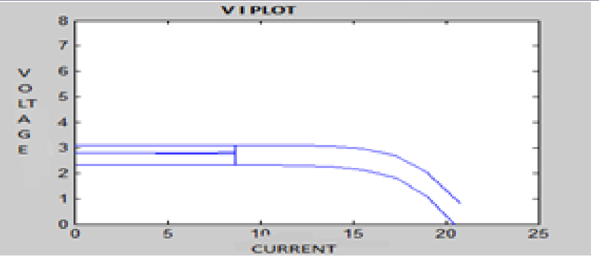


Fig.9. P-V and I-V characteristics of PV module at different working temperature.

On the other hand, with the increase in insolation, the short circuit current of the PV module increases, as well as the maximum power output increases.

Specification PV panel	
Maximum Power	100 W
Open Circuit Voltage	22 V
Short Circuit Current	5.75 A
Optimum Operating Voltage	18.9 V
Optimum Operating Current	5.29A
Temperature Coefficient Of Voc	-0.30%/deg.C
Tolerence	± 3%
Rating Of Boost Converter	
Input Voltage	21V
Output Voltage	36V
Duty Ratio	42%
Capacitance	0.0116F
Inductance	0.08H
Resistance	12.96 ohm

Rating Of Buck-Boost(supercapacitor)	
Input Voltage	36V
Output Voltage	24V
Duty Ratio	40%
Capacitance	0.011 F
Inductance	0.14 H
Resistance	12.96 ohm

8.2 SIMULATION RESULTS

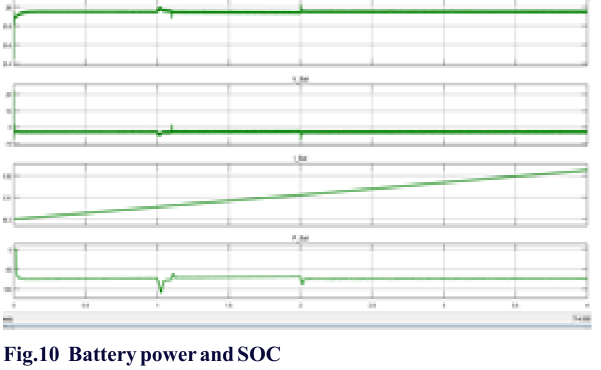


Fig.10 Battery power and SOC

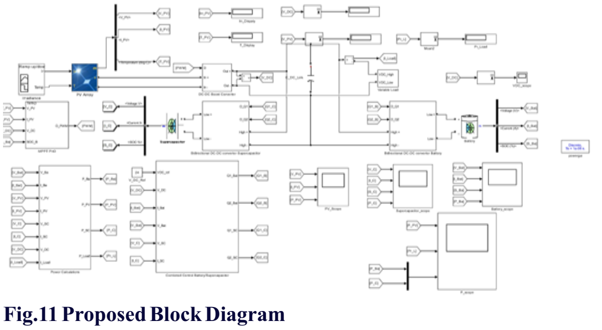


Fig.11 Proposed Block Diagram

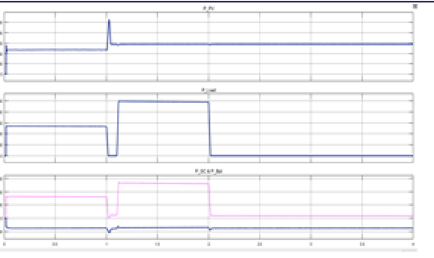


Fig.12 PV and hybrid system power

From 0s to 1s: In this period it is assumed to be day time. The PV started generating power but the storage system is still needed to supply the highest priority load, the delivered power reached the needs of the load and the supervisory switched back on the second load. It is clear from Figure 12 that the battery started charging also; meanwhile, when the SOC reached 90%, the supervisory stopped the battery charging to be protected against the overcharging and the surplus energy delivered to the grid.

From 1s to 1.2s: In this period fluctuation of load resulted in discharging of super-capacitor to power up battery and load. For protecting the battery against deep discharging, the load of lowest priority had switched off, when the SOC reach 30%.

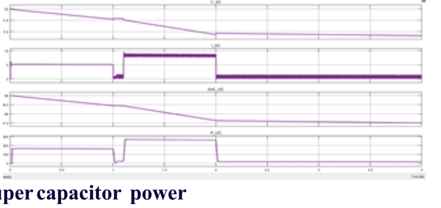


Fig.13 Super capacitor power

From 1s to 2s: In this period, it is assumed to be night time, both loads were supplied by the storage system.

8. CONCLUSION

The simulation results confirm the high efficiency of the proposed management system, as well as the benefits of using hybrid energy storage system and HSRPEC control. The PV system has been simulated in the worst cases, where the load requested a peak current, even though, the hybrid storage system responded to this demand without destabilizing the system performance.

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