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# Reactive Power Control for Single-Phase Grid-Connected PV Inverter using Fuzzy Controller

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## ABSTRACT

*This paper proposes grid system and its controlling techniques to regulate the continuous changes in operational requirements and deregulation problems. In the present scenario, the distribution energy systems play an important role in maintaining the power system reliability and stability in distribution domain. The proposed grid is a structure of PV and hybrid system. To achieve the maximum operation from the renewable sources an MPPT methods is proposed. This paper also proposes a concept for controlling of reactive power in single phase grid connected PV system. In order to achieve this reactive power control, this paper is implemented with different current regulated controllers such as conventional PI controller, PR controller, ASDM controller and Fuzzy Logic Controller. This proposed system with different controllers are tested and verified in MATLAB environment.*

***KEYWORDS:*** *PV System, Grid Interconnected, Proportional Integral and Proportional Resonant Controller, ASDM and Fuzzy Logic Controller.*

## INTRODUCTION

Generally, the utilization demand of electricity will increases rapidly from 2010. The solution to overcome these problems is only increasing of more power plants. The main problem with utilization of these conventional plants causes pollution and greenhouse emissions and also damages the environmental conditions. To overcome this effects, a renewable energy systems are chooses. Increasing the supply of non-conventional sources reduces the carbon-intensive energy sources and significantly reduce the global warming emissions.

In the present scenario, the utilization of renewable energy has been increased rapidly due to available nature conditions. In this paper a PV and Wind energy systems are considered as input sources and connected to the grid, during this interaction between grids and Distributed Sources a power quality problem arises. In small-scale power plants, the Distributed Energy Sources play a key role, for example, non-conventional power source like, photovoltaic cell, wind systems hydro sources designing the microgrid idea close to the load center have the advantage of improving effectiveness by decreasing the transmission line misfortunes or voltage drops.

The photovoltaic system is one of the most convenient renewable energy system as compared to all other renewable sources. Photovoltaic systems are not naturally stable in time, location, season and weather and also the cost for installation of PV system is very high. The changes of weather conditions effect the generated output from the PV system. Therefore, to achieve maximum output and for increasing the efficiency from the PV panel, an MPPT techniques is implemented. Generally, the maximum power point position is unknown, and this can be achieved by using some searching algorithms or model calculations. In this paper an Incremental Conductance based MPPT technique is used.

And also the system need to maintain synchronization with the grid. For this, to match the frequency levels and system rating the solar system is connected to voltage source inverter. The control diagram for the inverter is designed with general PWM technique and the reference signals are chosen from the grid parameters.

## GRID INTERCONNECTED NETWORK

In general, the coordination of grid sustainable power sources, for example, photovoltaic framework is the most significant application. These points of interest incorporate the ideal motivators in numerous nations that effect clearly on the business acknowledgment of grid associated PV frameworks. This condition forces the need of having great quality planning apparatuses and an approach to precisely foresee the dynamic execution of three-stage grid-associated PV frameworks under various working conditions so as to settle on a cool headed choice on whether to consolidate this innovation into the electric utility grid.

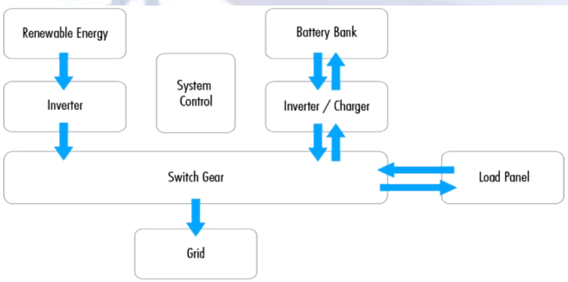


**Figure 1: Structure of general Grid System**

### 2.1 *PV Solar System:*

Solar PV system play a key role in distribution energy systems in present scenario as its flexibility and reliable nature. The PV system converts sun irradiance to electrical energy by photon effect. In PV system the solar cells are arranged in series and parallel combination to meet the load requirement such as voltage and current. The main components in solar system is, PV panel which converters sun photon light to electrical current further it converted to dc voltage with the help of electrical equivalent circuit. To reach, the maximum power from the solar system an MPPT based DC-DC converter is implemented.

