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Comparison and analysis of fault ride through capability for grid integrated Photovoltaic system with Continuous mixed P-Norm, Fuzzy and Proportional-Resonant Controllers

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***Abstract*—This paper exhibits a Comparative study among the different controllers used for PV grid integration and its low voltage ride through (LVRT) capacity enhancement. PV system integration performed through DC-DC converter, DC-AC converter, DC link and DC link capacitor. The FRT capability of grid integrated PV system is analyzed using PI controllers, PR controllers and Fuzzy logic controllers. The test system FRT capability is tested in MATLB/ Simulink software environment. The FRT capability of fuzzy based controller is greater than among the three controllers used for inverter control during integration. The fuzzy logic controller is faster in response and it has an ability to maintain error closer to zero. Due to this it can enhances system stability by reducing maximum peak overshoot and time taken to stable and improves the system performance.**

IndexTerms—***Photovoltaic (PV) power systems, power system dynamic stability, power system control, adaptive control, PR and Fuzzy control, low voltage ride through (LVRT)***

I. INTRODUCTION

Global primary energy demand is growing steadily since the industrial revolution. In the last two decades (1991 to 2012), total primary energy demand has grown by 60% and further growth of 40% by 2040 is predicted. According to IEA's (International Energy Agency's), Global Photovoltaic Markets 2016 report, installed global PV capacity is 300GW with additional 75GW installed in 2016, supplying 2% of worldwide electricity demands. PV power systems are being considered among most promising sustainable energy systems with increasing installed capacity and reducing installation prices worldwide [1]. Factors affecting the increase in utilization of PV power systems for electricity generation are raising environmental concerns, need for clean and sustainable energy, increased fuel prices and reduced integration costs of PV systems. With high penetration of PV systems integration into electrical power grid, maintaining the stability of grid is a challenge for the utilities [2]. For uninterrupted power supply to grid, low voltage ride (LVRT) through is one of the major requirement to be met by the solar PV system.

In recent time, medium voltage grid codes have been developed for the PV systems to enable the integrated systems to supply and provide grid support during fault conditions [3]. To operating in terms of defined grid code, the PV system must satisfy low voltage ride through (LVRT) capability requirements and fast connectivity of PV system to grid after fault conditions.

Several techniques have been developed to review, analyze and enhance the LVRT capability of the PV system. For single phase grid connected systems [4], LVRT capability is proposed through a control method, which controls both active and reactive powers in the integrated PV system.

In this study, same control technique is incorporated for PV systems integrated without transformer to electric grid [5]. Also, impact of dynamic performance of PV power systems on short term voltage stability was discussed [6]. For controlling the inverter on grid side, cascaded proportional integral (PI) control scheme is proposed. Further, PI controller can be utilized for LVRT capability enhancement in integrated PV systems [7] – [9]. However, through the literature survey it is observed that, design of PI controller is carried out by experience of designer using a trial and error method.

Usage of PI controller is limited due to low sensitivity to variable parameters in dynamic systems such as PV systems despite its robustness and various industrial applications. In this light, new techniques of fuzzy control and PR control were proposed for optimization [10] – [13]. The optimization techniques proposed are complex computational procedures and are effectively enabled to deal with the nonlinear systems. The complexity of these techniques is the motivation for further research in this area, developing a continuous mixed norm (CMPN) algorithm based PI controller for LVRT capability enhancement. The CMPN algorithm is one of the latest adaptive filtering algorithms. Adaptive filtering algorithms have been used to solve several engineering problems in different applications such as signal processing, electronics engineering, audio, speech, and language applications [14]–[16]. In this technique, algorithm complexity and solution convergence are both considered for development of algorithm.

In this paper, comparisons are made for adaptive PI controller, fuzzy controller and PR controller. The control techniques are adopted for enhancing the LVRT capability of integrated PV systems (represented by the power plant model). For maximum power point tracking, DC-DC boost converter is utilised with open circuit voltage technique. At point of common coupling, grid side inverter is used to control DC link voltage.

For analysing the effectiveness of the proposed control strategy and integrated PV system, the PV model designed in MATLAB SIMULINK is subjected to symmetrical and unsymmetrical faults and the observed results are recorded in this paper.

The paper is organized as follows: Section II describes the system model to be integrated to electric grid and the Power Electronic controllers are described. In Section III, different control techniques are studied. Section IV presents the simulation results when the system is subjected to different types of faults. Finally, Section V draws the conclusion.

