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# A Novel Approach for Control of Power Flow in Grid Connected PV System

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***Abstract:*** Now-a-days Renewable Energy Sources became an alternative to meet the increasing load demand because they are environmental friendly and also available abundant in nature. Among the Renewable Energy Sources, the Photo Voltaic (PV) System is gaining more attention due abundant availability of solar energy. The Maximum Power Point Tracking Technique is used to extract maximum power from the Photovoltaic system. When there is a need to transfer bulk amount of power from PV system to Grid, the power quality issues are a major concern. In this paper, a novel approach was proposed to control the power flow and to deal with power quality issues that arise when PV Array is integrated with power grid. It consists of a Fuzzy-GA based Cascaded Controller fed unified power flow controller for effective control of real and reactive power flow in grid connected photovoltaic system. The output of the cascaded controller is fine tuned by using Genetic Algorithm approach.

***Keywords:*** Cascaded Fuzzy Logic Controller (CFLC), Unified Power Flow Controller (UPFC), Fuzzy Logic Controller (FLC), Photo Voltaic (PV), Genetic Algorithm (GA).

## 1. INTRODUCTION

In the recent years, there is a rapid growth in the photovoltaic energy generation as compared to wind energy. The solar photovoltaic energy along with other renewable energy sources forms an important source of power generation to meet the increasing load demand. Even though solar energy is available abundant in nature but its usage is limited due to less efficiency and high cost of solar cells. In the literature it is shown that efforts are made to increase the efficiency and reduce the cost of PV modules. Mainly there are two reasons for increasing popularity of solar photovoltaic power generation one is abundant availability of solar energy from sun and the other was it is environment friendly. There is a tremendous growth in solar photovoltaic energy generation around the globe, 1.2 Gigawatts in 1992 to 136 Gigawatts in 2013[1]. In India, by the end of year 2020, planning has been made to produce 20 GW of solar power.

Among the total installed capacity of photovoltaic system, most of them are integrated to grid compared to stand-alone systems. In grid connected photovoltaic system, storage batteries are not required because all the generated power is directly connected to grid. Power electronic converters are used as interfacing devices in grid connected photovoltaic system. In the recent years there is a rapid development in the power semiconductor technology which enable them for wide spread use in the area of renewable energy sources [2]. In order to meet the increasing power demand around the world, the grid integrated photovoltaic system is going to play dominant role in the near future [3]. As compared to traditional energy sources the photovoltaic systems gained more popularity due to development in the solid-state inverters [4].

Grid integrated photovoltaic systems are mainly categorized into distributed and centralized. The distributed photovoltaic systems are the low generating capacity systems which are installed near to the consumer premises. As these types of systems are installed near to the consumer premises, the distribution losses are low. Centralized photovoltaic systems are the high generating capacity systems which are

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integrated to the grid. These systems are having better monitoring and maintenance as compared to distributed systems [5].

## 2. PV CELL MODEL

The solar module consists of a number of solar cells connected in series and these modules are connected in series to form a string. The photovoltaic array comprises number of strings connected in parallel. The required voltage level from the array decides the number of modules in each string and the required current rating of the array decides the number of strings.

The single-diode model of a photovoltaic cell shown in Figure 1 consists of a current source, $I_{ph}$, represents the current generated in the cell by incident photons from the sun. The *p-n* junction of the photovoltaic cell is represented by using a shunt diode. The leakage current due to the impurities of the *p-n* junction is accounted by using a shunt resistance, $R_{sh}$, and its value should be high. The ohmic resistance of the semiconductor and the metallic contacts are represented by using a series resistance, $R_s$.

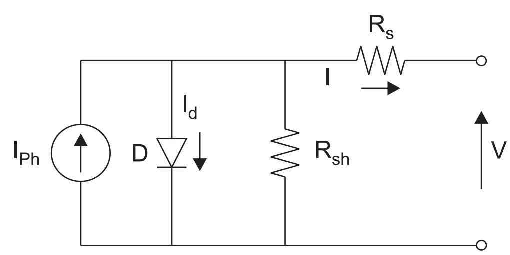



**Figure 1: Basic PV Cell Model**

The output current of the current source is related to solar irradiation and temperature, according to:

$$I_{ph} = [I_{sc} + K_1[T - 298]]\frac{G}{100} \tag{1}$$

Where $K_1$ is the cells short-circuit current temperature coefficient, $I_{sc}$ the cells short-circuit current at 25°C, T is the cell's temperature and G is the solar irradiance in W/$m^2$. Considering $I_d$ the current flowing through the diode and I the output current, the current-voltage characteristic of the photovoltaic cell is defined by:

$$I = I_{ph} - I_d - \frac{V + R_s I}{R_{sh}} \tag{2}$$

Where *V* is the output voltage of the solar cell.

