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Fuzzy Logic Controller for Low Voltage Ride through Capability Improvement of Grid Connected Photovoltaic Power Plants

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ABSTRACT: This work describes novel utilization of Fuzzy controller with the motivation behind upgrading the low voltage ride through (LVRT) capacity of grid connected photovoltaic (PV) control plants. The PV plants are connected with the point of common coupling (PCC) through a DC-DC boost converter, a DC-link capacitor, a grid side inverter and a three-phase transformer. The DC-DC converter is utilized for a most extreme power point tracking operation in view of the operation based on the fractional open circuit voltage method. The grid side inverter is used to control the DC-interface voltage and terminal voltage at the PCC through a vector control plot. The Fuzzy controller is utilized to control the power electronic circuits because of its quick response. For practical reactions, the PV control plant is connected with the IEEE 39-transport New England test system. The adequacy of the proposed control procedure is contrasted and that acquired utilizing - adaptive PI andFuzzy controller considering subjecting the system to symmetrical, unsymmetrical faults. The validity of adaptive control system and Fuzzy control system is widely checked by the simulation results.

KEYWORDS: Adaptive control, low voltage ride through (LVRT), photovoltaic (PV) power systems, power system control.

I.INTRODUCTION

Photovoltaic (PV) system will be a standout amongst the most promising renewable energy systems in the near future. The expenses of the installed PV systems are consistently diminishing worldwide as a result of falling part average offering costs [1]. A few variables influence the high penetration of the PV systems into power networks, such as natural concerns, clean energy, increment in fuel cost, political issues, and PV system cost diminishment. Also, establishments of the MW PV power plants take just a couple of months. Extensive scale PV power plants were connected with the electric grid in the most recent couple of years. On account of this large integration with the electric grid, numerous issues emerge and need to settle like low voltage ride through (LVRT) capacity improvement of such systems.

With the high level of penetration of the PV power plants in the electric grids, keeping up the grid stability and reliability represents a greater challenge to the network operators [2]. As of late, the utilities have released medium voltage grid codes to the PV systems that force on these systems to add to also, have a part in the grid support during grid faults [3]. To satisfy these grid codes, the PV system needs to fulfill the LVRT capability prerequisite and stays in the grid-connected mode quickly after an unsettling influence happens.

A few techniques have been utilized to examine, dissect, and make strides the LVRT ability of the PV systems[6], the effect of dynamic performance of the PV systems on short term voltage stability was presented. A cascaded proportional-integral (PI) control scheme was proposed to control the grid-side inverter. In addition, many reviews have used the PI controller for LVRT change of grid-connected PV systems [7]–[9]. Be that as it may, in all these past announced reviews, the design of the PI controller depends on the experimentation technique which relies on upon the designer experience. As of late, extraordinary improvement strategies were executed to tackle this issue [10]. This represents a principle motivation of the creator to apply the continuous Fuzzy logic controller to upgrade the

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LVRT ability of grid- connected PV control plants. The Fuzzy logic controller is one of the most up to date intelligent algorithm which is used in this work.

Adaptive filtering algorithms have been utilized to solve a few engineering issues in various applications, for example, signal processing, electronics engineering, audio, speech, and language applications. As of late, these calculations were investigated in electric power systems, since affine projection calculation was used to adjust the PI controller parameters in a wind energy conversion system.

In these algorithms, a compromise should be taken into complexity and the convergence speed. Numerous comparisons have been made among the proposed Fuzzycontroller and adaptive PI controller.In this paper, a novel utilization of the Fuzzycontrollerisarray for upgrading the LVRT capacity of grid-connected PV power plants. The DC-DC boost converter is utilized for a most extreme power point tracking operation based on the partial open circuit voltage strategy. The grid-side inverter is used to control the DC-link voltage and terminal voltage at the point of common coupling (PCC) through a vector control scheme. The Fuzzy controller is utilized to control the power electronic circuits due to its fast convergence. The PV power plant is connected with the IEEE 39-bus New England test system.the effectiveness of the proposed control strategy is compared with the obtained adaptive PI controller taking in to account subjecting the system to symmetrical and unsymmetrical faults.

II.PV POWER PLANT MODEL

In this review, the PV module is spoken to by a single diode PV model, which is quickstraightforward, and a precise model. The proportional circuit of this model is demonstrated in Fig. 1. The single diode PV model incorporates a present source, diode, and parallel and series resistances. The fundamental normal I-Vcharacteristics PV module is composed as takes after:

$$I = I_{pv} - I_o \left[exp\left(\frac{V+R_S I}{aV_t}\right) - 1\right] - \frac{V+R_S I}{R_p} \qquad (1)$$

whereI_{PV} is the photovoltaic current,I_o is the diode reverse saturation current, is the diode ideality factor, $R_s$is the series resistance,R_p is the parallel resistance, $V_t = N_s kT/q$and is the module thermal voltage.$N_s$is the quantity of series connected PV cells in the module, k is the Boltzmann constant$(1.3806503 \times 10^{-23} J/K)$

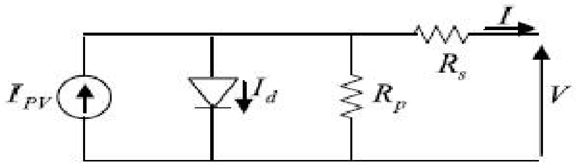

Fig. 1. Equivalent circuit of the single diode pv model.

