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Development of Grid-Tied Solar Photovoltaic System with Cascaded PQ Controller

[1*,a]R.Gopinath, [2,b]M.Karuppasamypandian, [3,c]R.Jenitha
[1,2]Department of Electrical and Electronics Engineering,*
[3]Department of Electronics and Communication Engineering,
[1*-3] Kalasalingam Academy of Research and Education, Krishnankoil, Tamil Nadu, India – 626 126.
[a]gopinath98kkl@gmail.com, [b]m.karuppasamypandian@klu.ac.in, [c]jenithaanburaj21217@gmail.com

***Abstract- -* To sustain the current environmental conditions solar energy is concentrated for the electricity in households and commercials looking at the single stand-alone system the entire harvested energy is not completely utilized throughout the clock. During the unused situation, the generated electricity can be tied to the grid to meet social welfare. So that our society can get benefitted. But during the integration of solar photo voltaic with the grid, there are a lot of issues are being faced like voltage fluctuation and power quality disturbances. Recent research is being carried out to reduce the harmonics and increase the power quality when it is interfaced with the grid. So the PQ controller is designed using a proportional-Integral algorithm, which provides a robust and reliable control strategy for grid-tied solar photovoltaic systems. In this paper, a cascaded PQ controller, and control strategy for grid-tied solar photovoltaic systems is used. The cascaded method uses a PQ controller to regulate the output of voltage and frequency of a solar inverter, ensuring that the energy supplied into the grid meets the required output. The proposed method involves a two-stage control system with the outer loop regulating the DC voltage of the PV array and the inner loop controlling the output frequency and voltage of the inverter. Simulation results demonstrate the effectiveness of a proposed cascaded control strategy in regulating the power output of solar inverter and maintaining the power quality of the grid and achieved the harmonics of less than 3% and obtained efficiency up to 92%.**

Keywords – Solar panel, PQ controller, Grid, Matlab / Simulink.

I. INTRODUCTION

Grid-tied solar PV system are becoming increasingly popular as means of generating clean, renewable energy for homes and industries. These system are designed to converts the direct current power generated by solar panel into alternating current power that can be fed into the electrical grid to decrease the exhaustible energy sources .A grid-connected solar PV using a PQ (Power Quality) controller is a system designed to optimize and regulate photovoltaic system performance that is linked to the electrical grid which ensures required output power, and solar photovoltaic system which is linked to the grid should be a simple[1], and a controller is necessary to manage both the active and reactive power which is injected into the grid in order to increase system efficiency. The PQ controller uses advanced algorithms and control strategies to regulate the voltage, current, and power flow [2]. A controller continuously analyses the solar PV system's electrical output and modifies its voltage and frequency to ensure that it complies with power quality [6]. The integration of Grid-tied solar system using an inverter can cause some main drawbacks like stability in voltage and frequency, problem regarding safety, high level of harmonics and low power quality of the system .To overcome this problems, the cascaded control method is used. And it helps to control the system for more precise output of the solar PV to maintain the stability and reliability of the grid[7].And this cascaded control algorithm[5] is used to control multiple parameters at the same time such as voltage ,frequency and power factor.When using an two level cascaded system it can control frequency and voltage of the grid tied system .The outerloop can controls ,voltage by adjusting the active power output of the system, while inner loop can control the frequency by adjusting the reactive output of the system. And in other case a three level cascaded algorithm helps to control frequency, voltage and power factor of a grid tied system .the outer loop can control the voltage and frequency ,the middle loop can control the power factor and the inner loop can control the DC bus voltage of the inverter.Cascaded control algorithm can provide improved performance compared to single-loop control algorithm ,by reducing the interaction between control loops, improving the robustness of the system and allowing for complex control strategies.

Overall, a grid-tied solar photovoltaic using a cascaded PQ controller is a crucial component of any modern solar energy system. It ensures that the electrical output of the system complies with the relevant power quality standards while maximizing the efficiency of the system.

