Integration of Solar PV, Grid and Critical Load using Multi-functional Droop control without Battery Storage *

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Abstract. This paper presents design of a sustainable solar (PV) system for an Indian city 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 installment 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 installment 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 load energy of 50kWh and can be scaled to any higher value as per requirement of individual/community building ranging from 50kWh/day to 60kWh/day, 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 tie/ off-grid system, DC voltage rejection, mppt control, critical load

1 Section heading

Green energy, also called regeneration energy, has gained much attention now a day s. 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[3,4,6]. 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[2,5,7], 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

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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. 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. The Photovoltaic inverters without the isolation transformer become more attractive due to higher efficiency and lower weight and other offered mentioned advantages. However, it may have dc offset current while injecting generated AC to the grid which is critical to the power system.

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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 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 2 describes the grid tie PV Inverter; Section 3 describes the novel control strategy with dc suppression loop; Section 4 analyzes the disturbance suppressing effect under the dc suppression loop. Section 5 provides experimental results to verify the theoretical analysis, and the conclusion is given in Section 6.

2 Proposed grid tied PV system

In this paper a grid-tied PV system without storage to power up on-site electrical loads; serve 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.

2.1 Proposed system configuration

Fig 1 illustrates, the proposed system will consist of PV arrays, a step-up dc-dc converter, a grid-tie 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-tie 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.

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.
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2.2 Grid tie inverter

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. Through the Fig. 2, a simplified schematic, depicted below, the operation principle of a grid-tied inverter with three power stages is illustrated. At the first stage, the DC input voltage is stepped up by the boost converter by a combination of inductor L1, MOSFET S1, diode D1 and capacitor C2.

As GTIs need to comply with utility electrical standards, the output power has to be clean, undistorted and in phase with the AC grid. Typical modern GTIs 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.

2.3 Control scheme

The control scheme for proposed system. We can describe it in three parts: 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. The MPPT block 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 $i_{PV}$.

- **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.

- **Anti-islanding control**

The condition where a GTI continues to electrify the grid during an outage is called is landing. 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 is landing grid, it will quickly 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 INDIAN 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. 3 bellow presents the complete flow chart of our proposed control scheme.

### 3 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.

In order to effectively restrain dc current injection to the grid, a control strategy for a Three-phase PV inverter without the isolation transformer is shown in Fig. 4. 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 $U_{dc}$ 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 $\Delta U_{dc}$, which
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is also the output of dc suppression loop, is added to the grid current reference iref of the grid current control loop.

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 uAB, a high-precision differential amplifier with low offset and high common-mode rejection ratio is needed. The using of differential amplifier can not only reduce the cost, but also avoid the zero-drift by using Hall-effect sensors. The second one is that dc suppression loop can suppress inverter output disturbances. Therefore, the dc current injected to the grid can be effectively suppressed.

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4 Analysis of disturbance suppressing effect

The control block diagram of PV grid-connected inverter is shown in Fig. 5, where $I_{ref}$ is current reference of the inverter, $G_c$ is digital controller of current loop, and $K_G$ is the gain from the output of current controller $G_c$, to inverter switch-side voltage. $U_{dis}$ 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 $L$. $I_g$ is the grid current of the inverter.

$$K_1$$ is the feedback gain of current loop. ADC is the analog-to-digital converter which converts the analog sampling value of $I_g$ to digital one. ZOH is zero-order holds which is connected in series between the output of digital controller and KG.

5 Simulation results

To verify the correctness and effectiveness of the proposed method, the Simulation of proposed controller has designed using MATLAB software. The proposed controller works in dual mode i.e. while solar power generation is above 12kWp, the generated power is fed to grid. While injecting to the grid, the grid parameters is measured to match with the nominal values, if any variations are observed the based on the flow chart shown in fig.3 the routine will be maintained. The design of proposed DC suppression controller as shown in fig.5. The Output of PV Inverter while fed to grid or AC load should be harmonic free and DC suppressed.

![Fig. 6: Output power of Solar PV system for changes in temperature and irradiation](image-url)
availability of Solar input above 30% of rated i.e. 12kWp. If the grid power is not equal to nominal then it should be change over to critical load based on flow chart shown in Fig. 3

![DSP Control signal generation for power flow between solar, grid and critical load](image)

**Fig. 7:** DSP Control signal generation for power flow between solar, grid and critical load

![Trip/ON signal corresponding to controller in Fig.7](image)

**Fig. 8:** Trip/ON signal corresponding to controller in Fig. 7

The Fig. 9 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 and availability of solar input above 12kWp. Otherwise if grid fails then by checking same condition power will be flown to critical load. Always there will be regular load connected at all conditions.

Fig. 10 and 11 shows the voltage across and current through the regular load during normal and abnormal conditions of grid respectively. Fig. 12 and 13 shows the voltage across and current through the critical load during normal and abnormal conditions of grid respectively. From Fig. 9 to Fig. 13, the observations show that the proposed controller is working smoothly during normal and abnormal cases of grid. The power shared between grid and critical load is clearly shown in Fig. 9 and Fig. 12 during which the conditions like minimum 30% of solar power will be generated to connect to grid or critical load. The algorithm designed DC/AC drive control has perfectly reducing the DC components in the AC output. The Fig. 14 is the result of FFT analysis is about 2.73% clearly depicting the low THD% in output AC of inverter fed to grid.

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Fig. 9: Power flow during grid normal and abnormal conditions from solar to grid. (a) Grid voltages. (b) current floating into grid. (c) Voltage at PCC (d) current at PCC

Fig. 10: Voltage across the regular load

Fig. 11: Current through the regular load
Fig. 12: Voltage across the critical load

Fig. 13: Current through the critical load

Fig. 14: THD of output voltage of proposed PV Inverter system
Conclusion

In this paper an 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. The power will flow to grid from solar inverter in case of grid normal conditions and availability of solar input above 12kWp. Otherwise if grid fails then by checking same condition power will be flown to critical load. Always there will be regular load connected at all conditions connected to Solar PV Inverter. Also 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. 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.

References