Grid Interconnection of Solar Energy System with Power Quality Improvement

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Abstract: **Renewable energy resources (RES) are being increasingly connected in distribution systems utilizing power electronic converters. This paper presents a novel control strategy for achieving maximum benefits from these grid - interfacing inverters when installed in 3-phase 4-wire distribution systems. The inverter is controlled to perform as a multi-function device by incorporating active power filter functionality. The inverter can thus be utilized as power converter to inject power generated from RES to the grid, and as a shunt APF to compensate current unbalance, load current harmonics, load reactive power demand and load neutral current. This new control concept is demonstrated with extensive MATLA B/Simulation.**

Index Terms: **Active power filter (APF), Distributed generation (DG), distribution system, grid interconnection, power quality (PQ), renewable energy**

I. INTRODUCTION

Renewable energy source (RES) integrated at distribution level is termed as distributed generation (DG). The utility is concerned due to the high penetration level of intermittent RES in distribution systems as it may pose a threat to network in terms of stability, voltage regulation and power-quality (PQ) issues. Therefore, the DG systems are required to comply with strict technical and regulatory frameworks to ensure safe, reliable and efficient operation of overall network. With the advancement in power electronics and digital control technology, the DG systems can now be actively controlled to Enhance the system operation with improved PQ at PCC. However, the extensive use of power electronics based equipment and non-linear loads at PCC generate harmonic currents, which may deteriorate the quality of power.

The non-linear load current harmonics may result in voltage harmonics and can create a serious PQ problem in the power system network. Active power filters (APF) are extensively used to compensate the load current harmonics and load unbalance at distribution level. This results in an additional hardware cost.. Here, the main idea is the maximum utilization of inverter rating which is most of the time underutilized due to intermittent nature of RES. It is shown in this paper that the grid-interfacing inverter can effectively be utilized to inject active power and having in load current performs following important functions: 1) transfer of active power harvested from the. Moreover, with adequate control of grid-interfacing inverter, the objectives can be accomplished either individually or simultaneously. The PQ constraints at the PCC can therefore be strictly maintained within the utility standards without additional hardware cost. In this paper inter connection of distributed generation and grid with reduced harmonics is proposed.

II. SYSTEM DESCRIPTION

The proposed system consists of RES connected to the dc-link of a grid-interfacing inverter as shown in Fig.1 the voltage source inverter is a key element of a DG system as it interfaces the renewable energy source to the grid and delivers the generated power. The RES may be a DC source or an AC source with rectifier coupled to dc-link. Usually, the fuel cell and photovoltaic energy sources generate power at variable low dc voltage, while the variable speed wind turbines generate power at variable ac voltage. Thus, the power generated from these renewable sources needs power conditioning (i.e., dc/dc or ac/dc) before connecting on dc-link. The dc-capacitor decouples the RES from grid and also allows independent control of converters on either side of dc-link.

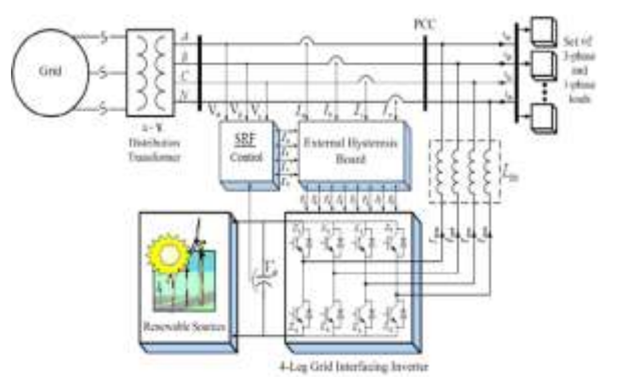

Fig. 1 Schematic of proposed renewable based distributed generation system

2. 1 A DC-Link Voltage and Power Control Operation

Due to the intermittent nature of RES, the generated power is of variable nature. The dc-link plays an important role in transferring this variable power from renewable energy source to the grid. RES are represented as current sources connected to the dc-link of a grid-interfacing inverter. The current injected by renewable into dc-link at voltage level V_{dc} can be given as

$$I_{DC1} = \frac{P_{RES}}{V_{DC}} \quad \dots\dots\dots\dots\dots\dots\dots.. \ (1)$$