II. METHODOLOGY

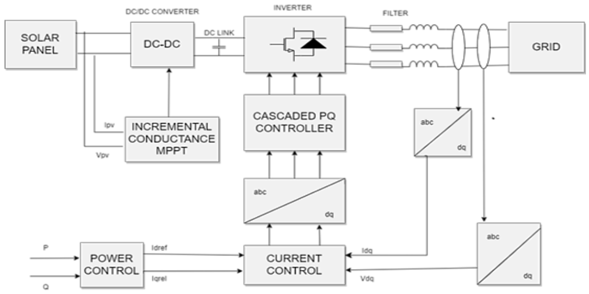

Fig.1. Block diagram of Intelligent controller for grid-connected solar PV using pq controller

Here in the grid-tied solar photovoltaic system using a cascaded PQ controller having a solarpanels rating of 100kw.The power which has been harvested from the panel may contain voltage drops and fluctuations, to avoid this problem use an MPPT controller. The MPPT controller is helps to track the maximum power point in the

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system .This MPPT system, there are various types of algorithms, but here mainly the MPP uses the incremental conductance algorithm and has the ability to follow the MPP under rapidly varying irradiance and temperature. This incremental conductance will activate particularly when the PV panel is working at a low irradiance level.

By contrasting the incremental changes, will happen in both power voltage, it will happen in both power and voltage, it operates when the power voltage curve is at zero, so assume that the algorithm attains MPP and the algorithm stop modifying the duty cycle of the DC-DC converter at this moment in order to maintain PV voltage at the MPP. This DC-DC converter is helps to convert unregulated direct current voltage into regulated direct current voltage at the output.

This DC-DC converter helps to regulate the voltage and is supplied to the inverter with the help of a DC link. It is mainly used to interface different frequency power supplies. The power control is used to stabilize the power system for various disturbances like short circuits and loss of generation and to meet the demand of consumers.

A power controller is used to adjust the output of the source and to control the flow of power through the grid. It is followed by the current controller which helps the power grid to maintain the required power quality. So by controlling the flow of power through various components, these systems can help to reduce energy losses and minimize wasted electricity.

And introducing an abc/dq block in the system is very much helpful to transform the three-phase quantities(abc) into two-phase quantities(dq). The dq reference frame rotates at the same frequency same as the three phases. The power is supplied to the cascaded pq controller, which controls multiple parameters at the same time like the voltage, power factor, and frequency.

The three-level cascaded system helps to controls the voltage, frequency, and the power factor.Outer loop controls the voltage and frequency,the middle loop can control the power factor[14-17], and the inner loop control the DC bus voltage of the inverter.

And DC power is converted into AC power with the help of inverter and supplied to the filter. The filter may contain RLC to reduce the high order frequency in the system and also to reduce power quality issues and decrease losses. And the power is finally given to the grid system and there it is used according to the requirements.

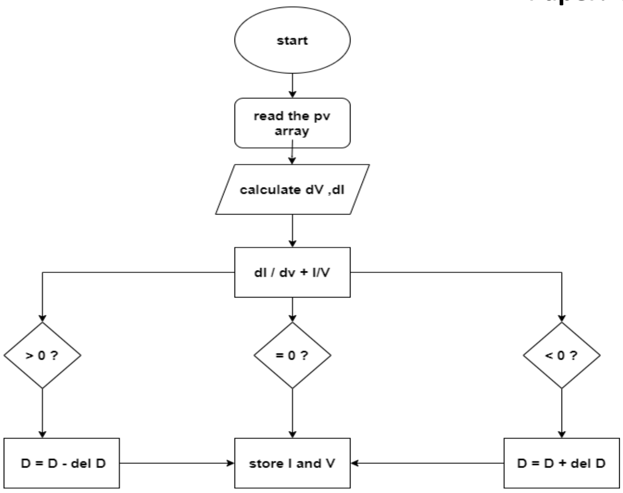

Fig .2. Incremental conductance flow chart

A. PQ inverter controller

It is a device which is used in grid tied solar photovoltaic system to maintain the quality of power delivered to end users. And this controller main aim is to monitor the voltage and current of the grid. PQ controller operates by measuring the voltage and current waveform, with a reference waveform. And if any error is detected, like deviation and voltage drops the signal are given to the voltage source inverter and active power filters to meet out the errors and also to correct the deviations. Main objective of the PQ controller to control the voltage regulation ,harmonic filtering, reactive power compensation and load balancing [9].

