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PI, Fuzzy Based Controllers for FACTS Device 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 Photo Voltaic (PV) Array. When there is a need to transfer bulk amount of power from PV Array to Power Grid, the power quality issues, especially the real and reactive power flow problems, are a major concern. In this paper a novel control technique 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 PI controller and Fuzzy Logic Controller (FLC) fed Flexible AC Transmission System device, namely STATCOM, for effective control of real and reactive power flow in grid connected photovoltaic system. The proposed system was simulated by using MATLAB-SIMULINK Tool Box and the results are compared.

Keywords: PI Controller, Fuzzy Logic Controller (FLC), FACTS Devices, STATCOM, Grid-connected Photo Voltaic (PV) System.

1. Introduction

Photovoltaic (PV) energy has grown at an average annual rate of 60% in the last five years, surpassing one third of the cumulative wind energy installed capacity, and is quickly becoming an important part of the energy mix in some regions and power systems [1]. This growth has also triggered the evolution of classic PV power converters from conventional single phase grid-tied inverters to more complex topologies to increase efficiency, power extraction from the modules, and reliability without impacting the cost. Solar PV energy conversion systems have had a huge growth from an accumulative total power equal to approximately 1.2 GW in 1992 to 136 GW in 2013 [2]. The factors which are responsible for this tremendous growth are cost reduction, increase in efficiency of the PV modules, the search for alternative clean energy sources, increased environmental awareness and favorable political regulations from local governments. Grid-connected PV systems account for more than 99% of the PV installed capacity compared to stand-alone systems. Storage batteries are not required in grid connected photovoltaic system since all of the power generated by the PV plant is uploaded to the grid for direct transmission, distribution, and consumption. The generated PV power reduces the use of other energy sources feeding the grid, such as hydro or fossil fuels, whose savings act as energy storage in the system, providing the same function of power regulation and backup as a battery would deliver in a stand-alone system. The power-electronic technology plays an important role in integration of renewable energy sources into the electrical grid. During the last few years, power electronics has undergone a fast evolution, which is mainly due to two factors. The first one is the development of fast semiconductor switches that are capable of switching

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quickly and handling high powers. The second factor is the introduction of real-time computer controllers that can implement advanced and complex control algorithms.

A common feature of the renewable energy based or micro sources based Distributed Generation systems is the power electronics interfaces that required to convert the energy sources output to the grid ready voltages [3]. Due to increasing power demand throughout the world, Photovoltaic (PV) power supplied to the utility grid is gaining more and
more visibility [4]. Not many PV systems have so far been placed into the grid due to the relatively high cost, compared with more traditional energy sources such as oil, gas, coal, nuclear, hydro, and wind. Solid-state inverters have been shown to be the enabling technology for putting PV systems into the grid [5]. If the stability is maintained at same degree within the given thermal limits then the FACTS devices are capable of increasing the power transfer in a given transmission line [6]-[10]. The Shunt compensation of a transmission line will increase the real power handling capacity and reactive power can be controlled over a wide range [11]-[13].
Grid-connected PV systems are classified into two categories, one is distributed and the other is centralized. Grid-connected distributed PV systems are installed to provide power to a grid-connected customer or directly to the electric network. The advantages of these systems are low distribution losses in the electric network as the system is installed at the point of use, extra land is not required and costs for mounting the systems can be reduced if the system is mounted on an existing structure and the PV array itself can be used as a cladding or roofing material, as in building-integrated PV.

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*.

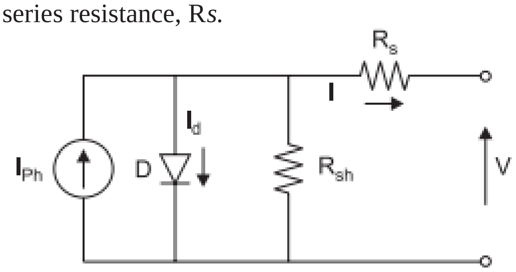

Fig. 1- Basic PV Cell Model

$$I_{ph} = [I_{sc} + K_1[T - 298]]\frac{G}{100} \quad \text{.....(1)}$$

$$I = I_{ph} - I_d - \frac{V + R_s I}{R_{sh}} \quad \text{........(2)}$$

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.