P_{RES} is the Power Output if Renewable Energy Sources

The current flow on the other side of dc-link can be represented as

$$I_{DC1} = \frac{P_{inv}}{V_{dc}} = \frac{P_G + P_{LOSS}}{V_{dc}} \quad \dots\dots \ (2)$$

Where P_{inv} and P_G, P_{LOSS} are total power available at grid-interfacing inverter side, active power supplied to the grid and inverter losses, respectively. If inverter losses are negligible then $P_{RES} = P_G$

2.2. Control of Grid Interfacing Inverter

The control diagram of grid- interfacing inverter for a 3-phase 4-wire system is shown in Fig. 1. The fourth leg of inverter is used to compensate the neutral current of load. The main aim of proposed approach is to regulate the power at PCC during 1) $P_{RES} = 0$ 2) $P_{RES} < total\ load\ power$ and 3) $P_{RES} > P_L$ While performing the power management operation, the inverter is actively controlled in such a way that it always draws/ supplies fundamental active power from/ to the grid.

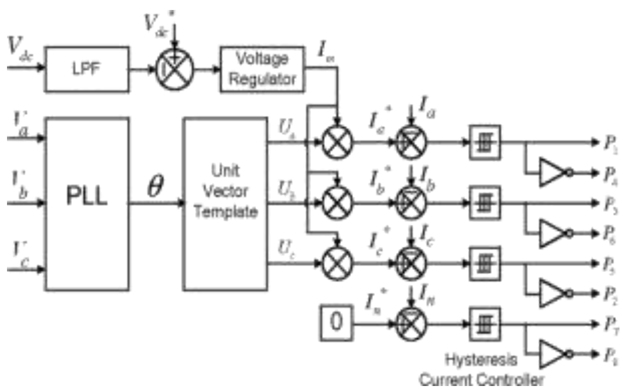

Fig.2 Block diagram representation of grid-interfacing inverter control

If the load connected to the PCC is non-linear or unbalanced or the combination of both, the given control approach also compensates the harmonics, unbalance, and neutral current. The duty ratio of inverter switches are varied in a power cycle such that the combination of load and inverter injected power, appears as balanced resistive load to the grid. The regulation of dc-link voltage carries the information regarding the exchange of active power in between renewable source and grid. Thus the output of dc-link voltage regulator results in an active current (I_m) . The multiplication of active current component (I_m)with unity grid voltage vector templates (U_a, U_b, U_c) generates the reference grid currents (I_a^*, I_b^*, I_c^*) . The reference grid neutral current I_n^* is set to zero, being the instantaneous sum of balanced grid currents. The grid synchronizing angle θ obtained from phase locked loop (PLL) is used to generated unity vector template as

$$U_a = \sin \emptyset \quad \dots\dots\dots\dots\dots\dots\dots.. (3)$$

$$U_b = \sin(\emptyset - \frac{2\pi}{2}) \dots\dots\dots\dots\dots\dots (4)$$

$$U_c = \sin(\emptyset + \frac{2\pi}{2}) \dots\dots\dots\dots\dots\dots (5)$$

The Actual dc link voltage ($_{Vdc}$) is sensed and passed through a first order low pass (LPF) to eliminate the presence of switching ripples on the dc-link voltage and in the generated reference current signals. The difference of this filtered dc-link voltage and reference dc-link voltage V_{dc}^* is given to a discrete PI regulator to maintain a constant dc-link voltage under varying generation and load conditions. The dc-link voltage error $V_{dcerr\,(n)}$ at nth sampling instant is given as :

$$V_{derr} = V_{dc}^* - V_{dc(n)} \quad \dots\dots. (6)$$

The controller for proposed system is shown in Fig.2.

III. RESULTS

The PV array is simulated and their Output characteristics are shown in below figures. It is known from that simulink model of PV cell is equivalent to single diode model representation as discussed in above. PV array with and without MPPT controller are simulated and output waveforms shown below and also MPPT based PV systems with single phase inverter is simulated and their Output waveforms are shown below.