II. SYSTEM MODELING

A. System Model

In this section, the system consists of PV arrays connected to the grid through double circuit transmission lines and three-phase step up transformer. The Power Electronic Circuits such as the DC-DC Boost Converter and Grid side inverter are used to integrate the PV system with the electrical grid. The grid under consideration is the IEEE 39-bus New England Test System which consists of 10 generator buses(generator 2 at Bus 31 is considered to be a slack bus) with 19 load buses. For better understanding, the PV module is portrayed as a diode-resistance combination as shown in figure 1. The basic I-V characteristics [19-21].

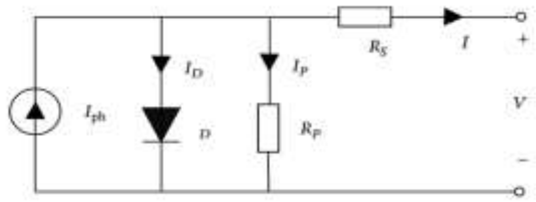


Figure 1: Basic PV Module

$$I = I_{PV} - I_0\left[exp\left(\frac{V+IR_S}{\alpha V_t}\right) - 1\right] - \frac{V+IR_S}{R_p} \qquad (1)$$

where I_{PV} is the current obtained from the photovoltaic module which is based on solar irradiation and temperature, I_0 is the reverse saturation current of the diode, R_p and R_S are the parallel and series resistances, α is the ideality factor of the diode, and $V_t$is the thermal voltage of the PV module.

The photovoltaic current can be mathematically expresses as:

$$I_{PV} = \left(I_{PV,n} + K_I \Delta T\right)\frac{G}{G_n} \qquad (2)$$

where $I_{PV,n}$ is the nominal current value of the PV module, K_I is the short circuit current per temperature coefficient, ΔT is the residue of the actual and nominal temperatures with G and G_n as the actual and nominal values of the solar irradiation on the surface of the module[19]. $I_{PV,n}$ and I_0 can be expressed mathematically[22] as follows:

$$I_{PV,n} = \frac{R_p+R_S}{R_p} I_{SC,n} \qquad (3)$$

$$I_0 = \frac{I_{SC,n}+K_1\Delta T}{exp\left(\frac{V_{oc,n}+K_1\Delta T}{aV_t}\right)-1} \qquad (4)$$

Where $I_{SC,n}$ is the short circuit nominal current and $V_{oc,n}$ is the open circuit nominal voltage with K_V being the coefficient of open circuit voltage per temperature.

The characteristics of a 2.5 MW Photo voltaic power plant are depicted in figure 2

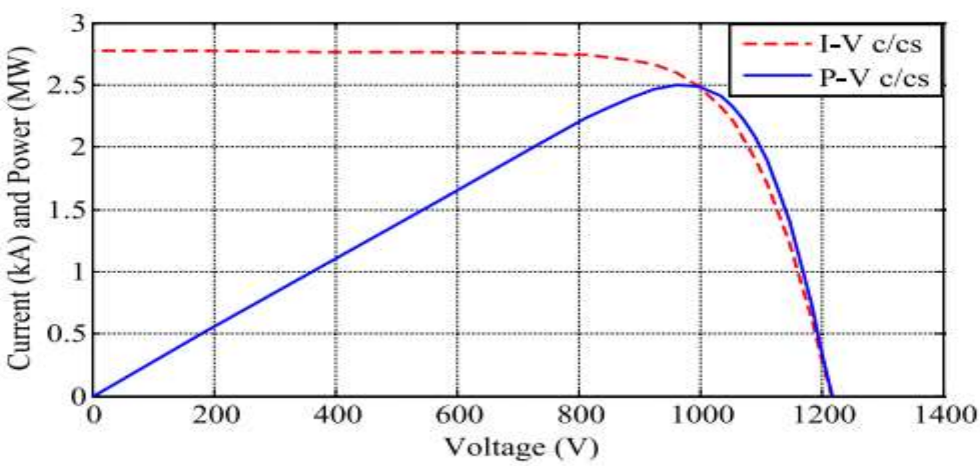


Figure 2: Characteristics of 2.5MW Power Plant

B. Modeling of Power Electronic circuits

DC-DC Boost Converter:

A DC-DC boost converter is incorporated to limit the output voltage of the power plant in order to satisfy the maximum output power condition by controlling the duty cycle of IGBT switch.

$$D_{ref} = 1 - \frac{N_M K_M V_{oc-pilot}}{V_0} \quad (5)$$

Where K_M is a constant gain $V_{OC\text{-}pilot}$ is the open circuit voltage of the pilot module and V_0 being the output voltage of the converter

Grid side inverter

In order to control the DC link voltage and the terminal voltage at the point of common coupling (PCC), a two level three phase six IGBT switches inverter is utilized. A phase locked loop (PLL) is used to detect the transformation angle from the three phase voltages at the point of common coupling with the DC link voltage being maintained constant at 1.2 KV.