The electric characteristics of the photovoltaic cell mainly depend on the irradiance and temperature of the photovoltaic cell as shown in Figure 2 and Figure 3 respectively. To investigate the effect of solar irradiance on the currents and voltages of the photovoltaic system, temperature was held constant at 25°C and the resulting current-voltage and power-voltage characteristics were plotted. Figure 2 shows the characteristics of the photovoltaic cell at different irradiation levels of 500, 800 and 1000 W/$m^2$. The peak output power of the photovoltaic system is reduced with the reduction in the solar irradiation. The output current varies proportionately along with the changes in irradiance with small variations in the voltage.

To find out the effect of temperature on the module performance, solar irradiation level was assumed constant at 1000 W/$m^2$ while allowing temperature to vary between 25 and 80°C. The result are shown in figures 3 for the I-V and P-V characteristics as temperature was set to 25, 60 and 80°C respectively. The open circuit voltage of the module decreases as surface temperature increases. Current, on the other hand, increases slightly with temperature. The peak output power of the module reduces as surface temperature rises.

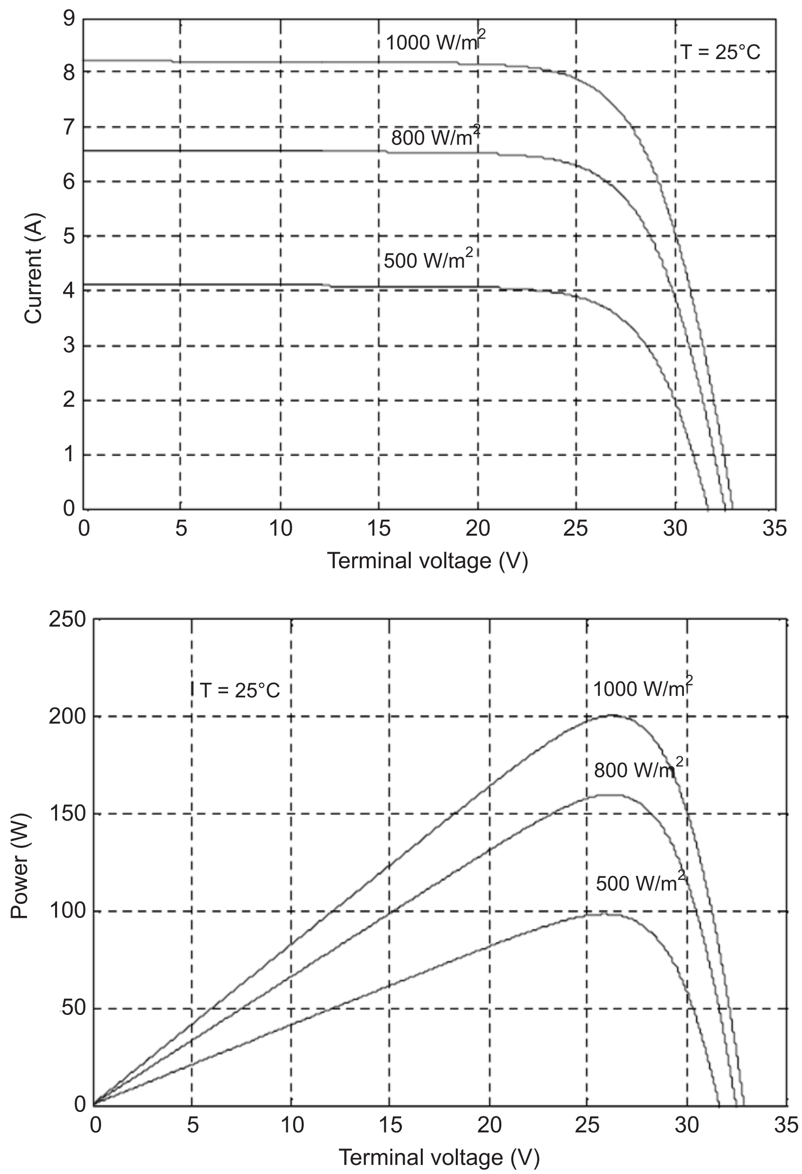
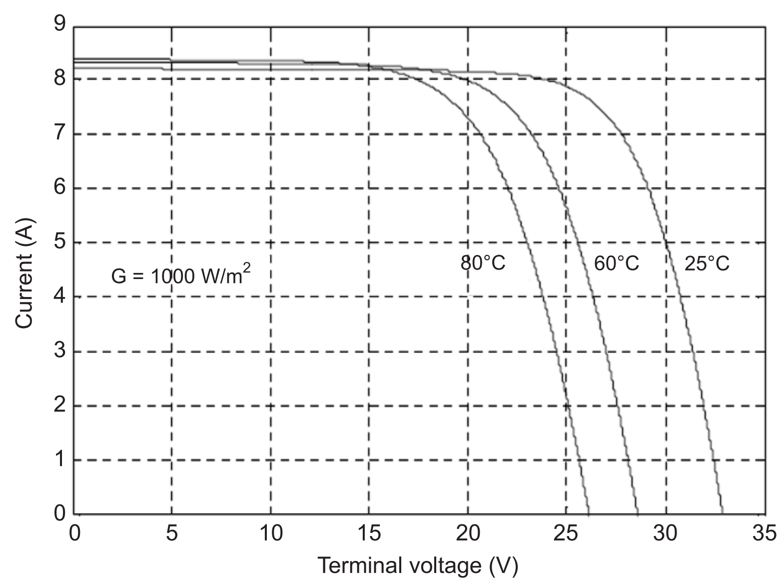



