Droop Control of Solar PV, Grid and Critical Load using Suppressing DC Current Injection Technique without Battery Storage

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Abstract—This paper presents design of a sustainable solar Photo voltaic system for an Indian cities based residential/community house, integrated with grid, supporting it as supplementary sources, to meet energy demand of domestic loads. The role of renewable energy sources in Distributed Generation (DG) is increasingly being recognized as a supplement and an alternative to large conventional central power supply. Though centralized economic system that solely depends on cities is hampered due to energy deficiency, the use of solar energy in cities is never been tried widely due to technical inconvenience and high installation cost. To mitigate these problems, this paper proposes an optimized design of grid-tied PV system without storage which is suitable for Indian origin as it requires less installallation cost and supplies residential loads when the grid power is unavailable. The energy requirement is mainly fulfilled from PV energy module for critical load of a city located residential house and supplemented by grid/DG for base and peak load. The system has been developed for maximum daily household demand of 50kW$_p$ and can be scaled to any higher value as per requirement of individual/community building ranging from 50kW$_p$ to 60kW$_p$ as per the requirement. A simplified control system model has been developed to optimize and control flow of power from these sources. The simulation work, using MATLAB Simulink software for proposed energy management, has resulted in an optimal yield leading efficient power flow control of proposed system.

Keywords— *Solar PV grid tied ,off-grid system, DC voltage rejection, MPPT control, Critical Load.*

I.INTRODUCTION

Green energy, also called regeneration energy, has gained much attention now a days. Green energy such as solar energy, water power, wind power, biomass energy, terrestrial heat, tidal energy, etc, can be recycled. Among them, Photovoltaic (PV) solar energy is the most powerful resource that can be used to generate power. PV systems as standalone devices are now the lowest cost option for satisfying most of the basic electrical energy needs of the areas not served by distributed electricity, particularly in the developing countries located in the tropics, where the amount of sunshine is generally high. An autonomous PV power system

with battery back-up had been proposed earlier, to provide electrical power in the areas where grid is either not available or a new installation/grid extension is yet to be done [1-3]. But this system is not viable for houses located in city/town areas due to the heavy demand of load energy consumption, resulting in a steep rise in the cost of the PV power system. Hence hybridization of PV power systems were thought and developed by many authors, as reported, in the past leading to a cost effective system[4-6], but in most of the systems, the sustainability feature of power supply from PV sources were not considered.
Renewable energy is abundantly found anywhere, free of cost and has non-polluting characteristics. However, these energy sources are based on the weather condition and possess inherited intermittent nature, which hinders stable power supply. Combining multiple renewable energy resources can be a possible solution to overcome defects, which not only provides reliable power but also leads to reduction in required storage capacity. Although an oversized hybrid system satisfies the load demand, it can be unnecessarily expensive. An undersized hybrid system is economical, but may not be able to meet the load demand. The optimal sizing of the renewable energy power system depends on the mathematical model of system components. This becomes very complex since there is a need to separate manipulate variables and non-manipulate variables. Finding right manipulated variable to control the output of converter is a bit complex task. Hence in this paper a simplified technique using only PV has proposed to meet energy.

PV systems are broadly classified as standalone and grid connected systems. Standalone systems are popular in remote areas where electricity is not viable. The reliability of such systems is improved by usage of storage batteries [4]. Grid connected systems allows to reduce our consumption from grid and in some instances, to feed surplus energy back to grid, which may give credit for energy returned. The improvement of power electronics has a positive impact on the grid connected PV systems [7-8]

The Photovoltaic inverters without the isolation transformer become more attractive due to higher efficiency and lower weight and other advantages. However, it may have dc offset current while injecting generated AC to the grid which is critical to the power system. In this paper, a simplified control strategy of suppressing dc current injection to the grid connected for PV inverters is analyzed using MATLAB simulink software. It is based on the idea of accurately sensing the dc offset voltage of PV inverter output which is fed to grid. Since dc component of the inverter output can be eliminated, dc injection to the grid can be effectively suppressed. To show the effectiveness of the proposed method FFT analysis has been implemented to the proposed method. The PV farm is connected to the DC bus through a DC-DC boost converter with Maximum Power Point Tracking (MPPT) functionality.

In this paper, the power flow management of Solar PV, Grid and Critical load using a novel control strategy to suppress dc current injection of transformerless PV inverters to the grid is investigated. This paper is organized as follows: Section II describes the grid tied PV Inverter; Section III describes the novel control strategy with dc suppression loop; Section IV analyzes the disturbance suppressing effect under the dc suppression loop. Section V provides experimental results to verify the theoretical analysis, and the conclusion is given in Section VI.

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II. PROPOSED GRID TIED PV SYSTEM

A grid-tied PV system without storage to power up on-site electrical loads; serves energy to the grid when the system output is greater than the on-site demand and supplies to critical load as well when the grid power is unavailable or nominal.