III.CONTROL TECHNIQUES

A. Continuous Mixed P-Norm Technique

Continuous Mixed P-Norm algorithm is one of the robust mixed norm algorithm in the family of adaptive filtering algorithms. The CMPN algorithm based adaptive PI controllers are developed to limit the voltages at the dc link and that at the PCC through a vector control scheme. Mixed P-Norm algorithm has the combined benefits of p-norm and least mean square(LMS) algorithm. The CMPN algorithm can be mathematically defined as follows[18]:

$$J(k) = \int_1^2 \lambda_k(p) E\{|e(k)|^p\} dp \quad (6)$$

where $\lambda_k(p)$ is a probability density weighting function with the following constraint imposed on it.

$$\int_1^2 \lambda_k(p) dp = 1 \quad (7)$$

The weight vector of the algorithm is updated according to the formula given below:

$$w(k+1) = w(k) - \mu \nabla_{w(k)} J(k) \quad (8)$$

where μ is the step size and $\nabla_{w(k)} J(k)$ is the instantaneous gradient of J(k) with respect to $w(k)$.

B. Fuzzy Logic Controller

Fuzzy Logic is about the relative importance of precision and is very convenient way to map an input to an output. But, fuzzy logic is not a cure-all. The fuzzy logic controller is incorporated in a DC-DC converter.

The first step towards designing a fuzzy logic controller is by building a fuzzy inference system. Fuzzy inference is a method that interprets the values in the input vector and, based on the user defined rules, assigns values to the output vector. Therefore, the rules must be set accurately with the help of Fuzzy Logic Toolbox. The primary tools of the Fuzzy Logic Toolbox can be seen in figure 3.

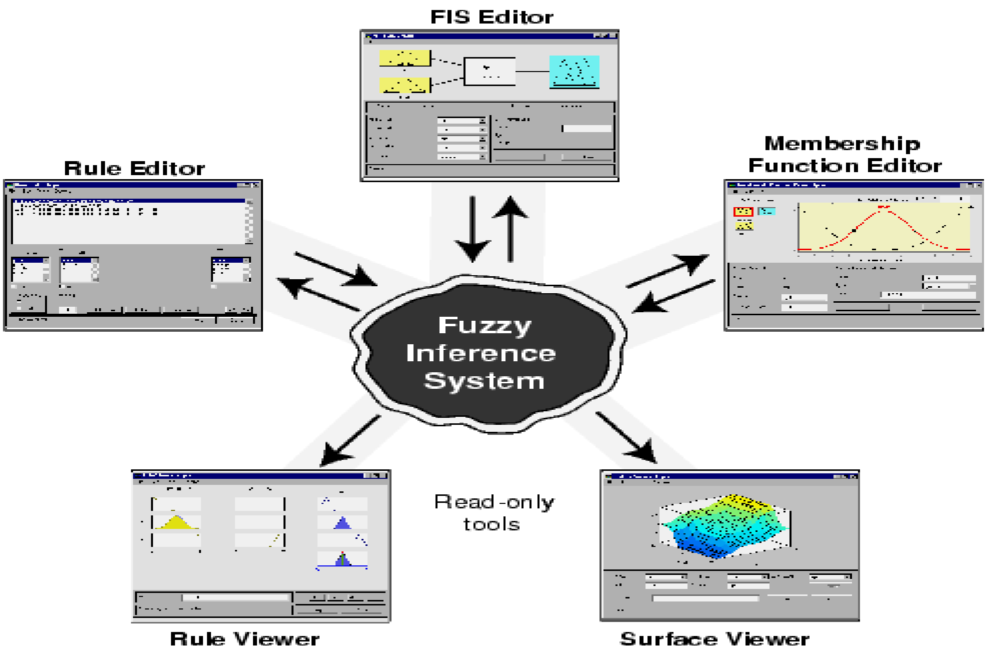


Figure 3: Fuzzy Inference System

The FIS editor handles the high-level issues like the number and the names of the input and output variables. The membership function editor defines the shapes of all membership functions associated with each variable. The rule editor edits the list of rules that define the behavior of the system. The rule viewer and the surface viewer are strictly read only tools which can be used as a diagnostic.