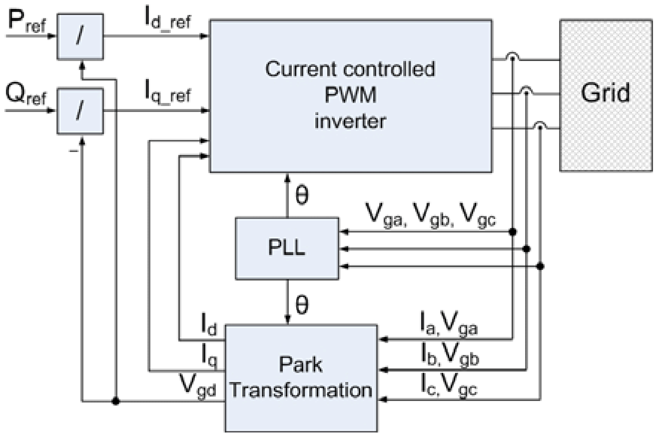

Fig. 3. PQ controller

The parameters such as P and Q are the important factors mainly required during the effective utilization of the power from the renewable resources connected to the grid. The attainment of PQ is established with the Eqn. 1 and Eqn. 2 below.

$$P = V_a * I_a + V_b * I_b + V_c * I_c \qquad -(1)$$

$$Q = 1/sqrt(3)^* \ (Vbc * Ia + Vca * Ib + Vab * Ic) \qquad -(2)$$

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The real power P is obtained with the summation of the three phases such as V_a along with I_a which is the first phase. Similarly the 2nd phase power is obtained by the product of V_b and I_b. In the similar manner the 3rd phase power is the product of V_c and I_c. By summing all the three phases product, the real power P is obtained. Along with the real power establishment, the reactive power is obtained with product of the three phases which is alternative to each other. The voltage of Ic along with the first phase current, the voltage of ca with 2nd phase current and finally voltage of ab with the 3rd phase current. All these voltages are summed and in inverse with the cubic square root of 3, the reactive power Q is obtained. Thus the power obtained at the renewable power sources are being effectively utilized by the uses using PQ inverter.

Here the cascaded PQ controller which is used in grid connected solar photovoltaic system is having the ability to meet out the problem and correct it very effectively. The cascaded PQ controller which is used to control the grid connected system where cascading the PQ controller is interconnection of two level PQ controllers. It consist of two loops they are inner loop and outer loop. Inner loop which is used to control the frequency by adjusting the reactive power and outer loop controls the voltage through adjusting active power.

III. MATLAB MODEL

The Matlab Simulink model of the proposed PQ inverter with solar MPPT controller has been designed and shown in Fig 4. The design has been carried out with variable step ODE 23t.