**Figure 2: Characteristics of the PV Cell at constant temperature and variable irradiation**



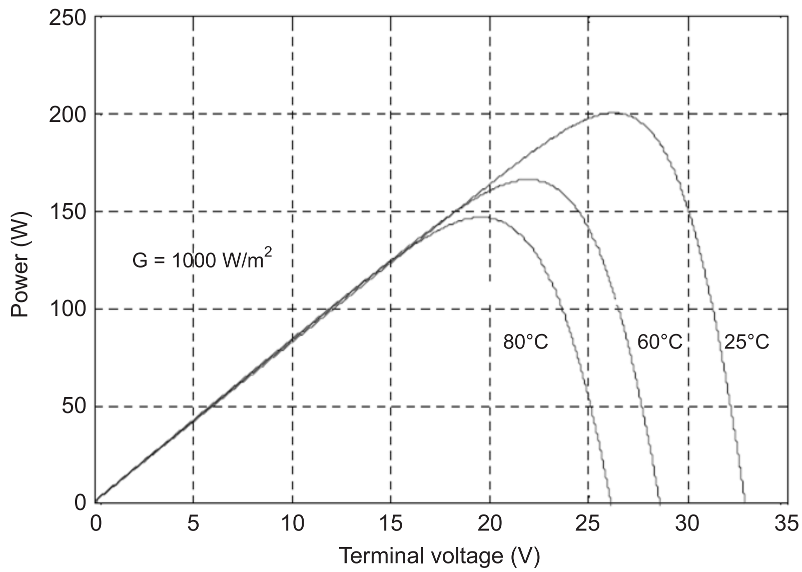



**Figure 3: Characteristics of the PV Cell at constant irradiation and variable temperature**

## 3. GRID INTEGRATED PHOTOVOLTAIC SYSTEM

PV System integrated to grid not only generates active power but also it acts as a reactive power compensator, especially at peak hours, when the main grid needs reactive power higher than average consumption. The main problem with the PV power generation is the rapid fluctuations in the output voltage. The main reason is that solar energy received from the sun is not constant throughout the day. The maximum power point technique was proposed to extract maximum power from the PV system. DC-DC Converters can be placed in between PV system and inverter to boost the output voltage of the PV system or to perform MPPT control [6].

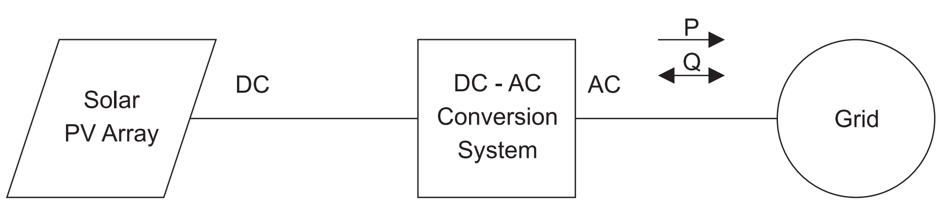



**Figure 4: Photovoltaic System integrated to grid**

With the development in the power converters technology and reduction of the cost of solar PV cells has lead to increased installed capacity of PV power generation, which is implemented in domestic, commercial and industrial applications [7], [8]. The PV system can be operated as standalone systems to meet the power demand of the remote areas where it is difficult to layout the transmission towers or underground cables.