The proposed rule base for the controller is shown in figure 4.

E_c	E						
	NB	NM	NS	ZO	PS	PM	PB
NB	PB	PB	PM	PM	PS	ZO	ZO
NM	PB	PB	PM	PS	PS	ZO	NS
NS	PM	PM	PM	PS	ZO	NS	NS
ZO	PM	PM	PS	ZO	NS	NM	NM
PS	PS	PS	ZO	NS	NS	NM	NM
PM	PS	ZO	NS	NM	NM	NM	NB
PB	ZO	ZO	NM	NM	NM	NB	NB

Figure 4: Fuzzy Rule Base

C. Proportional Resonant Controller

In proportional controller the output is proportional to the error signal. The proportional resonant controller is one of the most popular controllers used to regulate the injected current into the grid. The PR controller can overcome few drawbacks of the proportional integral controller. A PR controller is a combination of a proportional term and a resonant term which can be expressed mathematically as

$$C_{PR}(s)= K_p + K_i \frac{s}{s^2+\omega^2} \quad (9)$$

where $\boldsymbol{\omega}$ is the resonant frequency. In order to improve the performance by handling harmonics a harmonic compensator is incorporated. this harmonic compensator can be expressed as:

$$C_{RC}(s) = \sum_{K=3,5,7\ldots} K_{ih} \frac{s}{s^2+(\omega h)^2} \quad (10)$$

Where h is the order of the harmonic.

A proportional resonant controller is adopted in stationary reference frame for inverter controller. However, it can be easily implemented in the frame as well.

IV. SYSTEM ANALYSIS UNDER FAULT

A. Unsymmetrical Faults

The designed system is subjected to line-to-ground (LG), double line-to-ground (LL) and double line-to-ground (LLG) faults and the results obtained are analyzed for each control strategy. The fault conditions are defined to occur at any instant when t = 0.05 sec with a duration of 0.1 sec. The point of fault in the system is shown in figure 5 and is represented by point F.

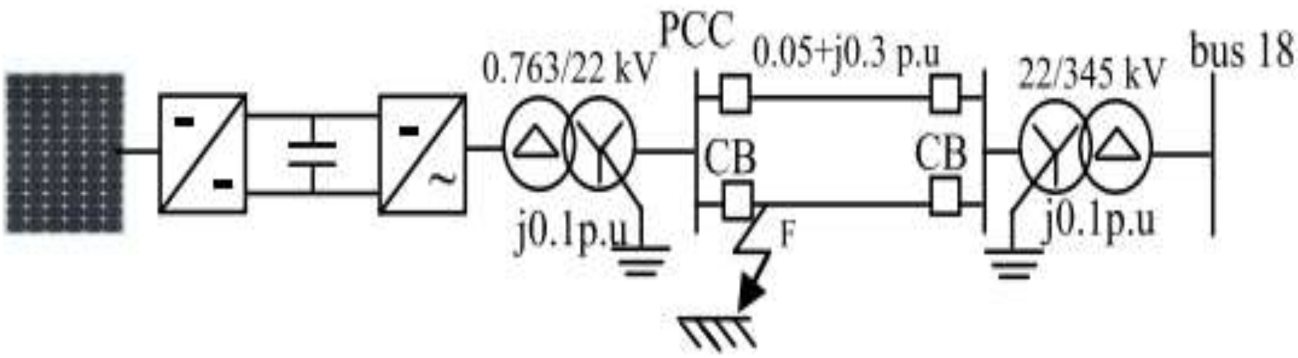


Figure 5: Connection of PV to Grid

System subjected to fault is simulated in MATLAB/ SIMULINK and the results obtained are illustrated in the graph given below.