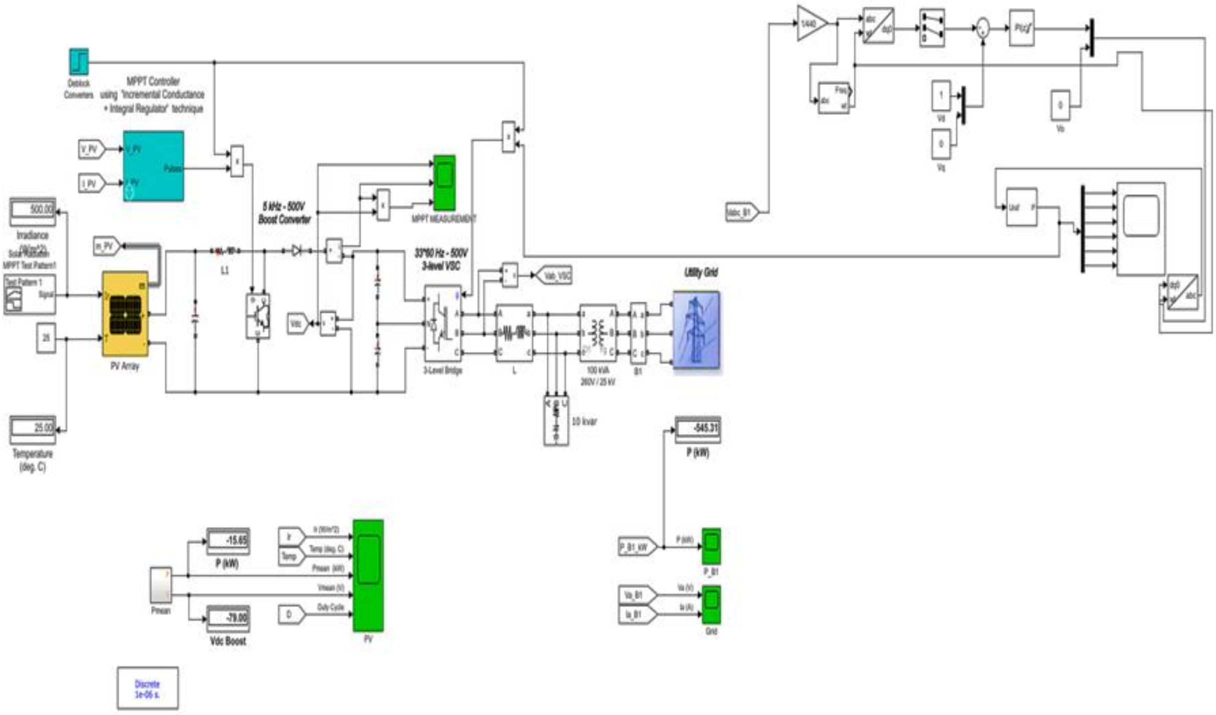

Fig.4. Simulink Model for the proposed PQ inverter along with MPPT controller

The system description of the designed Simulink model of a PQ inverter is tabulated below.

Table I. System description of the designed SPV

No. of solar panels	330
No. Cells per module	96
Open-circuit voltage(Vsc)	63.4 V
Short-circuited current(Isc)	5.94 amps
Max voltage power(vmp)	53.7V
Max current power(Imp)	5.58 amps
Temperature	25°C

IV. RESULTS AND DISCUSSION

Photovoltaic Array which is tied to the grid, needs a controller to make sure their power production is coordinated with the grid. In this simulation, Matlab Simulink is used to create and analyse a Grid-tied photovoltaic using a PQ controller. The real power and reactive power injected into the solar photovoltaic array and, grid will be regulated by the PQ controller. Proportional-Integral(PI) algorithm is used to control and used in the controller.

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The controller's functions include preserving a power factor of one and copping the current at its rated value. The graph below displays the voltage and current waveforms of the grid and solar photovoltaic system. And grid voltage is sinusoidal, however, the voltage output of the photovoltaic system is practically constant during the experiment. The solar PV system's current waveform is also sinusoidal, and the current and voltage are in synchrony. The waveform of the grid's current is also sinusoidal, and the current and voltage are same. And figure below displays output of the solar photovoltaic system and power factor. And PQ controller regulates the photovoltaic system's output power, ensuring that the power factor stays at unity. The output of the photovoltaic system and the grid-tied voltage are in phase.

The simulation for the entire proposed grid-connected solar PQ inverter model was carried out with the Matlab Simulink environment tool. The utilized version of Matlab is Matlab R2020b and the solver is ODE23t. The setup consists of a 100kW PV array connected with the single-phase utility grid. It is mainly utilized for commercial and home applications. The detailed simulation results are shown in the following illustrations.

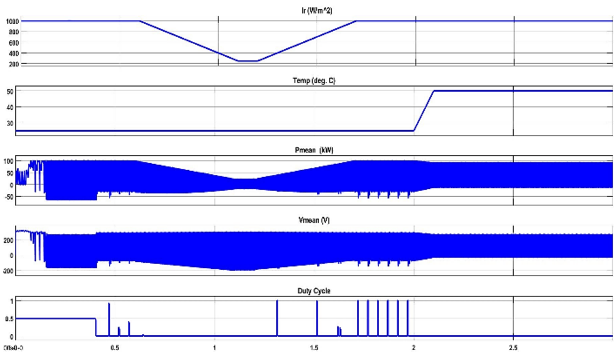

Fig. 5**.** Simulation result for the output power, voltage, and duty cycle for irradiance and temperature

Fig. 5 clearly showcases that the irradiance of Solar PV is slowly decreasing and increasing from 0,6 seconds to 1.6 seconds and temperature from 2.0 to 2.1 seconds. It is understood from the figure that the power and voltage vary according to the Ir and Temp. And to reduce the fluctuation during time of operation, the duty cycles are being activated and allow Solar power for the operation of the load.