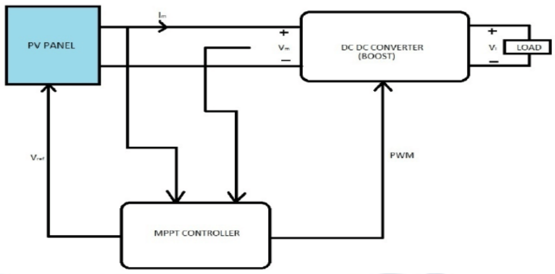


Figure 2: PV System with Power Converter

The purpose of MPPT technique is to track the power from the solar system. A maximum power point tracker is a basic DC to DC converter that synchronize between the PV system and Point of Common Coupling. The purpose of this converter is to control the solar voltage and track the maximum power from the panels

### 2.2 Incremental Conductance Method

Incremental conductance method is one of the best searching algorithm in MPPT techniques. In this method, the maximum power is obtained by the slope derivative of the PV current w.r.t PV voltage.

The voltage and current of the PV cells are results the maximum power and this cells consists of single operating point. The relation between the PV system voltage and current is exponential form and the curve is in non-linear form, so that MPP is presents at knee of the curve. The INC searching algorithm for PV system is shown in flowchart. In this, the solar power is calculated from the PV voltage and current.

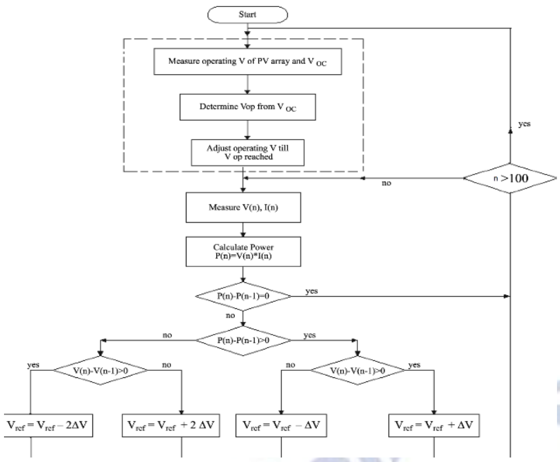


Figure 3: Incremental Conductance Method Algorithm

## PROPOSED SYSTEM AND CONTROL STRATEGY

The proposed system for grid interfaced PV system with conventional asynchronous delta modulation technique is shown in figure 4. In this system, the PV is designed with INC mppt technique and applied to VSC inverter. The system consists of two inner control loops, which is used to regulate the DC link voltages and grid currents.

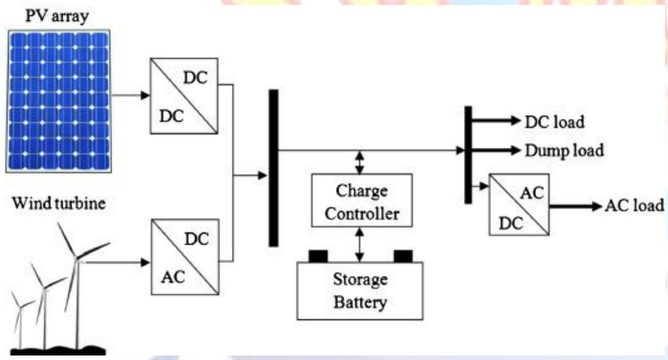


Figure 4: Configuration of proposed grid connected hybrid system

In figure 4, a cascaded asynchronous delta modulation technique is implemented to control the grid currents and to generate gate signals required for voltage source inverter. Figure 5 shows the general control diagram for grid currents. In this transfer function approach model is proposed. The transfer functions for voltage reference signal is represented as $G_{ASDM}(s)$ and is obtained from the current control signal i.e $G_i(s)$ is a function of actual and reference grid currents and from these the transfer function $G_{id}(s)$ is calculated which is applied to comparator to generate gate signals. For steady-state analysis, the dc bus voltage $V_{DC}$ and the grid voltage $V_{ac}$ are assumed to be steady without disturbance.