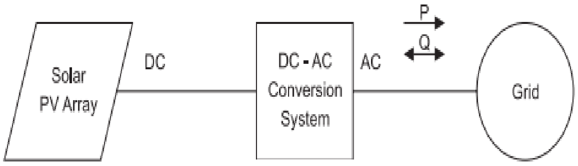

Fig. 2 - Photovoltaic System integrated to grid

3. Controllers

Design of PID Controller

It continuously uses for PID controller which calculates the error value with the difference between a desired or reference point and a measured or output process variable and includes a correction and it depends on proportional, integral, and derivative terms of the PID controller. The attempt of the controller is to reduce the error over the time by adjust settling time of a control variable in this model:

- P controller represents the error including the adjustments of the parameters of the controller. For example, if the error may be large and positive value, the control output will may also be large and positive.
- I controller considers for the stored values of the system error. For example, if the output current is not strong sufficiently, the error of the integral will accumulate over time, and the controller may respond for applying a stronger action.
- D accounts for possible future trends of the error, based on its current rate of change.

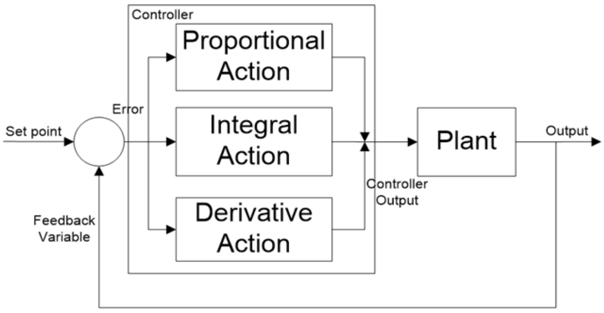

Fig. 3- Block Diagram of PID Controller

Design of FLC Controller

The fuzzy logic controller proposed integration for DG implies Mamdani and Sugeno fuzzy inference system. The sizing of the DG is estimated using fuzzy logic controller i.e. Mamdani type on the

primary basis of distribution feeder for better performance parameters such as substation reserve power capacity.

The process of Inference process for Mamdani type fuzzy logic controller has method of MIN-MAX aggregation and defuzzification process as standard settings of the SOM. The other setting for fuzzy logic controller is Sugeno type remains the same for defuzzification method Proposed for the Mamdani type inference. A set of 15 fuzzy rules, which involve all the rules of heuristic for calculating the size of DG in the fuzzification process. In the process of fuzzification, these inputs are converted into logic form in accordance with the membership functions associated. Triangle membership function is adopted for medium values whereas membership functions of trapezoidal are considered for the low and high of the above three variables.

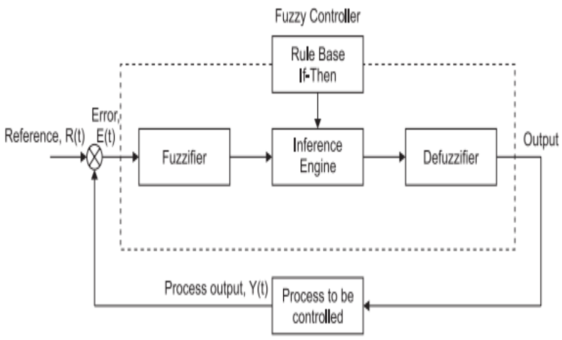

Fig. 4 - Block Diagram of Fuzzy Logic Controller

The error, E(*t*) and the rate of change of error, DE(*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*).

$$E(t) = R(t) - Y(t) \quad \ldots\ldots\ldots\ldots(3)$$
$$DE(t) = E(t) - E(t - 1)\ldots\ldots\ldots\ldots(4)$$

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. 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 nonlinear properties.