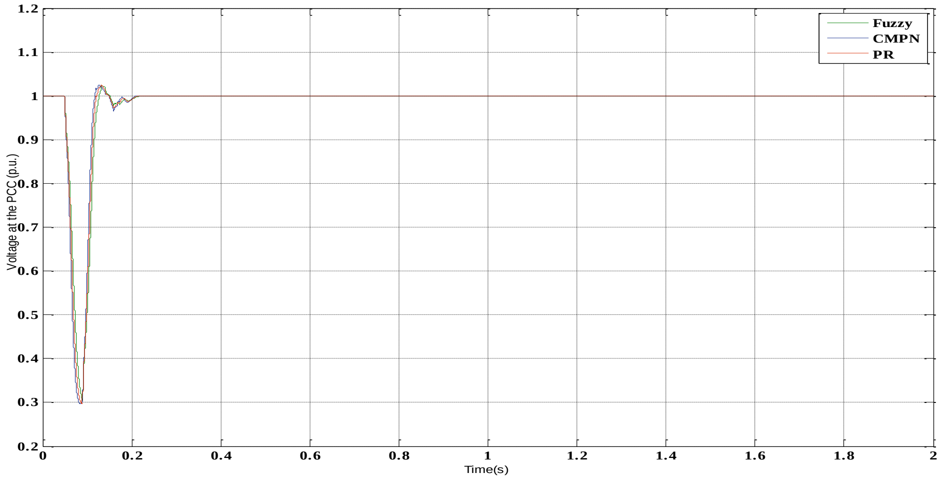


Figure 6: Single Line to Ground Fault

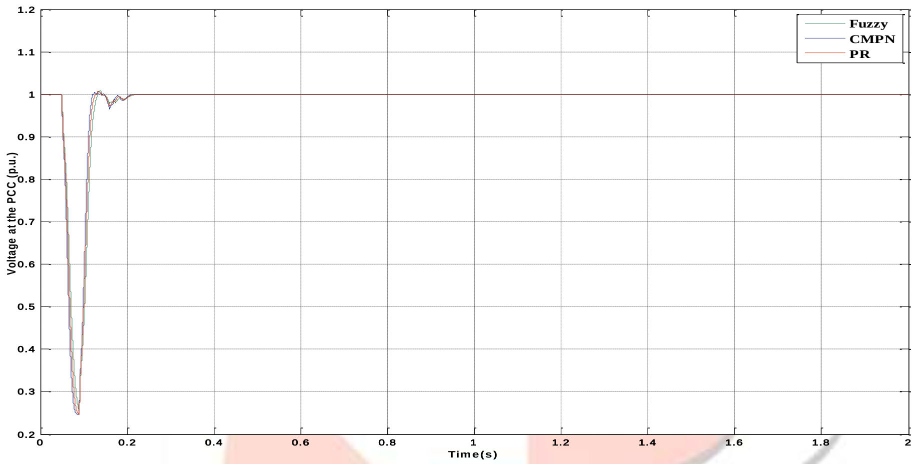


Figure 7: Line to line fault

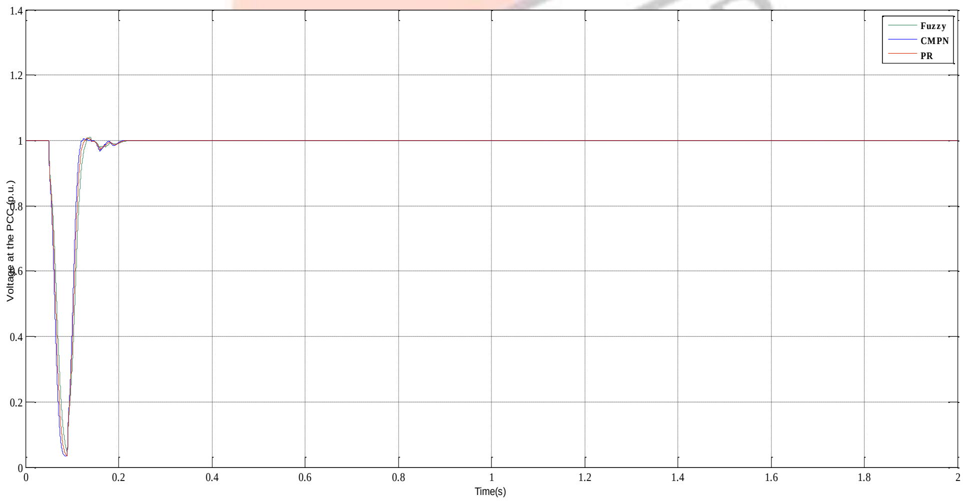
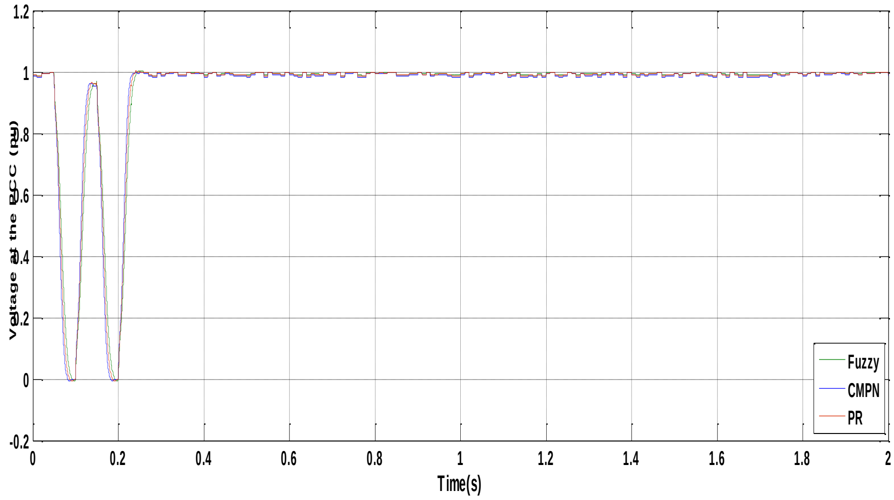