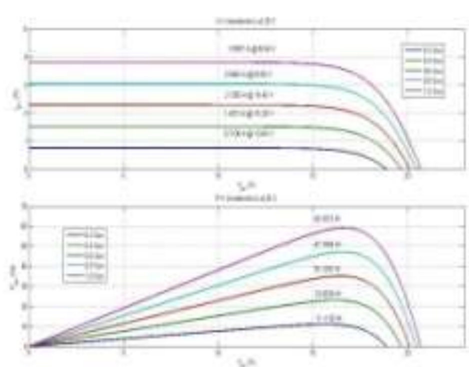

Fig.3: Characteristic curves of the PV array with different solar Irradiations and constant solar temperature 25°C

PV array is simulated either by programming or modeling .Output characteristics of PV array is shown in below figures by programming as mentioned in appendix . Simulink model of PV is equivalent to single diode model representation.

The above Fig.3 shows I-V and P-V curves obtained from PV array with different solar Irradiations and constant solar temperature 25°C .The Maximum power is obtained at 1.0 sun i.e at $1000W/m^2$.

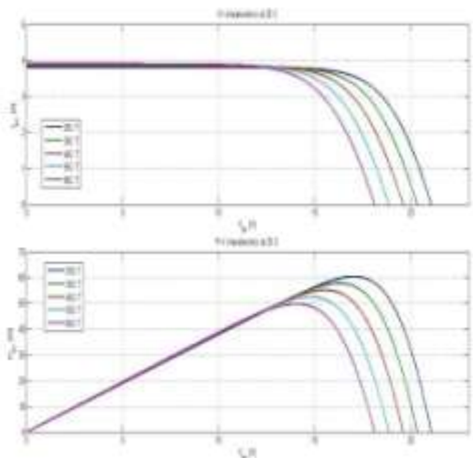

Fig.4: Characteristic curves of the PV array with different cell temperatures and irradiation solar constant 1000 W/m^2

The below Fig4 shows I-V and P-V curves obtained from PV array with constant solar Irradiations at 1000 W/m^2 with different cell temperatures .The Maximum power is obtained at maximum temperature.

The terms V_{pv} ,P_{pv} and I_{pv} are the voltage, power and current from solar panel. From Fig.3 and Fig.4 the maximum power is obtained at maximum solar value when temperature constant and maximum at minimum temperature when solar value constant.

3.1 Simulation of PV Array without MPPT Algorithm

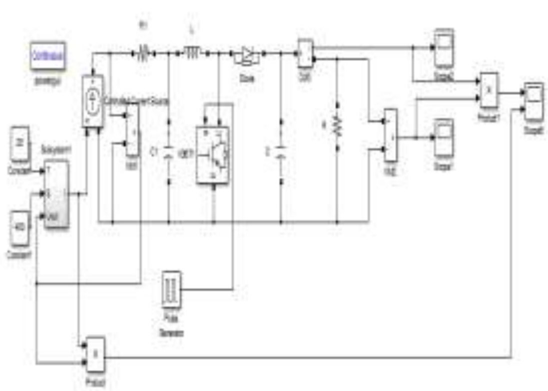

Fig 5: Simulation diagram of PV array without MPPT algorithm.

The Above Fig .5 is the Simulation diagram of PV array without MPPT algorithm keeping cell temperature as constant 25°C and constant solar irrandiance at 400 W/m$^{2.}$ Simulation diagram is construction by using single diode model representation and Solar electrical model based on Shockley diode equations.

Below Fig.6 is the internal subcircuit of simulation of PV array without MPPT system. The subcircuit is designed based on Solar electrical model based on Shockley diode equations which are mentioned above.