The compensated current loop gain $T_i(s)$ is expressed as

$$T_i(s) = G_i(s) G_{ASDM}(s) G_{id}(s)$$

Where,

The mathematical expression for current transfer function on frequency domain is

$$G_{id}(s) = \frac{2V_{DC}}{sL + R_L}$$

The mathematical expression for ASDM in the frequency domain is

$$G_{ASDM}(s) = \frac{2dV_{CC} - \hat{v}_{ref}}{2V_{CC}}$$

And the transfer function for current in open-loop function is

$$G_{open-loop}(s) = \frac{V_{DC}(sR_1C_1 + 1)}{V_{CC}(sL + R_L)}$$

The below figure shows the closed loop control diagram for current transfer functions.

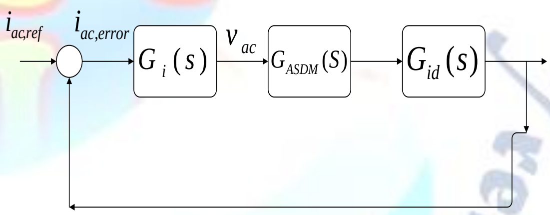


Figure 5. Current control block diagram of the proposed PV inverter

The reactive power of the inverter is obtained with help of ac mains voltage and current measured when zero crossing point. The expression for reactive power of inverter is expressed as,

$$Q_{out} = \frac{1}{2} V_m I_m \sin\theta_i = \frac{1}{2} V_m i_{ac}(t_q)$$

Where, $i_{ac}(t) = I_m \sin(\pi - \theta_i)$

From the above equation, the reactive power of the inverter can be easily calculated by two sampled current values within one cycle.

To achieve better steady state analysis this control diagram is implemented with different controllers such as (a) conventional PI controller,

(b) Proportional Resonant Controller, (c) ASDM controller and (d) Fuzzy Logic Controller.

**Proportional Integral Control**

PI controllers commonly called as conventional controllers, which helps to minimize the steady state errors of the regulators. In this the value of the output signal is proportional to error signals with minimized steady state error.

The general expression for PI controller is expressed as

$$U_e = K_p e(t) + \int K_i e(t) dt$$

In this system, PI controller is applied at inverter control diagram to regulate the grid and dc link voltages. The PI controller used here is type-1 system which helps to minimize the steady state error.

### 3.1 Proportional Resonant Control

To get the better tracking for a reference and also to eliminate the disturbed signal, the proportional resonant controller is best method as it is based on the internal model principal of the system.

The mathematical model representation for PR controller is

$$G_{PR}(s) = K_P + \frac{2K_r s}{s^2 + w_o^2}$$

Based on the internal model principal, the stability of the system is obtained by PR controller with above mathematical analysis it ensures zero steady state error for sinusoidal tracking at system frequency $w_r$.

### 3.2 Asynchronous Sigma-Delta Modulation

The key building block in all electronic systems such as audio, communication, industry measurements and sensors are ADC converter. Sigma delta converters are feedback devices and operating in closed-loop mode; this makes them tolerant to some analogue imperfections, including offset and mismatch.

The expression for current amplitude generaor to regulate the voltage $V_{dc}$ is expressed as

$$I_m(n+1) = I_m(n) + k * \Delta I$$

If $V_{dc} > V_{dch}$ then k=+1

If $V_{dc} > V_{dcl}$ then k=-1

Else k=0

A new sigma delta modulation is introduced by kikkert. The basic structure of asynchronous sigma delta modulation consists of two components i.e (a) integrator and (b) hysteretic comparator. The function of integrator is to regulate the error signal between input signal and Schmitt trigger output signal. The major advantages of the ASDM controller is simplicity in circuit configuration and consists of low harmonic components and plays a key role in power electronics applications.