A. Proposed System Configuration Fig 3 illustrates, the proposed system will consist of PV arrays, a step-up dc–dc converter, a grid-tied inverter using a controlled AC transfer switch. PV arrays convert solar energy into electric energy. Step-up dc–dc converter boosts the array voltage to a higher level; the grid-tied inverter inverts the DC power reduced by the PV array into AC power aligned with the voltage and power quality requirements of the utility grid and the transfer switch changes supply source and also selects serving loads according to availability.

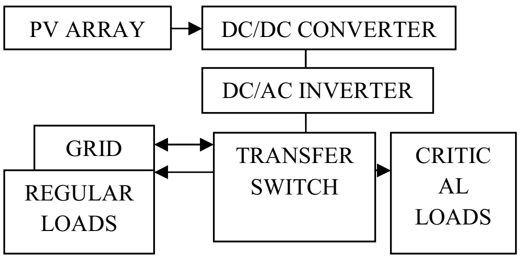

Fig.1 Block Diagram of Grid Tied Solar Inverter

In normal condition, the system power up on-site electrical loads and serve energy to the grid if the system output is greater than the on-site demand. Net metering would allow the homeowner to sell energy back to government. But when the utility grid power is not available or when the utility voltage level or frequency goes beyond accepted limits, the system automatically disconnects the grid through an anti-islanding scheme. In this condition, existing battery less grid-tied PV systems do not serve the residential loads also.
But in our proposed design it will supply residential loads during the grid failure or blackout for load shedding by an automatic AC transfer switch. This feature is indispensible considering the grid load shedding condition.

B. Grid-Tied Inverter (GTI)

The major component of Grid-tied PV system is the GTI which along with regulating the voltage and current received from solar panels ensures that the power supply is in phase with the grid power. On AC side, it keeps the sinusoidal output synchronized to the grid frequency (nominally 50Hz). The voltage of the inverter output needs to be variable and a touch higher than the grid voltage to enable current to supply the loads in the house or even supplies excess power to the utility. Fig.2 depicts a simplified schematic diagram which illustrate the operation principle of a grid-tied inverter with three power stages.

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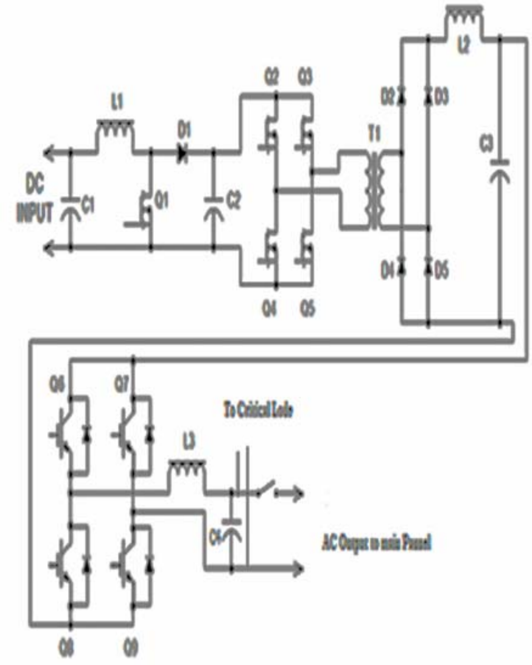

Fig. 2 Schematic Diagram of A Grid-Tied Inverter

At the first stage, the DC input voltage is stepped up by the boost converter by a combination of inductor L1, MOSFET Q1, diode D1 and capacitor C2. The inverter has to provide a galvanic isolation between input and the output. With a step-up transformer T1, the first stage (boost converter) may be omitted. In this example, a high frequency transformer is used to provide isolation in the second conversion stage. The stage is basically a pulse-width modulator DC-DC converter. The voltage must be higher than the peak of the utility AC voltage. For example, 220 VAC service, the DC link should be greater than 220*√2= 312 V. On the third conversion stage, DC is converted into AC by a full bridge converter consisting of IGBT Q6-Q9 and LC-filter L3, C4. Output LC-filter reduces high frequency harmonics to produce a sine-wave voltage.

As GTI need to comply with utility electrical standards, the output power has to be clean, undistorted and in phase with the AC grid. Typical modern GTI have a fixed unity power factor which means its output voltage and current are perfectly 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 AC grid waveform and output a voltage to correspond with the grid. Besides, when the grid is down, the GTI will provide AC output synchronized with own pre-defined references.