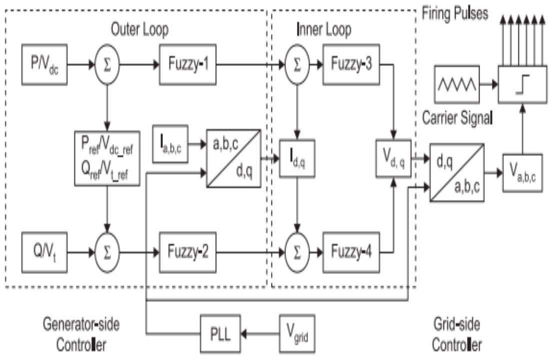

Fig. 5 - Sub Block Diagram of Cascaded FLC controller

The quantities P, Q, Vgrid & I*abc* are represented the measured or actual values. The transformation angle 'q', I*dq*, V*dq*, V*abc* represents calculated values. The Pref, Qref 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. 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.

4.Simulation Model And Results

MATLAB (short for MATrix LABoratory) is a special purpose computer program optimized to perform engineering and scientific calculations. It started life as a program designed to perform matrix mathematics, but over the years it has grown into a flexible computing system capable of solving essentially any technical problem. A MATLAB program provides a very extensive library of predefined functions to make technical programming tasks easier and more efficient. It is a huge program, with an incredibly rich variety of functions. It has an extensive library of built-in functions for data manipulation and the toolkits extend this capability with many more functions in various specialties. MATLAB comes complete with a library of pre-programmed and tested models, ranging from simple passive elements and control functions, to more complex models.

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.

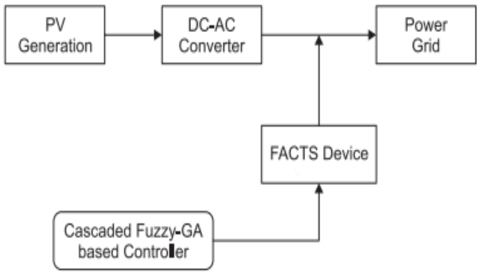

Fig. 6 - Block Diagram of FACTS controller with AI controllers

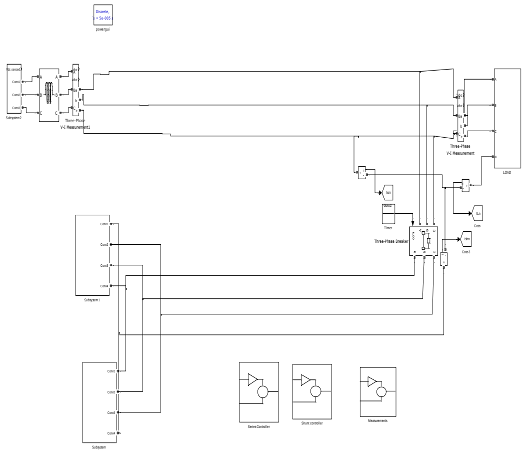

Fig. 7 - Simulation Model of STATCOM with PV Source

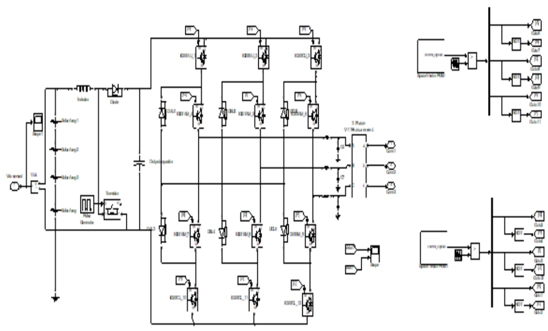

Fig. 8 - Subsystem of PV Source

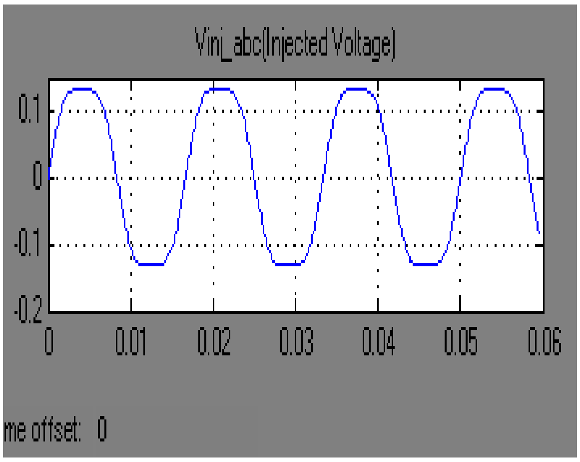

Fig. 9 - Injected Voltage versus Time (Secs)