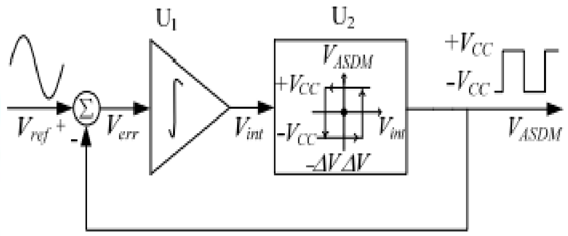


Figure 6: Block diagram of the ASDM

Figure 6 shows the control diagram of asynchronous sigma delta modulation technique. This block diagram consists of integrator, comparator and error amplifier. In the above control diagram, the error voltage signal is obtained by the comparison of reference input voltage and output pulsating signal. The integrated signal is the accumulated error signal which is processed by comparator to generate pulsating signal required for the power converter switches in order to control the electrical power.

### 3.3 Fuzzy Logic Controller:

The major complexity in conventional PID controller is mathematical analysis with multiple variables and constant interfacing. The major three issues with conventional PID controller is (a) time delay, (b) step function response and (c) ramp or soak function response.
In order to overcome these issues, this paper is implemented with soft computing controller called as Fuzzy logic Controller. Fuzzy Logic is one type of artificial intelligence and it is based on the information which is either true or false. FLC is a function or group of flexible set of if-then rules.

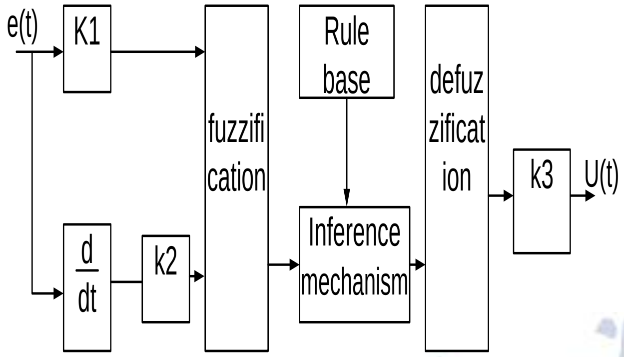


Figure 7: Architecture of FLC system

Figure 7, shows the basic structure of fuzzy logic controller with two inputs namely error of dc link voltage and change in error. Each input of FLC is a set of 5 memberships (i.e MS, S, Z, H, VH). The minimum of the two inputs of Medium small, small, zero, high and medium high are chosen which ultimately try to fire the set of IF-THEN rules. If error is Z AND change in error is H then the output is MH.

| e/ce | MS | S | Z | H | MH |
|---|---|---|---|---|---|
| MS | MS | S | Z | H | MH |
| S | MH | H | Z | S | MS |
| Z | S | Z | H | MH | MS |
| H | S | S | MS | H | H |
| MH | S | Z | H | H | MH |

Table 3.1 Rule-Base formation for 5*5 input FLC

**SIMULATION CASE STUDY:**

Figure 8 shows the simulation diagram for the proposed grid interfaced PV system. This model is tested and verified in simulink environment under three cases. And the simulation results for all these three cases are shown below.