C. Control Scheme

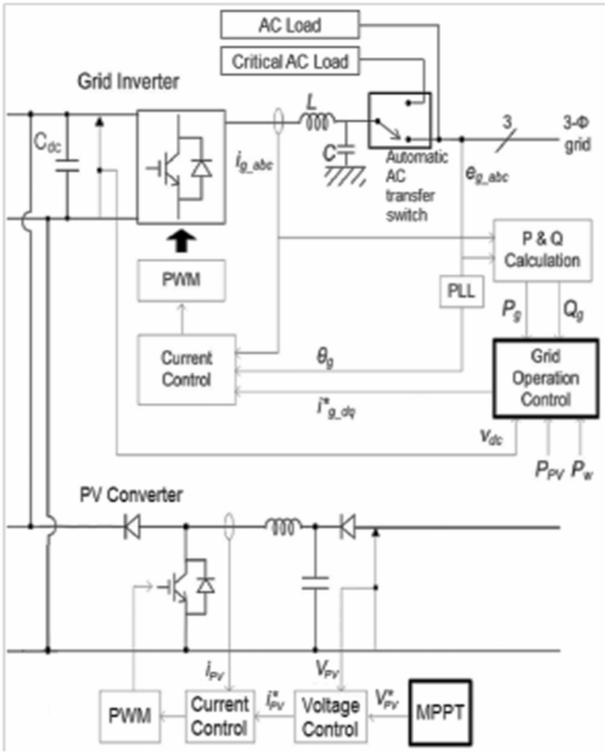

Fig. 3 Schematic Control for Grid-Tied PV System

Fig. 3 demonstrates the control scheme of system. The three parts have been described as PV converter control: Power output of a PV array depends on the voltage level where it operates under a given condition of irradiance and cell-surface temperature. For efficient operation, a PV array should operate near at the peak point of the $V-P$ curve. Various Maximum Power Point Tracking (MPPT) techniques have been proposed in [7] and [8]. The MPPT block in Fig. 3 senses the PV array current I_{PV} and array voltage V_{PV} and returns the array voltage command. The PV converter regulates the array voltage V_{PV} at the reference voltage V_{PV}^* commanded by the MPPT controller and boosts it to the level of required 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}.

1. GTI control

Basic concept of GTI control is to obtain the maximum power from varying insolation and minimize the rating of the inverter by regulating reactive power generation at zero. Below rated insolation, real power from the PV system is regulated to capture the maximum energy from varying insolation to supply either on-site electrical loads, or to supply power to the grid when the PV system output is greater than the on-site load demand in a way that the inverter's power supply is synchronized with the grid power.

In addition, when the grid fails or goes through blackout for load shedding, the inverter stops output initially, then the transfer switch shifts to inverter only position and finally the inverter starts to give output synchronized to serve the critical on-site loads with own pre-defined references until the grid is back.

2. Anti-islanding control

The condition where a GTI continues to electrify the grid during an outage is called islanding. According to the technical requirements in IEEE 1547, to prevent this situation, inverter will monitor the voltage and frequency of the grid. If either of voltage and frequency falls outside set parameters, the inverter will shut down. In addition to this passive scheme a more sophisticated active detection scheme is necessary to decrease the non-detection zone. So the inverter will employ a variety of methods to effectively push and pull slightly on the grid voltage and frequency. When the grid is present, this little push-and-pull has no effect. However, if the inverter is the only source supporting an islanding grid, it will quickly push the voltage and frequency outside the inverter's acceptable window of operation, triggering the inverter to shut down.

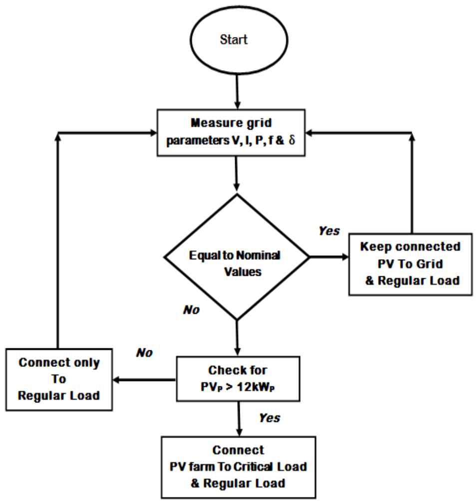

Fig.4 Flow chart describing proposed approach

But the problem is that in Bangladesh, power crisis is so drastic that the grid shuts down its feeders many a time in a day and existing battery less inverters will remain off until the grid is back up and running again. In our design, we employed an automatic transfer switch so that immediately after turning off its output transistors, the inverter will also use a transfer switch to disconnect from the grid. Once disconnected, however, the inverter will reactivate the output transistors to continue supplying electricity to loads wired into the critical load subpanel which is isolated from the grid.
This way, when the grid goes down and the inverter is sending power only to the critical load subpanel, PV power is prevented from energizing the utility lines. Fig. 6 presents the complete flow chart of our proposed control scheme.

A. Net Metering

In our scheme a customer can also enjoy the opportunity of net metering by selling the surplus energy to the grid when the generation is more than required for onsite demand. Fig.5 illustrates the net metering.