Figure 4 shows the single stage PV System integrated to the grid. The inclusion of storage system is optional in grid tied systems but it is mandatory in case of standalone systems. In single stage system, the PV system is connected to grid through DC-AC converter. The output of a PV system depends on the irradiance, temperature and terminal voltage. The DC output of the PV system is transformed to sinusoidal AC by using inverter before integrating to grid. The DC-AC converter acts as a current source and produces sinusoidal output current. The output current of the inverter should be in phase with the voltage of grid in order to maintain unity power factor. Suitable converter control strategies are implemented to control the real and reactive power, voltage variations due to imbalances on grid side and source side, reductions of harmonics etc

## 4. CONTROL STRUCTURE FOR GRID CONNECTED POWER CONVERTERS

In Synchronous rotating reference frame, control variables are transformed from *abc* frame to *dq* frame appear as *dc* quantities, facilitating easier control. The phase angle of the grid is necessary to transform the feedback variables as shown in equation (4).

$$V_{dq} = [V_d \quad V_q]^T = [T_{dq}]\, U_{\alpha\beta} \tag{3}$$

$$V_{dq} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} V_{\alpha\beta} \tag{4}$$

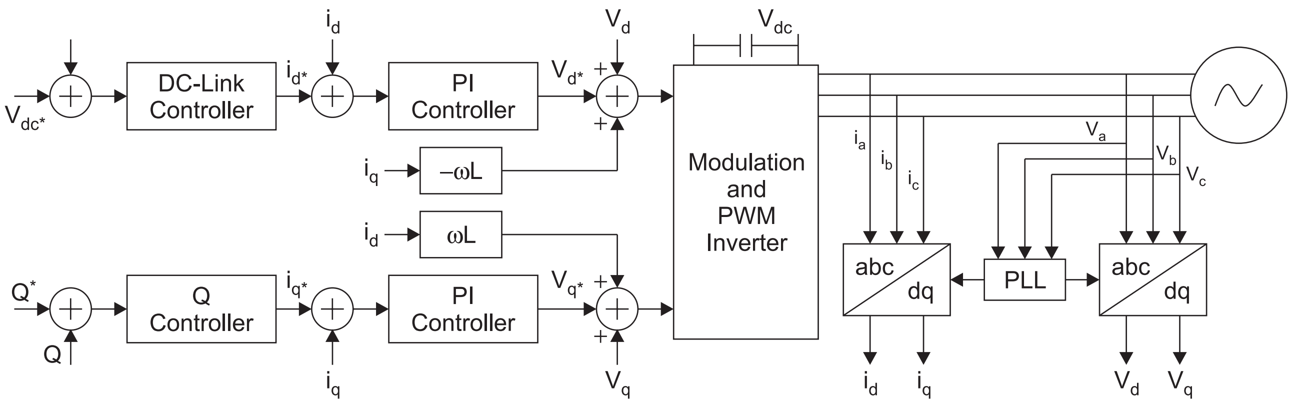



**Figure 5: Control structure implemented in synchronous rotating reference frame using PI controllers for current regulation.**

Figure 5 illustrates the *dc*-link voltage cascaded with an inner current loop is the most common control strategy implemented in pulse width modulation (PWM) driven voltage source inverter (VSI) converters [9-15]. In order to achieve unity power factor, the reactive current reference $i_q^*$ must be set to zero, otherwise, reactive power controller must be used to compensate the reactive power at the point of common coupling (PCC). If active and reactive power reference is supplied to the grid side converter, *dc*-link voltage control can be replaced by an active power control [16-18].

## 5. FUZZY LOGIC CONTROLLER

The main elements of the Fuzzy Logic Controller are the fuzzifier at the input terminal, rule base or knowledge base, inference engine and defuzzifier at the output terminal as shown in Figure 6. The input variables and output variables are the required variables in the Fuzzy Logic Control System. The inputs to the Fuzzy Logic Controller are the parameters or variables of the process to be controlled [19].