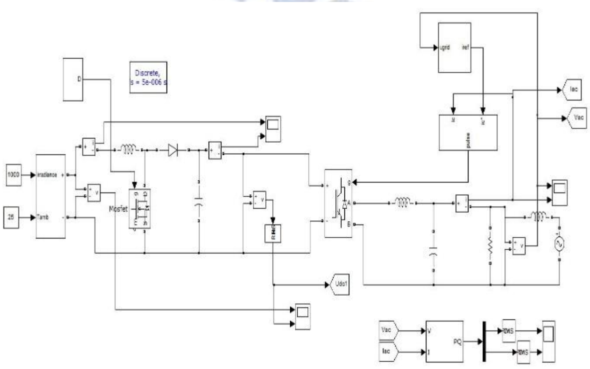

Figure 8: Simulation Diagram for proposed System

**Case 1:** Simulation results of Proportional Resonant Controller

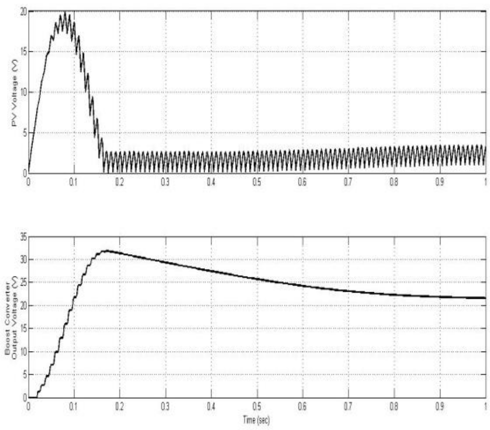

Figure 9: Simulation Result for DC Voltage of PV and Boost Converter

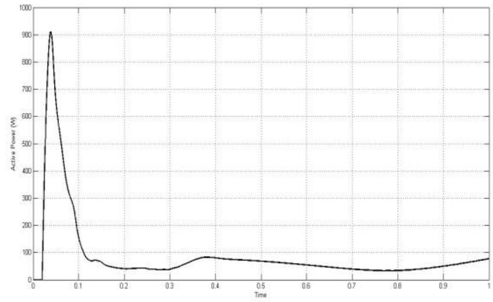

Figure 10: Simulation Result for Grid Active Power

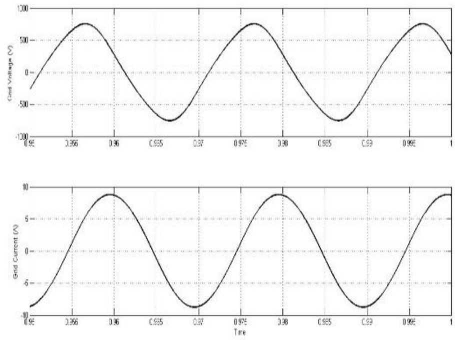

Figure 11: Simulation Result for Grid Voltage and Current

In this case, the proposed system is implemented with PR controller. The simulation results from figure 9 to figure 11 shows the output waveforms for solar panel voltage and boost converter voltages, grid voltage, current and active powers. The voltage from the pv panel is 5v and it increased to 25v with MPPT based boost converter.