Figure 8: Line to Line to Ground Fault

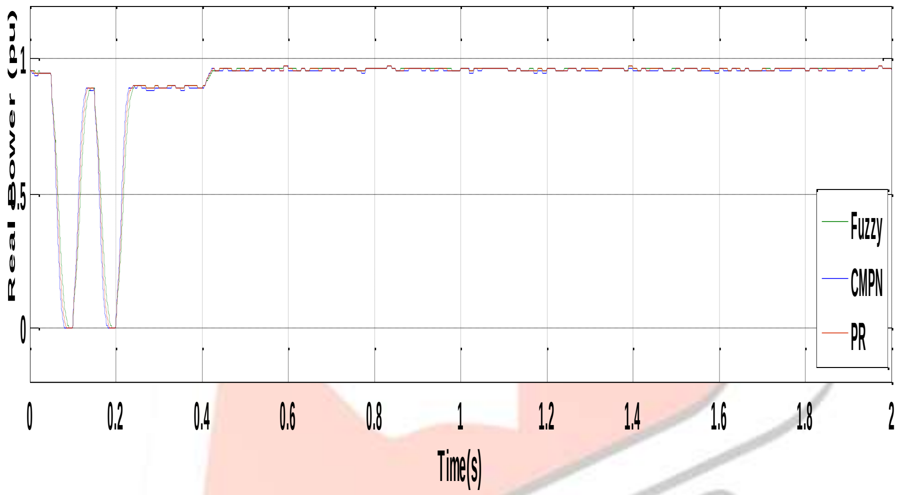
The voltage at the point of common coupling is observed in each case.

B. Symmetrical Faults

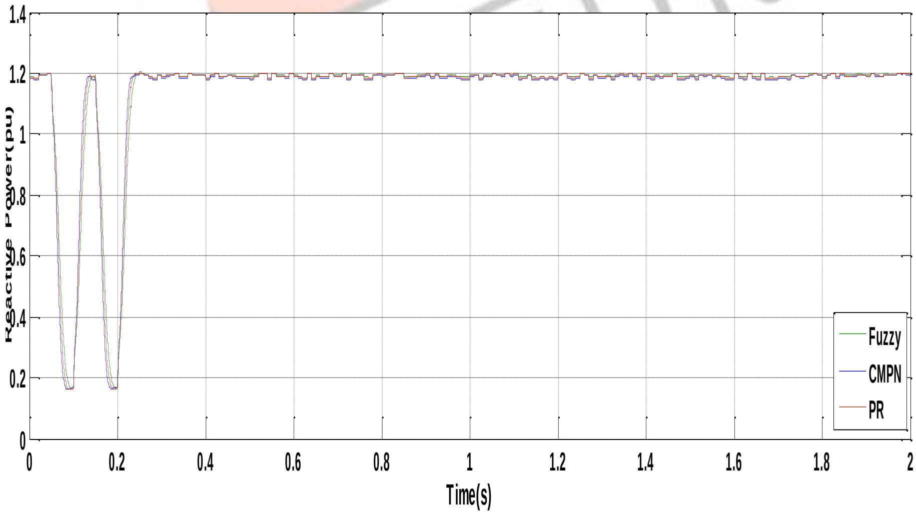
The symmetrical faults imposed on the system are three phase temporary fault and three phase permanent fault. Since the duration of the fault is for a considerable time, i.e., the fault occurs at the instant t=0.05 and the duration is assumed to be 0.69 sec.