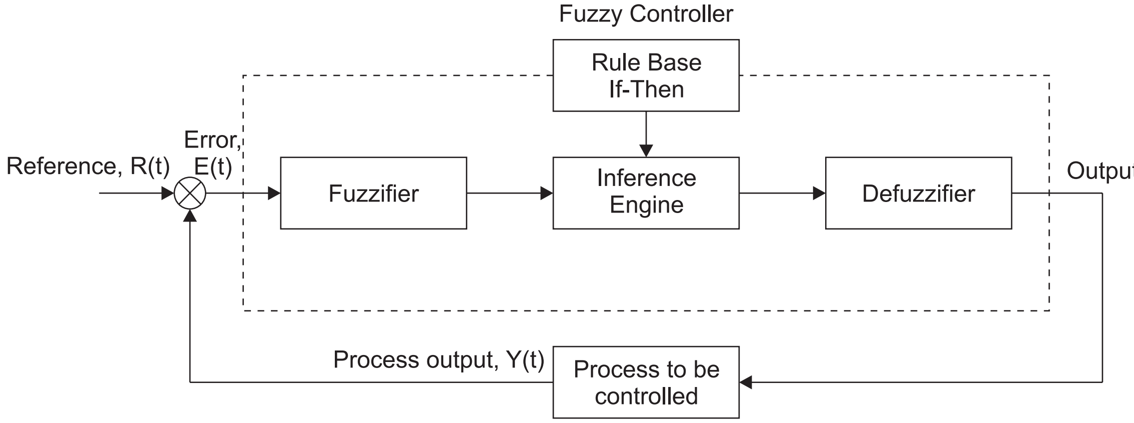



**Figure 6: Basic Fuzzy Logic Controller**

The error, E($t$) and the rate of change of error, ΔE($t$) are chosen as input variables. Change in current and change in voltage are chosen as output variables. Error, E($t$) is defined as the difference between the desired output or reference, R($t$) and the process output variable, Y($t$).

$$E(t) = R(t) - Y(t) \tag{5}$$

$$\Delta E(t) = E(t) - E(t-1) \tag{6}$$

The input variables are fuzzified through the membership functions. By using triangular and trapezoidal membership functions, the controller will reduce the error signal and increases the transient response of the system. Rule-based or knowledge-based element consists of a list of fuzzy rules. According to If-Then rules the inference process will generate a fuzzy output set.

## 6. CASCADED FUZZY LOGIC CONTROLLER

Power conversion system is common is common engineering practice in our electrical power system. Example: Rectifiers, Inverters, FACTS Devices etc. Suitable controller is required for efficient operation of these Power conversion devices in their applications. Out of the wide variety of controllers as mentioned in the literature by so many authors, cascaded PI Controller is one among them which is suitable for all power conversion devices. Designing parameters for cascaded PI Controller is cumbersome due its non-linear properties. Here a new topology as shown in Figure 7 is proposed for optimum design of cascaded fuzzy logic controller (CFLC) used in power conversion system.