T is the PV module temperature in Kelvin, q and is the electron charge$(1.60217646 \times 10^{-19})$ C. I_{PV}depends on the solar irradiation and temperature. It is communicated by the following condition:

$$I_{PV} = (I_{PVn} + K_I \Delta T)\frac{G}{G_n} \qquad (2)$$

WhereI_{PVn} is the photovoltaic current under the nominal condition (temperature of 25 and illumination of 1000), $K_I$is the short circuit current per temperature coefficient,ΔT is the contrast between the actual and nominal temperatures, G is the actual solar irradiation on the module surface, and G_n is the actual solar irradiation under the nominal condition.what's more,$I_{PV,n,}$and $I_o$can be mathematically modeled as takes after:

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

$$I_o = \frac{I_{sc,n}+K_I\Delta T}{exp\left(\frac{V_{oc,n}+K_V\Delta T}{aV_t}\right)-1} \qquad (4)$$

Where,$I_{sc,n}, V_{oc,n}$is the short circuit current and open circuit voltage under the nominal condition, respectively.$K_V$is the open circuit voltage per temperature coefficient.

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The extensive PV power plant comprises of a few PV modules that are connected in series- parallel to create the desired output power. The numerical model of this PV plant can be composed as follows [9]:

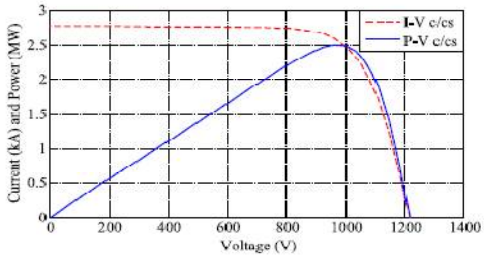


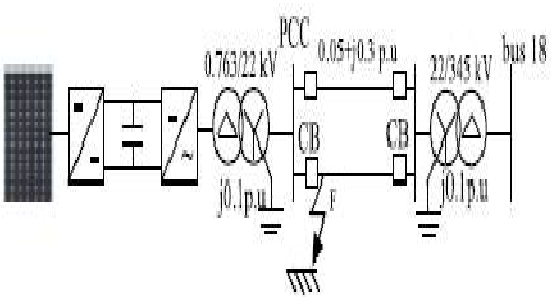
Fig. 2.I-V and P-V characteristics of a 2.5-MW PV power plant.

$$I = N_p I_{PV} - N_p I_0 \left[\exp\left(\frac{V + R_S\left(\frac{N_m}{N_p}\right) I}{N_m a V_t} \right) - 1 \right] - \frac{V + R_S\left(\frac{N_m}{N_p}\right) I}{R_p\left(\frac{N_m}{N_p}\right)} \quad (5)$$

Where$N_m$is the number of series connected modules in a string furthermore, $N_p$is the number of parallel connected strings. The I-V and P-V , characteristics of a 2.5-MW PV powerplant aredemonstrated in Fig. 2.

III.SYSTEM MODELING

The PV array are connected with bus 18 of the test system through a DC-DC boost converter, a DC-link capacitor of 15 mF, a grid side inverter, three-phase venture up transformers, what's more, double circuit transmission lines, as appeared in Fig. 3(a). Fig. 3(b) illustrates a single line diagram of the IEEE 39-bus New England test system under study. This system is considered a compact version of the first New England System what's more, it is utilized for reasonable reactions think about. The IEEE 39-bus system incorporates 39 bus out of which 19 are load buses . There are 10 generators in the system. Bus 31 at which generator 2 isconnected, is characterized as the slack bus. The load model is thought to be steady current and constant admittance load. Keeping in mind the end goal to test the PV power plant with the IEEE 39-bus system, the PV power plant is connected with bus 18. All information of the IEEE 39-bus system is accessible [11].



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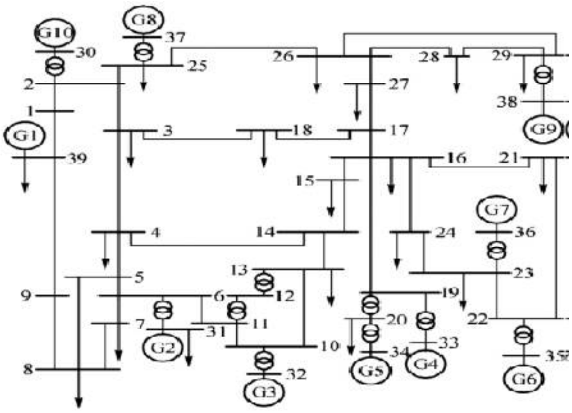

(b)

Fig. 3.Grid-connected PV power plant. (a) Connection of PV power plant. (b) Single line diagram of the IEEE 39-bus New England test system.