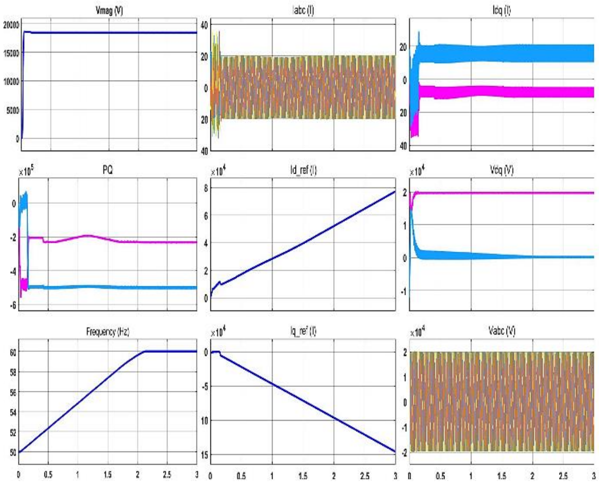

Fig .6**.** Simulation result for the cascaded PQ-controlled inverter

The above Fig. 6 shows the simulation result for the PQ inverter which is connected to the grid side of the solar PV. The figure clearly shows the voltage at the output side, PQ values, frequency, I_{abc}, V_{abc}, I_{dq}, and V_{dq}. It is inferred from the graphs that the corresponding attainment of power and voltage with minimum power loss at the grid side.

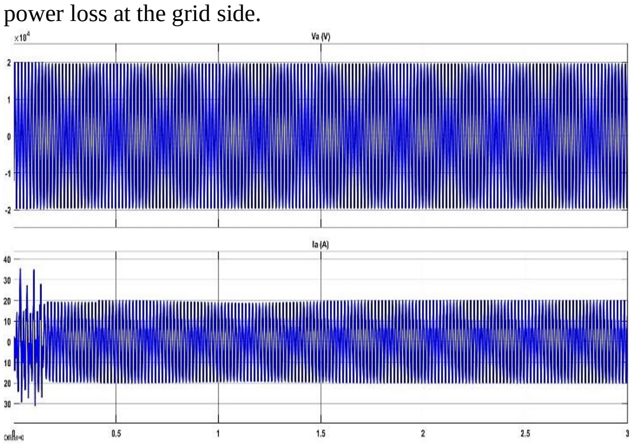

Fig. 7**.** Simulation result at the utility grid

The above Fig. 7 shows the simulation result at the utility grid which is utilized for load applications. By observing the figure, the obtained power harvested from the solar PV energy is being carefully maintained by the MPPT controller and effectively delivered to the grid using PQ inverter modu

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Simulation results demonstrate the Intelligent controller for grid-connected Solar PV using a cascaded PQ controller is an effective system that can ensure optimal power transfer while ensuring power quality. The Cascaded PQ controller can detect faults in the system and protect it from any damage. This system can be used in grid-connected solar PV systems to ensure efficient and safe power transfer

V. CONCLUSION

By using a cascaded PQ controller, the power quality issues in a grid-tied solar PV system are rectified, eliminates harmonics, compensates a reactive power, and balances the load and the simulation results show solar irradiance at different levels, the THD of the grid is under the required standards. The cascaded PQ controller uses a voltage source inverter and active power filters to handle multiple power quality issues simultaneously, the harmonics are achieved less than 3% and obtained efficiency of up to 92%. Overall the use of cascaded PQ controllers in grid-tied solar PV systems is giving assurance of a high-quality power supply to consumers and reduces the errors on the grid system.

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