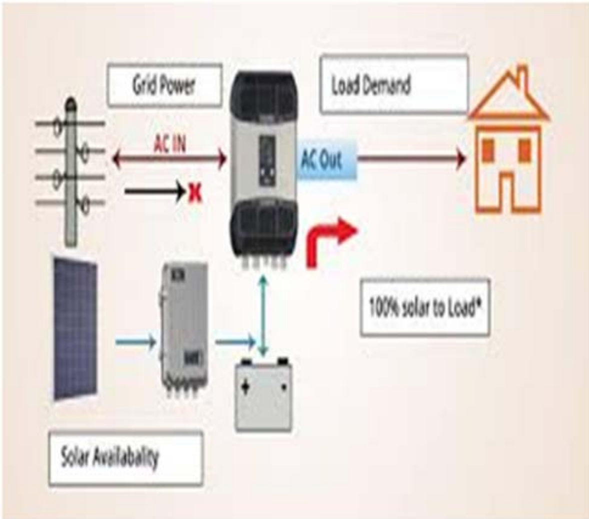

Fig.5 Net Metering Scheme

There will be two separate meters – one is the generation meter and another is the billing meter. The customer will be charged from the data of the billing meter and the total kWh consumption of the site will be the sum of the generation meter and the billing meter.

III. PROPOSED CONTROLLER

PV inverter output generally has dc offset voltage component, which results from disparity of power modules, asymmetry of driving pulses, detection error of current, etc. Traditionally, a transformer is inserted between the PV inverter and the grid. Although the PV inverter output may have dc voltage component, there is no dc current injection to the grid. However, in the case of the PV inverter without isolation transformer, the inverter output dc offset may cause a significant dc current injection to the grid, which may violate the grid connection standards and cannot be neglected [5].

In order to effectively restrain dc current injection to the grid, a control strategy for a Three-phase PV inverter. The dc suppression loop is composed of a differential amplifier, a low-pass filter, and a dc controller.

The input of dc suppression loop is u_{AB} , which is a high frequency PWM waveform sampled between the point A of inverter bridge-leg 1 and the point B of inverter bridge-leg 2. DC offset voltage of u_{AB} is accurately extracted by a differential amplifier and a low-pass filter. Then, it is compared with inverter dc voltage reference U_{dc} ref which is set to zero, and dc offset voltage error is obtained. The error is regulated by the integral controller. Finally, the output of dc controller ΔU_{dc}, which is also the output of dc suppression loop, is added to the grid current reference i_{ref} of the grid current control loop.

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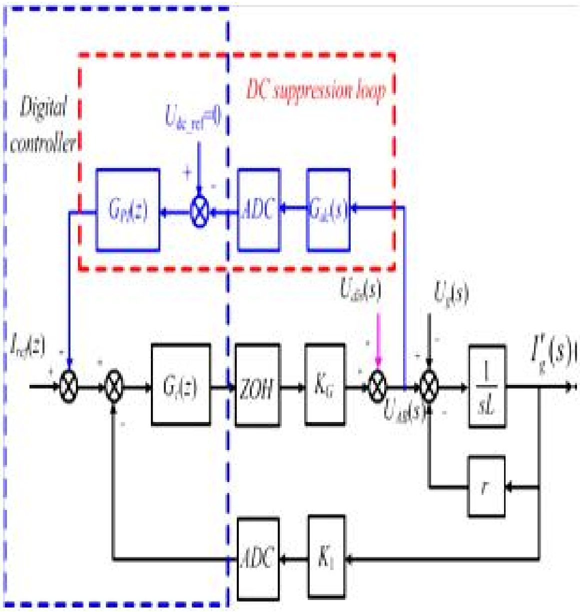

Fig.6 DC Suppression Controller

The novel control strategy has two significant features. The first is that the differential amplifier is used to sample the dc offset voltage between the two bridge-leg middle points of full bridge inverter. To accurately detect the dc offset voltage of the inverter switch-side output voltage u_{AB}, a high-precision differential amplifier with low offset and high common-mode rejection ratio is needed. The use of differential amplifier can not only reduce the cost, but also avoid the zero-drift by using Hall-effect sensors. The second feature is that dc suppression loop can suppress inverter output disturbances. Therefore, the dc current injected to the grid can be effectively suppressed.

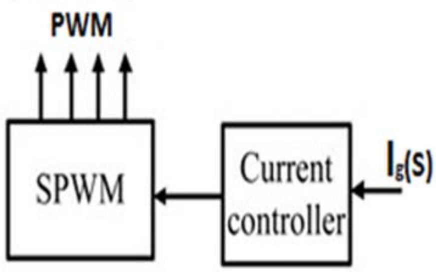

Fig.7 PWM Pulse Generation From Reference Current

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IV. ANALYSIS OF DISTURBANCE SUPPRESSING EFFECT

The control block diagram of PV grid-connected inverter is shown in Fig. 6, where $I_{\mathrm{ref}}(z)$ is current reference of the inverter, $G_c\ (z)$ is digital controller of current loop, and K_G is the gain from the output of current controller $G_c\ (z)$ to inverter switch-side voltage. $U_{\mathrm{dis}}(s)$ represents the disturbance caused by the turn-on and turn-off difference of the four switches, the saturation voltage difference of the four switches, the gate drive signal delay difference of the four switches, and so on. L is the output filter inductor. r is the equivalent resistance of output filter inductor L. $I_g\ (s)$ is the grid current of the inverter. $K1$ is the feedback gain of current loop. ADC is the analog-to-digital converter which converts the analog sampling value of I_g (s) to digital one. *ZOH* is zero-order holds which is connected in series between the output of digital controller and *KG*.