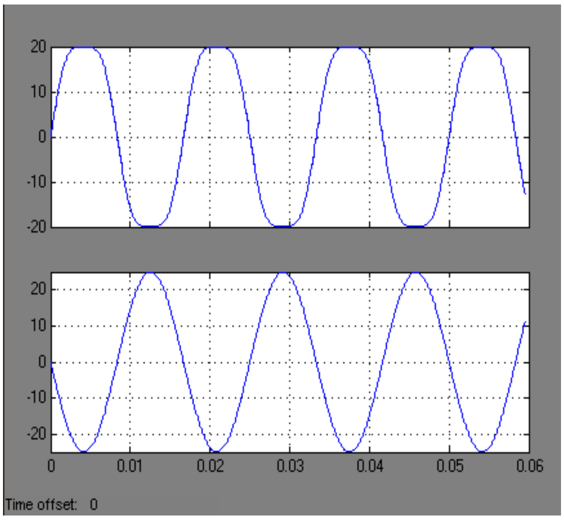

Fig. 10 - Current versus Time (Secs)

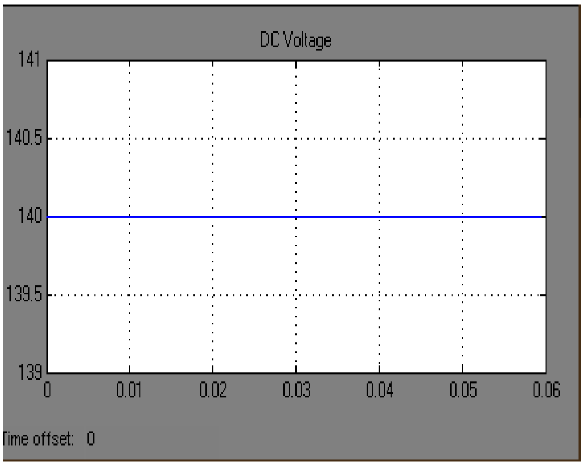

Fig. 11 - DC Voltage Versus Time (Secs)

From the above simulations, it's observed that STATCOM compensator has less overshoot in real, reactive powers and DC voltage, THD.

Table 1 - PI controller – Z-N Method, PSO and GA method

S.No	Category	Sub Category	Controller Technique	Sub controller	Active Power (MW) (Overshoot)	Reactive Power (MVar) (Overshoot)	Voltage Harmonics (THD) (Overshoot)	Voltage control (V) (Overshoot)
1	Identification of Specifications of Grid connected system with Source	PV source	STATCOM	No	18.23	20.1	0.4757	32
				PI (Z-N)	20.8	32.8	0.589	42
				PI (PSO)	11.2	21	0.253	13
				PI (GA)	17.1	20.1	0.35	26.1