**Case 2:** Simulation results of ASDM Controller

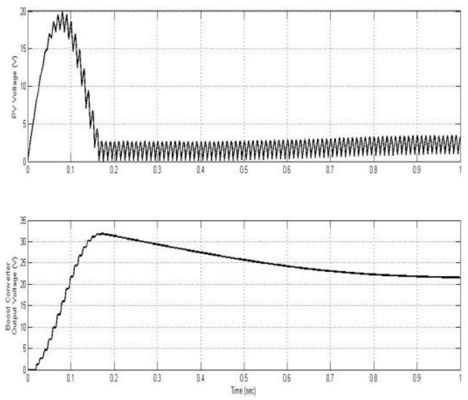

Figure 12: Simulation Result for DC Voltage of PV and Boost Converter

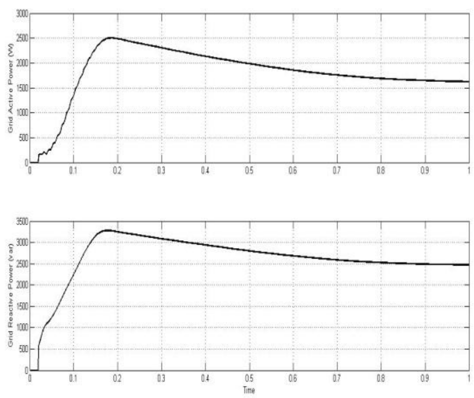

Figure 13: Simulation Result for Grid Active and Reactive Powers

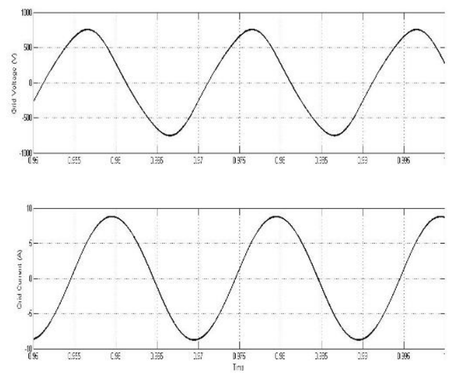

Figure 14: Simulation Result for Grid Voltage and Current

This case is implemented with ASDM based proposed hybrid system. The simulation result figure 12 shows the pv voltage and boost converter voltages. The waveforms for grid voltage and current is shown in figure 14. The grid system active and reactive powers are shown in figure 13. In this the disturbances in the reactive power is compensated with ASDM controller.

**Case 3:** Simulation results of Fuzzy Logic Controller

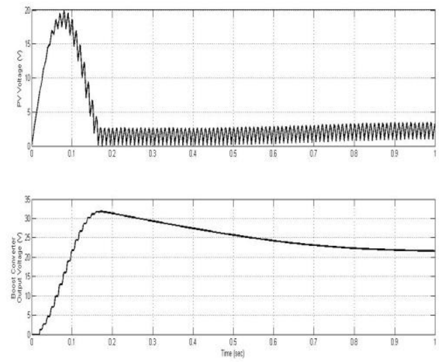

Figure 15: Simulation Result for DC Voltage of PV and Boost Converter

Figure 15, shows the simulation result for solar voltage and boost converter voltage of the proposed system with application of Fuzzy logic controller. With this controller, the boost converter voltage is improved to 25v from pv voltage of 5v.

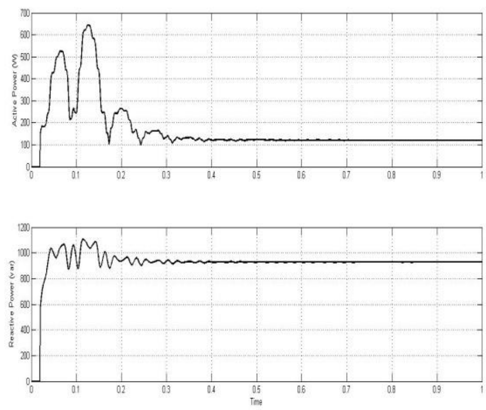

Figure 16: Simulation Result for Grid Active and Reactive Powers

Figure 16 shows the simulation result for grid active and reactive powers of the hybrid system. In this case the system is implemented with fuzzy logic controller to compensate the deviations in the reactive power. As compared to conventional PR and ASDM controllers the fuzzy controller produced better result.

Figure 17 shows the grid voltage and current of proposed hybrid system with fuzzy controller.

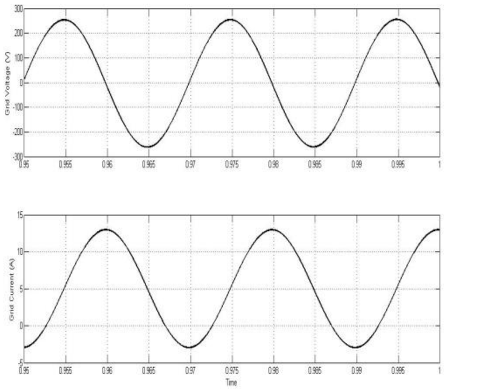

Figure 17: Simulation Result for Grid Voltage and Current

## CONCLUSION

The reactive power control for grid interconnected PV system with different control strategies has successfully implemented in this paper. The proposed simplified reactive power controller can reduce the computational effect of processor, so that a low-cost converter can be implemented for cost effective PV inverter. A small signal analysis is implemented for ASDM controller to prove control stability. With these controllers, the proposed Fuzzy logic and ASDM controllers can achieve the desired reactive power control to the proposed single phase grid connected PV system.

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