V.SIMULATION RESULTS

The simulation of proposed controller which has been designed using MATLAB software is shown in Fig.8**.**

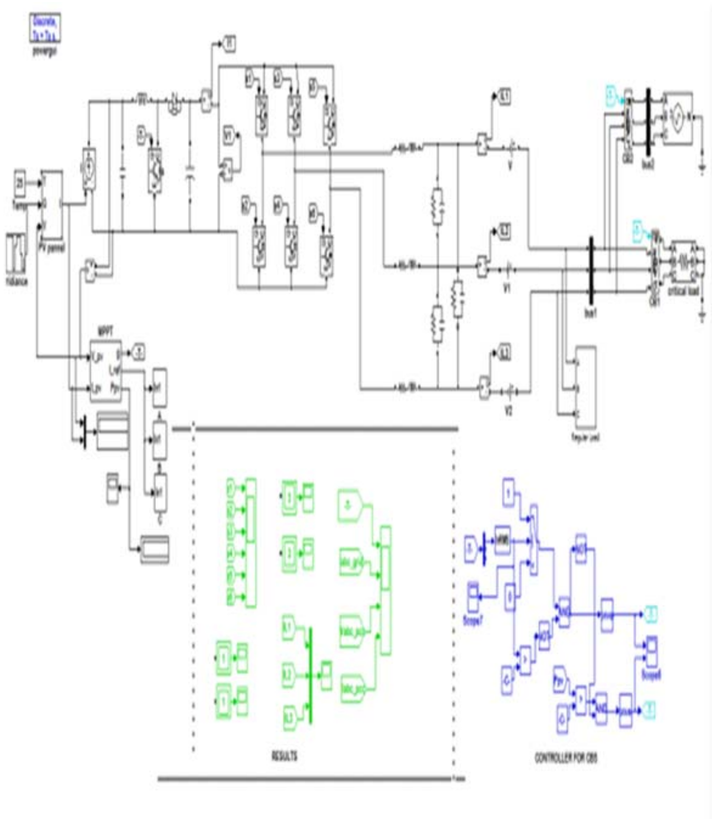

Fig.8 PV, Grid and Critical load connected system

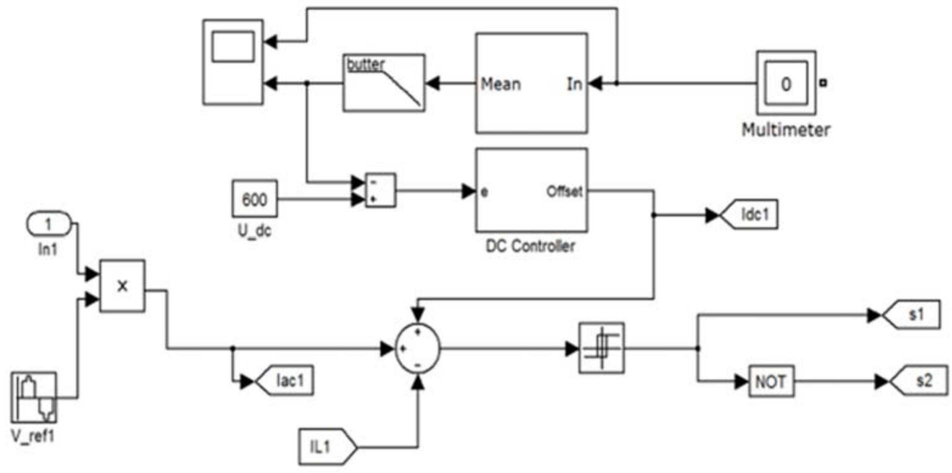

Fig.9 Simplified Controller for DC Suppression in AC Output

Fig.9 shows the design of proposed DC suppression controller using MATLAB. The output of PV Inverter while fed to grid or AC load should be harmonic free and DC suppressed.