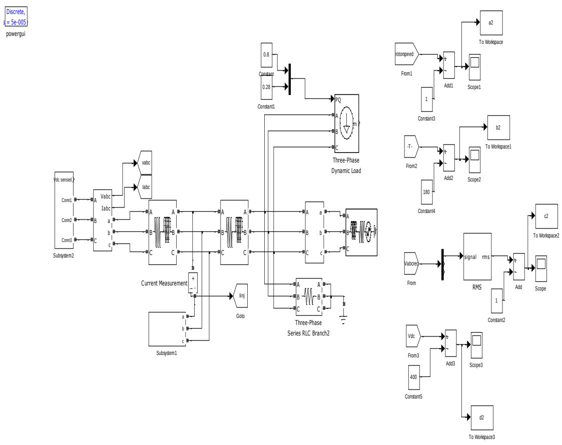

Fig. 12 - Simulation of STATCOM with Fuzzy Logic Controller

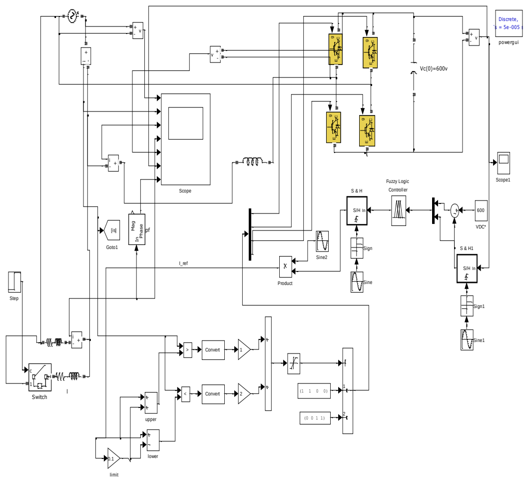

Fig. 13 - Simulation model with Fuzzy logic controller

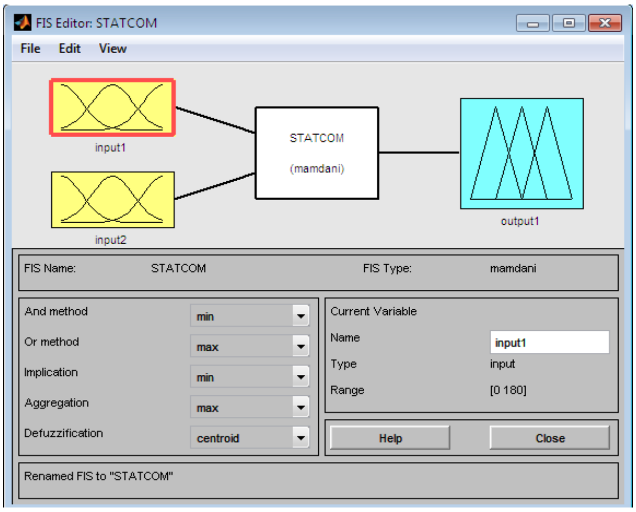

Fig. 14 - FIS editor

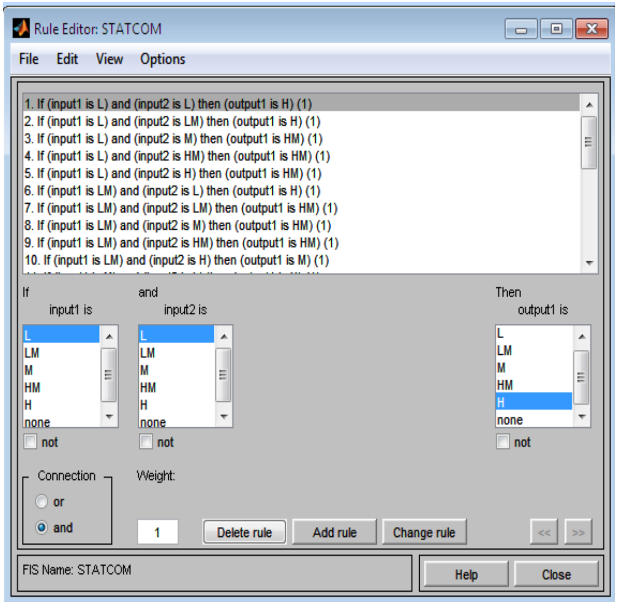

Fig-15 - FIS rule editor

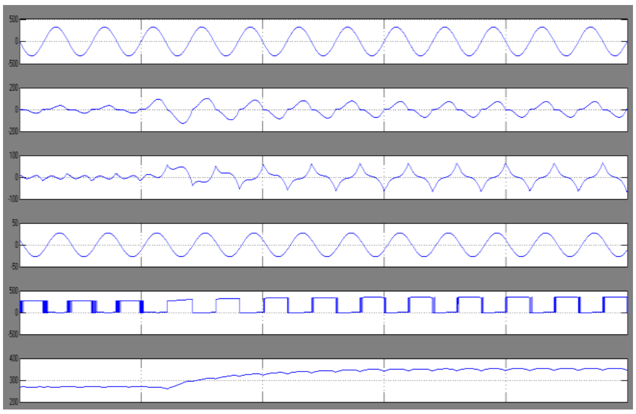

Fig. 16- Simulation results of three phase voltages, currents, DC voltages and currents versus time (secs)