(a)

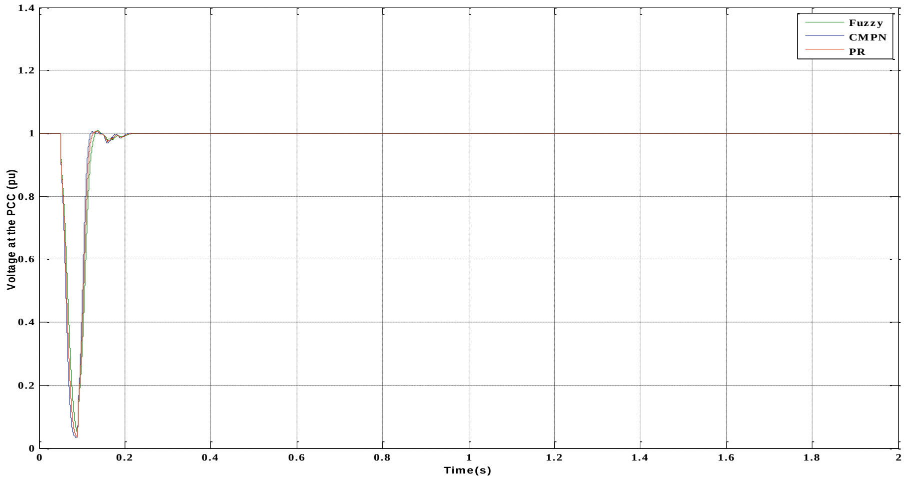


(b)

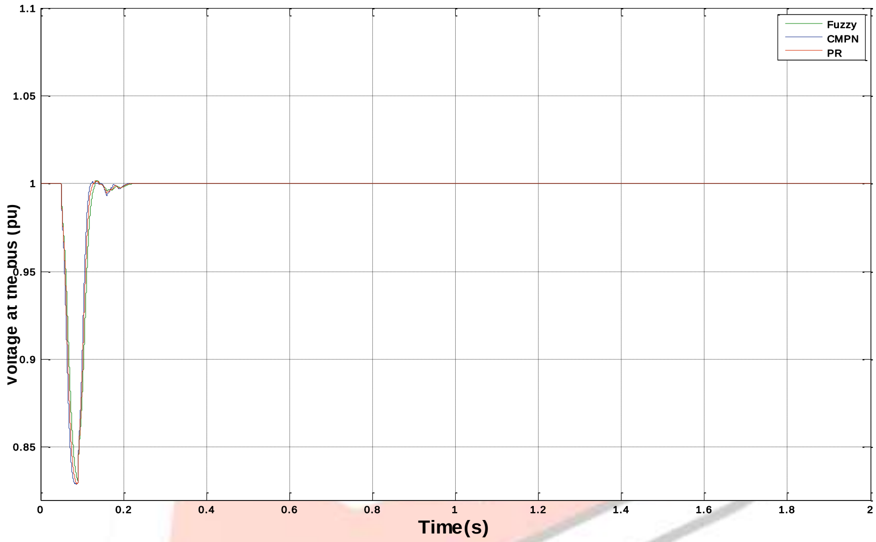


(c)

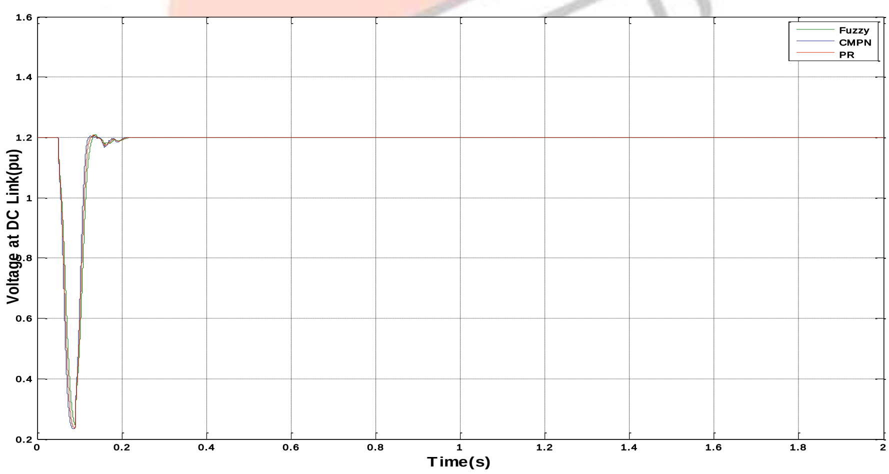
Figure 9: Three phase permanent fault (a) Voltage at the PCC; (b) Real Power and; (c)Reactive Power