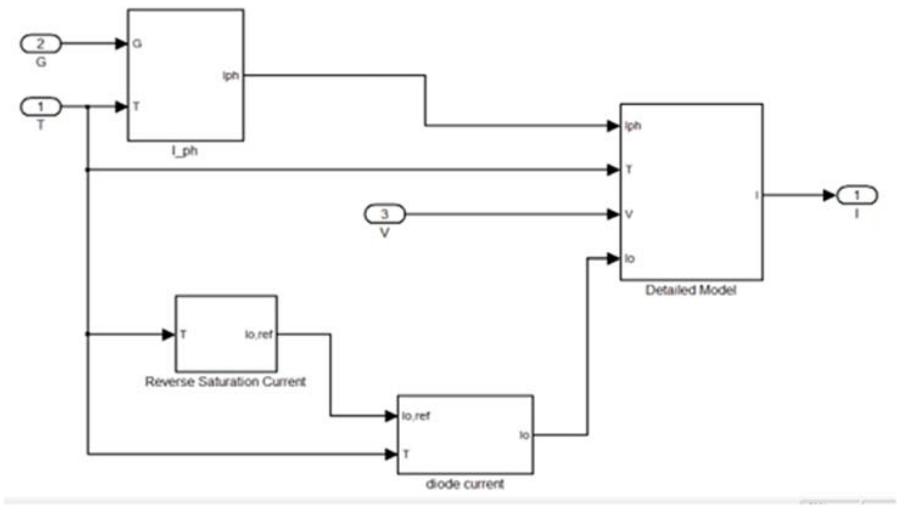

Fig.10 Equivalent Circuit of Solar PV System.

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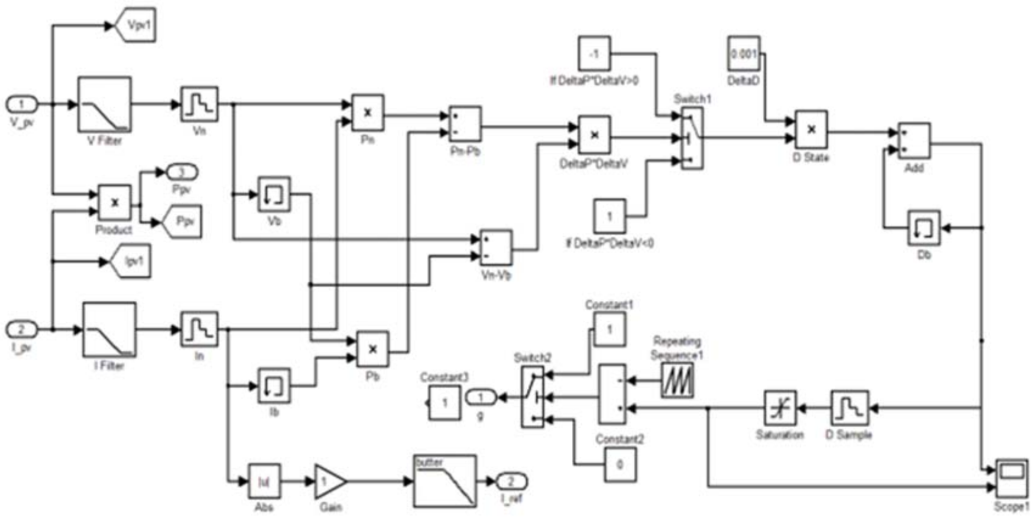


Fig.11 MPPT controller used to DC-DC control of Boost converter

Fig.12 and Fig. 13 are showing the Solar PV Inverter output whether to be connected to grid or critical load based on the availability of Solar input above 30% of rated i.e. 12kW$_p$. If the grid power is not equal to nominal then it should be changes over to critical load based on flow chart shown in Fig.4.

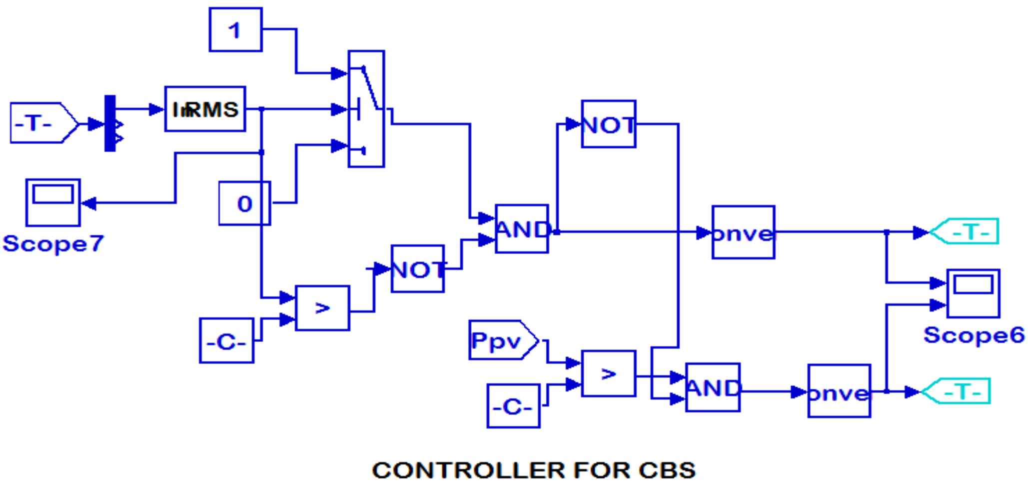


Fig.12 Control Signal Generation for Power Flow Between Solar, Grid and Critical Load