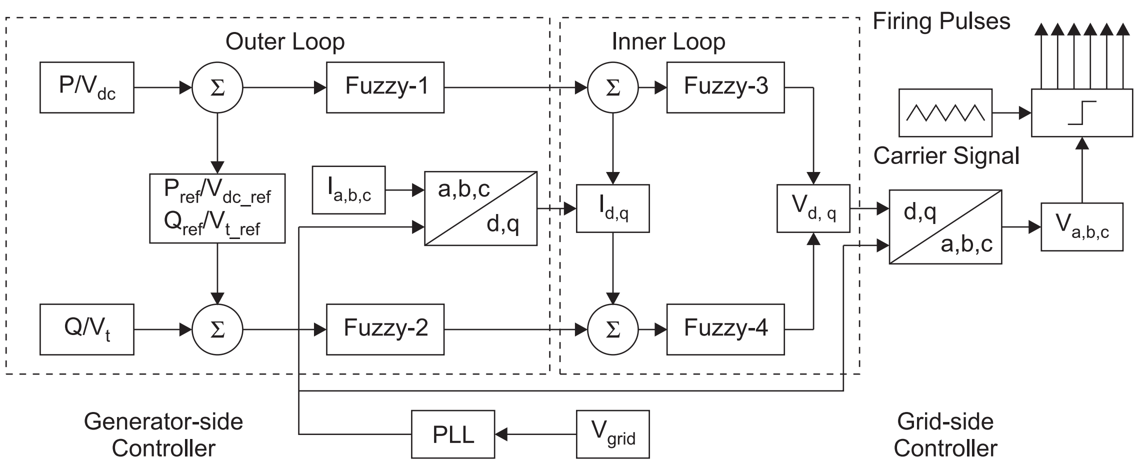



**Figure 7: Cascaded Fuzzy Logic Controller**

The quantities P, Q, $V_{grid}$ & $I_{abc}$ shown in Figure 7 represents the measured or actual values. The transformation angle 'θ', $I_{dq}$, $V_{dq}$, $V_{abc}$ represents calculated values. The $P_{ref,}$ $Q_{ref}$ represents reference values or set points. The cascaded fuzzy-logic controller consists of two loops, namely inner loop and outer loop, each loop contains two fuzzy logic controllers for processing the error signals. The outputs of the CFLC are the three-phase voltage references which are used to generate the pulse width modulation signals to drive the power electronic switches. The output of the CFLC is a controlled vector applied to the power electronic switches. Tuning of four fuzzy controllers is a cumbersome process and time consuming. This problem can be solved by optimal design of cascaded controller parameters used in the power conversion system.

## 7. PROPOSED SYSTEM

The cascaded fuzzy-logic controller consists of two loops, namely inner loop and outer loop, each loop contains two fuzzy controllers which progress the error signals. The final outputs from the cascaded controller are the three-phase voltage references which generate the pulse width modulation (PWM) signal to drive the power electronic switches of the power converter. The output of the fuzzy logic controller is a controlled vector which is fine tuned by Genetic Algorithm and is applied to the power electronic switches for better controllability.

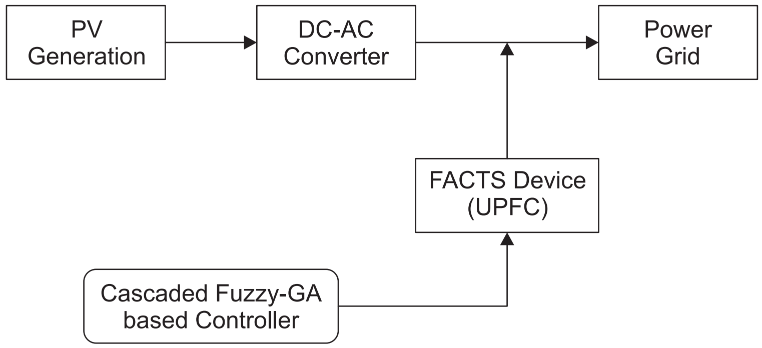



**Figure 8: Grid Connected PV system with Proposed Controller and FACTS device**

Figure 8 shows a PV system connected to the utility grid through a single stage conversion by using inverter i.e., DC/AC Conversion. Unified Power Flow Controller (UPFC) is connected in between inverter and utility grid to regulate and control the power flow from Photo Voltaic (PV) system to the utility grid. The UPFC consists of two voltage source converters, one is connected in series and the other is connected in shunt with the transmission line, with a common *dc* link capacitor and connected to a power transmission system through coupling transformers.

The active power is exchanged between the converters through a common *dc* link capacitor. Each converter exchanges the reactive power with the *ac* system independently and does not flow through the *dc* link. The injected active and reactive power by series converter is determined by the injected voltage and line current. Transmission line parameters such as voltage, impedance and phase angle can be controlled simultaneously by using UPFC. Shunt compensation and series compensation of active and reactive power flow, phase shifting and many other control objectives can be performed by using this controller. The Proposed Cascaded Fuzzy-GA based Controller is connected to the UPFC for better controllability and to minimize the effect due to problems occurring on the grid side and generation side.

## 8. CONCLUSION

Novel structure introduced in this paper improves functionality in grid integrated PV systems. In the literature, various types of controllers have been proposed to extract maximum power from the photovoltaic array and to increase the power transfer efficiency of the photovoltaic system. Out of these, cascaded control structure has proven to give better performance as compared to conventional control structures. But designing parameters for cascaded control structure is cumbersome due its non-linear properties. Optimal design of cascaded controller parameters used in the power conversion system gives the effective solution. Output of the proposed controller is a controlled Vector, which is fine tuned by genetic algorithm technique. The other applications of proposed CFLC are in the area of energy storage systems, renewable energy sources, variable speed drives etc.

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