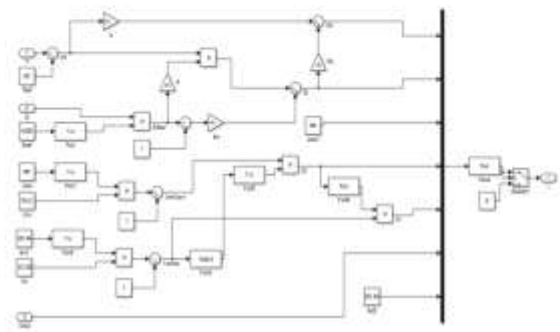

Fig.6: Subcircuit of simulation of PV system

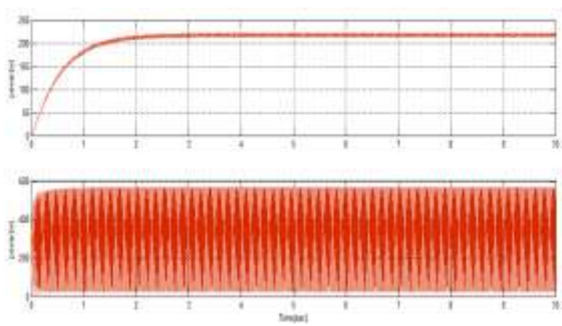

Fig.7: Output wave forms PV array without MPPT algorithm.

Fig.7 shows output powers of PV array of boost circuit without MPPT control the above curve is a ouput power of boost circuit and below curve is output power of PV panel.

3.2 Simulation of PV Array with MPPT Algorithm.

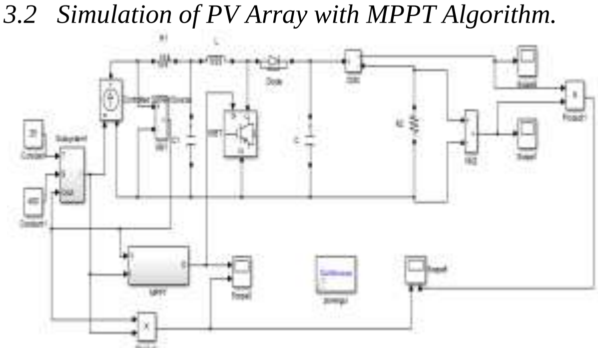

Fig.8: Simulation diagram of PV array and boost circuit with MPPT algorithm.

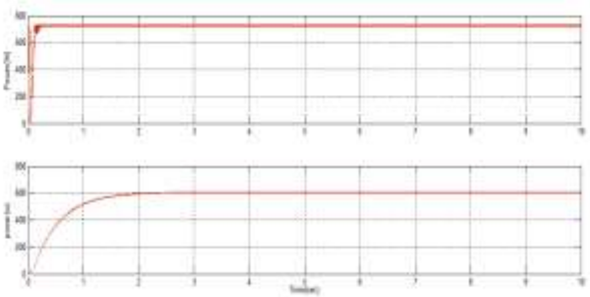

Fig.9: Output wave forms PV array with MPPT algorithm.

Above Fig .8 is the Simulation diagram of PV array with MPPT algorithm keeping cell temperature as constant 25°C and constant solar irrandiance at400 W/m^2. Fig.9 shows output powers of PV array of boost circuit with MPPT control the above curve is a ouput power of boost circuit and below curve is output power of PV panel. Comparing simulation PV of boost circuit with controller gives maximum power with less fluxvations.

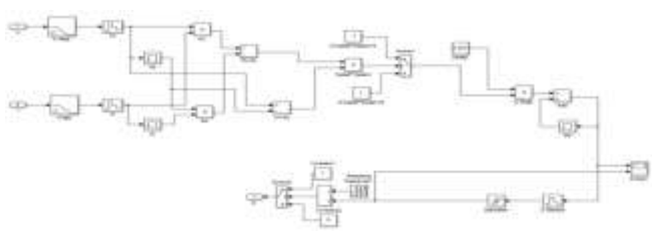

Fig.10:Subcircuit diagram of MPPT controller.

The above Fig.10 is internal subsystem of MPPT controller with P&O techinique. In this method every instant of time calculated power and obtained voltage from PV panel is compared with before instants after some delay time. Using P&O technique maximum power point is tracked which is mentioned in above chapter.

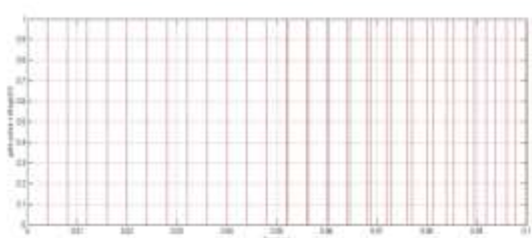

Fig.11: Output waveform of MPPT controller.