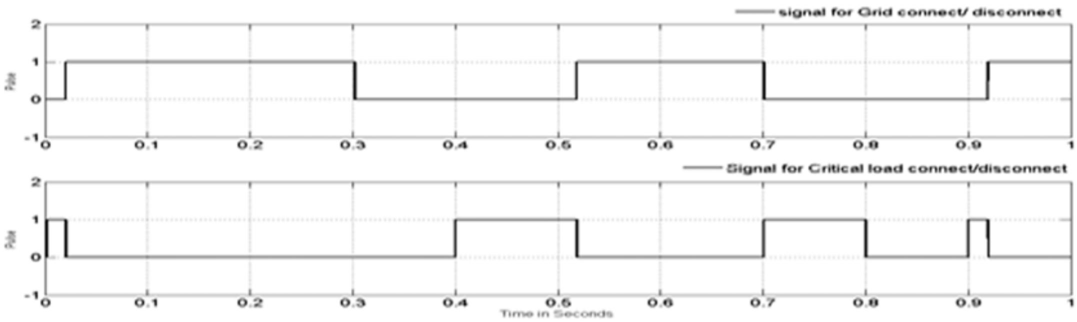


Fig.13 PWMs Corresponding To Controller In Fig.12

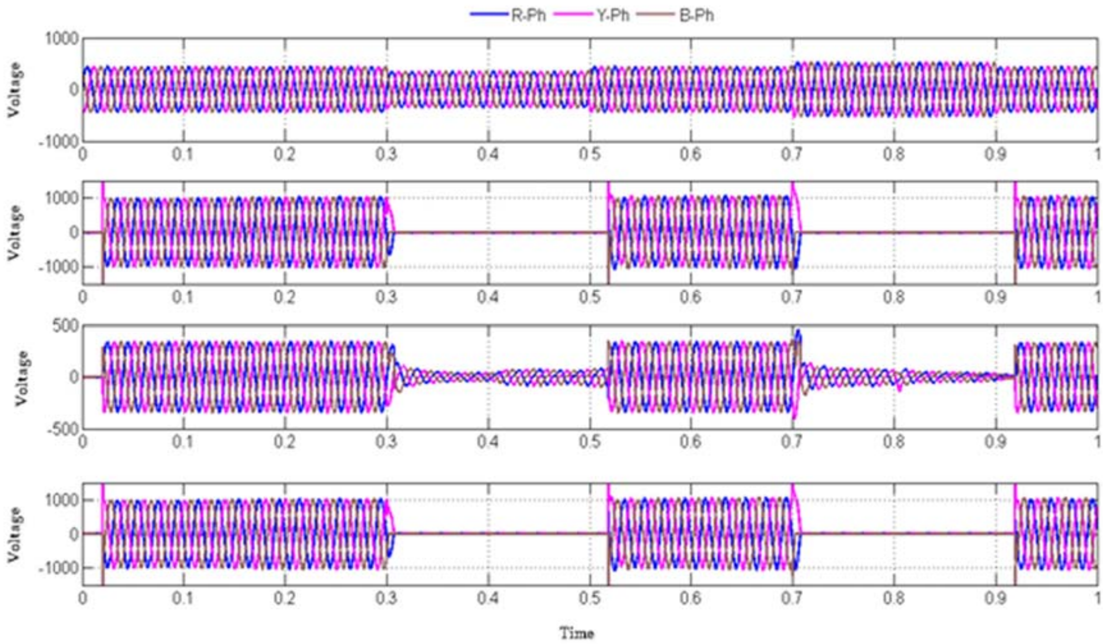


Fig.14 Power Flow During Grid Normal and Abnormal Conditions

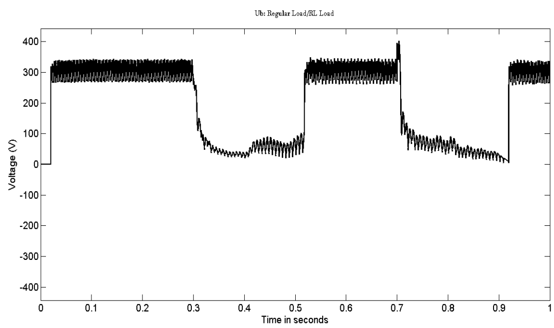


Fig. 15 Voltage Across the Regular Load

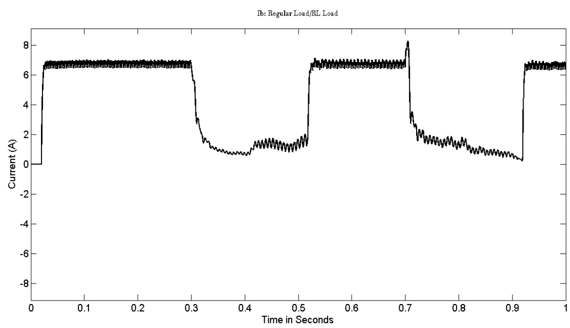
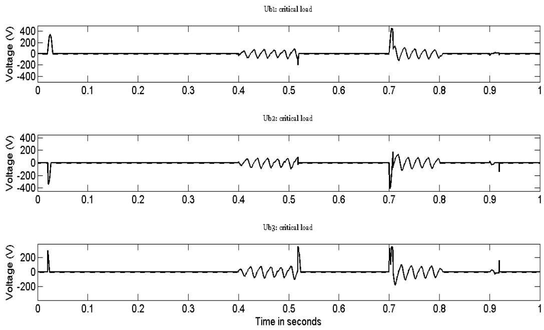


Fig. 16 Current through the regular load

Fig.14, Fig.15 and Fig.16 shows the results of power flows during the grid normal condition and abnormal conditions. The power will flow to grid from solar inverter in case of grid normal conditions. Otherwise if grid fails then availability of solar input above $12kW_p$.by checking above condition power will be flow to critical load. Always there will be regular load connected at all conditions.



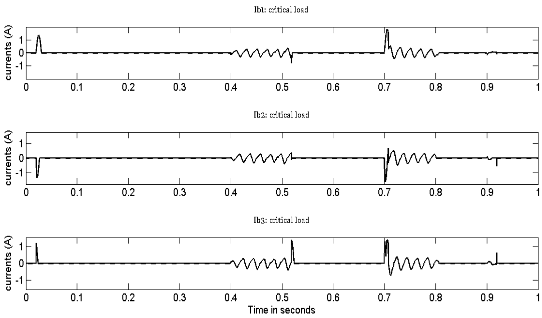


Fig.17 Voltage Across the Critical Load Fig.18 Current Through the Critical Load

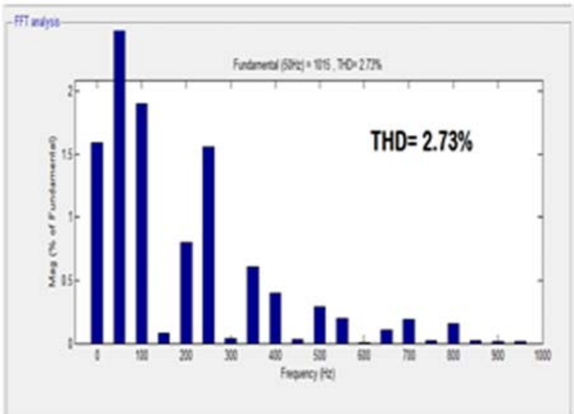


Fig.19 THD of Output Voltage of Proposed PV Inverter

CONCLUSION

In this paper a optimized scheme for power flow during the grid normal condition and abnormal conditions of PV Inverter without battery shifts between a critical load and grid for $50kW_p$. The power will flow to grid from solar inverter in case of grid normal conditions. If grid fails then availability of solar input power above 30% of rated installation capacity i.e. $12kW_p$ then power will flow to critical loads. Always there will be regular load connected at all conditions to grid. If grid power is resumed automatically critical load will disconnect from solar PV System and connect to grid. If grid fails and power available in solar PV system is less than 30% of rated installation capacity i.e. $12kW_p$ the critical loads will also switched off. This project the control structure of converter, inverter and anti-islanding scheme. The simulation of DC suppression controller has designed using MATLAB software.