Table 2 - Comparison of PI controller using PSO Method & Fuzzy logic controller

S.No	Category	Sub Category	Controller Technique	Sub controller	Active Power (MW) (Overshoot)	Reactive Power (MVar) (Overshoot)	Harmonics (THD) (Overshoot)	Voltage control (V) (Overshoot)
1	Identification of Specifications of Grid connected system with Source	PV source	STATCOM	PI (PSO)	11.2	21	0.253	13
				FLC	5.8	9.7	0.113	10.9

From the above simulations, it's observed that STATCOM compensator with FLC is better than PI-PSO for reducing Overshoots in real, reactive powers and voltage, THD.

5. Summary

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. 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 artificial intelligence techniques. STATCOM, a shunt connected FACTS device, was introduced in this paper to control the power flow in large scale integration of PV supply to the power grid. To achieve this objective effectively, the performance of the STATCOM was compared by using PI controller and Fuzzy logic controller whose output is tuned by using ZN, GA and PSO methods and their results are analyzed. It was found that the performance of the STATCOM was improved better by using Fuzzy logic controller.

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References

[1] Samir Kouro, Jose I. Leon, Dimitri Vinnikov,"Grid-ConnectedPhotovoltaic ystems: An Overview of Recent Research and Emerging PV Converter Technology", IEEE Industrial Electronics Magazine. 2015; 9(1), 47-61.

[2] Carrasco JM, Franquelo LG, Bialasiewicz JT, Galvan E, Portillo R et. al., Power-electronic systems for the grid integration of renewable energy sources: A survey. *IEEE Trans. Ind. Electronics*. 2006; 53(4): 1002-1016.

[3] Kazmierkowski M, Krishnan R, Blaabjerg F. Control in Power Electronics-Selected Problems. Academic Press, 2002.

[4] Blasko V, Kaura V. A novel control to actively damp resonance in input LC filter of a three-phase voltage source converter. *IEEE Trans. on Industry Applications*. 1997; 33(2):542-550.

[5] Surin Khomfoi, Nattapat Praisuwanna,"A hybrid cascaded multilevel inverter for interfacing with renewable energy resources", The 2010 International Power Electronics Conference-ECCE ASIA.2010.

[6] **M** H Haque "Optimal location of shunt FACTS devices in long transmission line" *IEEE Proceeding. Generation. Transmission & Distribution.* Vol. **147**, No.4, July 2000.

[7] Gyugyi, L.: 'Unified power-flow control concept for flexible AC transmission systems', IEE Proc.-C, 1992, 139, (4), pp. 323-331.

[8] Moore, P., Ashmole, P. 'Flexible AC transmission systems: Part 2 - Methods of transmission line compensation'. IEE Power Erg. J., 1996, 10, (6), pp. 273-278.

[9] Rahman, M., Ahmed, M., Gutman, K., Okeefe. KJ., Nelson, R.J., and Bian, J.: 'UPFC application on the AEP system: planning considerations', IEEE Trans., 1997, PWRS-12, (4), pp. 1695-1 701.

[10] Gyugyi, L., Schauder, C.D., William, S.L., Rietman, T.R., Torgeizson, D.R., and Edris, A.: 'The unified power flow controller: A new approach to power transmission control', IEEE Trans., 1995, PD-10, (2), pp. 1085-1093.

[11] Schauder, C, Gernhardt **M.** Staev E, Lemark, T. Gyugyl, L. Cease T **W** and Edris, **A** " Development of a +1 00MVAR static condenser **for** voltage control of transmission system" *IEEE Tran*. 1995, PD-IO **(3),**pp 1486-1496.

[12] Chandrakar, V.K. Kothari, A.G. “Optimal location for line compensation by shunt connected FACTS controller”, *The Fifth International IEEE Conference on Power Electronics and Drive Systems*”, Vol **1**, pp 151 -156, Nov 2003.
[13] Lin tan, Yowgi wang “Design of series and shunt FACTS controller using adaptive nonlinear coordinated design techniques”, IEEE Tran. on power system Vol. 12,No. 3, Aug. 1997.