The above Fig 11 shows Output pulses of MPPT controller which is input to gate signal of IGBT or MOSFET of boost circuit. These pulses are generated by using MPPT technique of Perturb and observe method.

3.3 Simulation of Single Phase Inverter

The inverters modeled in this paper use the tool Sim Power Systems from Matlab since it allows the simulation of complex power elements like transistors without having to idealize them, thus taking into consideration their nonlinearity and losses. The system proposed in below Fig.12 is modeled in Matlab using MOSFETs as power devices in which having four MOSFETs of two leg. MOSFETs 2 and 3on at the same time remaining in off condition in which pulses are generated from pulse generator after a certain duration of time which mentioned in pulse generator MOSFETs 1and 4 are came to on condition using opposite pulse generator which is nothing but NOT operation .

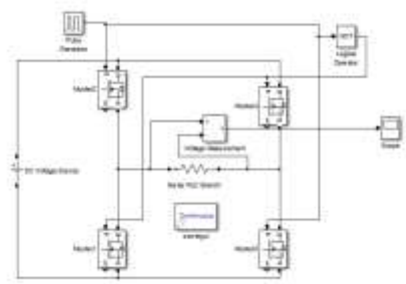

Fig.12: Modeling of a single phase inverter

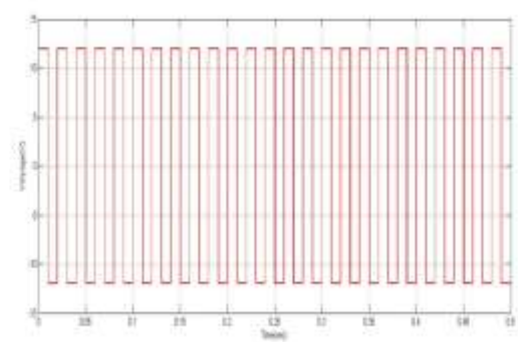

Fig.13: Output waveform of single phase inverter.

Obtained simulation Output waveform of single phase inverter is shown in above Fig.5.13 a square wave is generated for given input voltage is 12V DC and obtained output voltage is 12VAC.

3.4 Simulation of MPPT Based PV Systems with Single Phase Inverter.

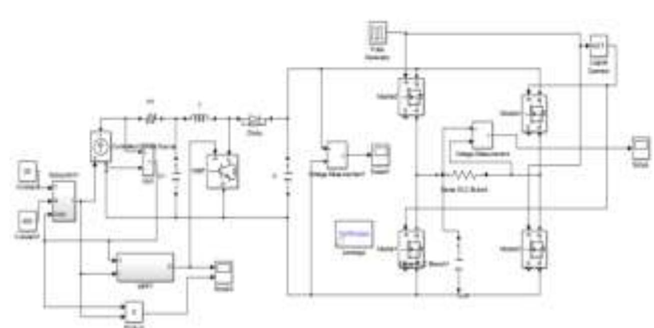

Fig. 14: Simulation diagram of MPPT based PV systems with single phase inverter.

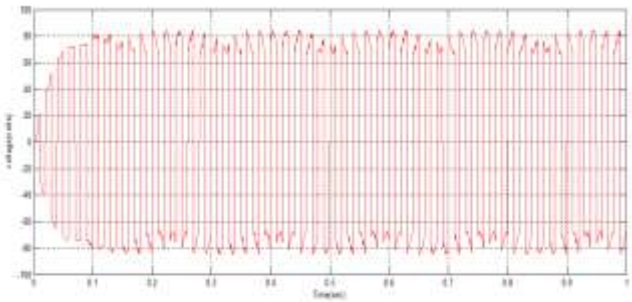

Fig.15: Output Waveform Of MPPT based PV systems with single phase inverter.

The above Fig.5.14 is a Fig.5.15 shows simulation diagram of MPPT based PV system with single phase inverter and the obtained waveform is a square wave with distortions which are eliminated using proper filters.

IV. CONCLUSION

This paper gives detailed explanation of PV cell, characteristics of PV array at different temperatures and solar irradiances values. Various MPPT techniques with comparison among them and proposed technique is Perturb and Observe technique. The results are validated using MATLAB.

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