In this paper by using a simplified control strategy to eliminate dc current injection to the grid for three-phase PV inverter without the isolation transformer has shown better outputs in terms of pure sine wave and low THD i.e.2.73%. It is based on accurately sensing the dc offset voltage between the two bridge-leg middle points of full-bridge inverter. The novel control strategy is inherently free from offset measurement errors.

The simulation results show that the novel control strategy can effectively suppress dc injection current of PV system under grid-connected normal and abnormal conditions.

The design and simulation of 50kW$_p$ grid-tied PV system without storage can supply critical loads of 12 kW$_p$ if utility grid is not available when sunlight is sufficient to generate power. The same model can be implemented in real time installation. The proposed grid-tied system without storage can not supply critical loads if utility grid is not available during night or on rainy day when sunlight is not sufficient to generate power, therefore inter connecting wind mill to solar PV panels will solve the problem up to certain extent provided sufficient wind velocity should present when sun light not available. There is a possibility to supply critical loads if Grid fails during the period when solar irradiance and wind velocity both are not available by connecting a generator. Renewable energy sources like solar and wind are not available on demand, so no continuity of supply to critical loads. A Hybrid System with advanced control logic will coordinate when power should be generated by renewable energy and when power should be generated by other sources like diesel generators.

Moreover, our utilities should step forward to upgrade the existing girds in India in order to get full advantage of grid-tied incentive tariff will promote and encourage grid-tied PV System.

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