Fuzzy
CMPN
PR
Voltage at the PCC (pu)
Time(s)

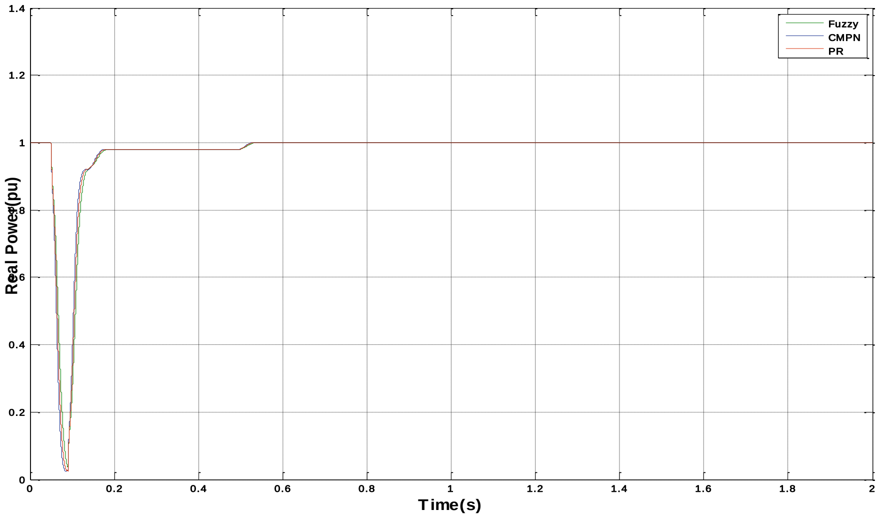
(a)


Fuzzy
CMPN
PR
Time(s)

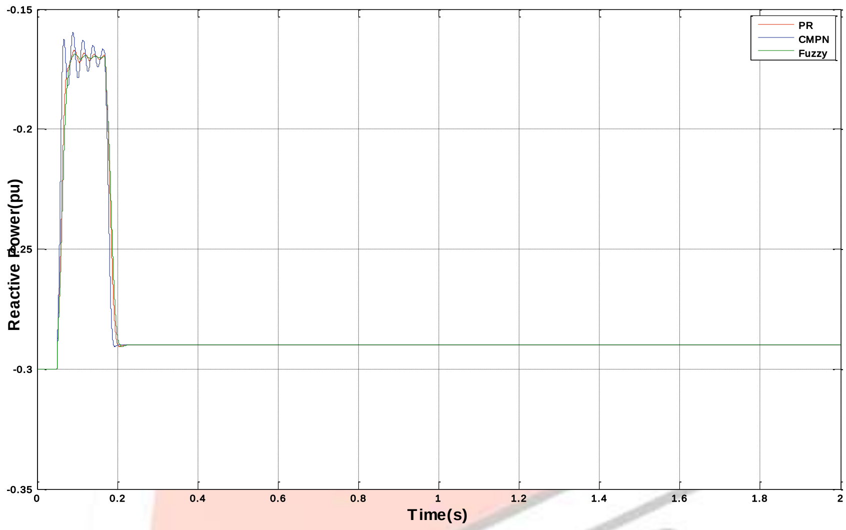
(b)


Fuzzy
CMPN
PR
Voltage at DC Link(pu)
Time(s)

(c)



(d)



(e)

Figure 10: Three phase temporary fault (a) Voltage at the PCC; (b) Voltage at the grid; (c)Voltage at the dc link capacitor; (d) Real Power; (e) Reactive Power.

CONCLUSION

This paper includes the integration of PV system with grid and analysis of its low voltage rid through capability during fault condition. Here the comparative study is performed among the different controllers used for error compensation used for integration. The FRT capability of grid integrated PV system is analyzed using PI controllers, PR controllers and Fuzzy logic controllers. By comparing the simulation results with three controllers conclude that fuzzy logic controller can have high FRT capacity than other two controllers. The Fuzzy logic controller can also enhance stability of the system more than other two.

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