IV. CONTROL STRATEGY OF POWER ELECTRONIC CIRCUITS

A. DC-DC Boost Converter

A DC-DC boost converter is utilized to control the output voltage of the PV plant so as to fulfill the maximum output power condition. This is finished by controlling the duty cycle of insulated gate bipolar transistor (IGBT) switch of the converter, as showed in Fig. 4. The fragmentary open circuit voltage technique is connected to satisfy the maximum power condition, where $V_{mp}$is direct proportional to$V_{oc.}$ The duty cycle reference signal can be determined by the accompanying condition;

$$D_{ref} = 1 - \frac{N_M K_M V_{OC-pilot}}{V_0} \qquad (6)$$

Where$K_m$is a steady gain, Voc_{-pilot} is open circuit voltage of pilot module, is the converter output voltage, and is theactual output voltage of the PV plant.AFuzzy is utilized for this reason. The controller outputsignal is compared and a triangular carrier waveform flag of 4-kHz frequency to create the firing pulses of IGBT switch.

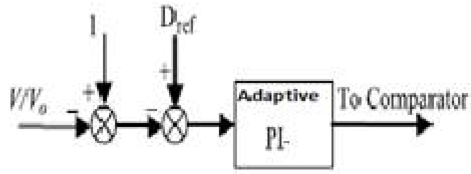

Fig. 4.Control of the DC-DC converter.

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B. Grid-Side Inverter

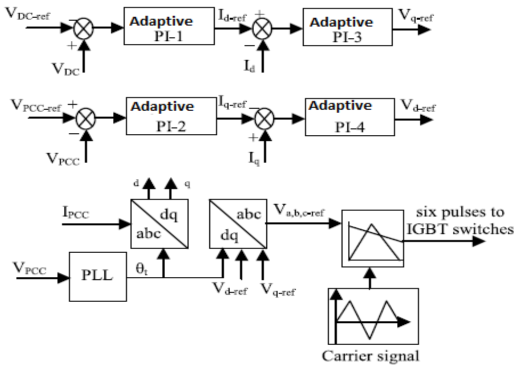

Fig. 5. Control block diagram of the grid-side inverter

A two-level, three-phase, six IGBT switches inverter is proposed in this study. The grid-side inverter is used to control the DC-link voltage $V_{dc}$and terminal voltage at the PCCV_{pcc} through a vector control plot, as showed in Fig. 5. The Adaptive PI controllers are developed for this reason. A phase locked loop (PLL) is devoted to recognize the transformation angle θ_t from the three-phase voltages at the PCC. The output signals of the control plot (V_{q-ref}andV_{d-ref}) are converted to three-phase sinusoidal reference signals, which are contrasted and a triangular carrier signal of 1-kHz frequency to deliver the firing pulses of IGBT switches. TheV_{dc} is maintained constant at 1.2 kV through the simulation utilizingthis pulse width modulation inverter

V.FUZZY LOGIC CONTROLLER

Fuzzy method of reasoning is a sort of various regarded justification in which reality estimations of variables may be any honest to goodness number some place around 0 and 1. By separation, in Boolean method of reasoning, reality estimations of variables may simply be 0 or 1. Fuzzy method of reasoning has been extended to handle the possibility of midway truth, where reality quality may stretch out between absolutely certifiable and absolutely false. Furthermore, when etymological variables are used, these degrees may be administered by specific limits.
Regularly Fuzzy method of reasoning control structure is produced using four huge segments displayed on Figure fuzzification interface, Fuzzy affectation engine, cushy standard system and Defuzzification interface. Each part close by principal Fuzzy method of reasoning operations will be delineated in more detail beneath.
The Fuzzy method of reasoning examination and control methodologies showed up in Figure 1 can be delineated as:
1. Receiving one or far reaching number of estimations or other evaluation of conditions existing in some system that will be analyzed or controlled.
2. Processing all got inputs as showed by human based, Fuzzy "expecting then" models, which can be imparted in essential lingo words, and combined with ordinary non- Fuzzy planning.
3. Averaging and weighting the results from all the individual standards into one single output decision or sign which picks what to do or exhorts a controlled system what to do. The result output sign is a precise defuzzified regard. Above all else, the distinctive level of output (rapid, low speed and so forth.) of the phase is characterized by determining the participation capacities for the Fuzzy sets.

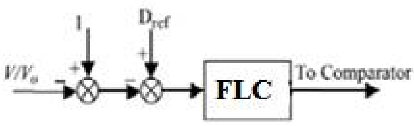

Fig.6.control of DC-DC converter using FUZZY controller.

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i.FUZZIFIER

The first step towards designing a Fuzzy Logic Controller is choosing appropriate inputs whichwill be fed to the same. These input variables should be such that, they represent the dynamical system completely. Then the function of the Fuzzifier comes into picture instead of using numerical variables, Fuzzy logic uses linguistic variables for processing information. But since the inputs to the FLC are in the form of numerical variables they need to be converted into linguistic variables. This function of converting these crisp sets into Fuzzy sets is performed by the Fuzzifier. The fuzzification technique involves outlining the membership functions for the inputs. These membership functions should cover the whole universe of discourse and each one represents a Fuzzy set or a linguistic variable. The crisp inputs are thus transformed into Fuzzy sets.

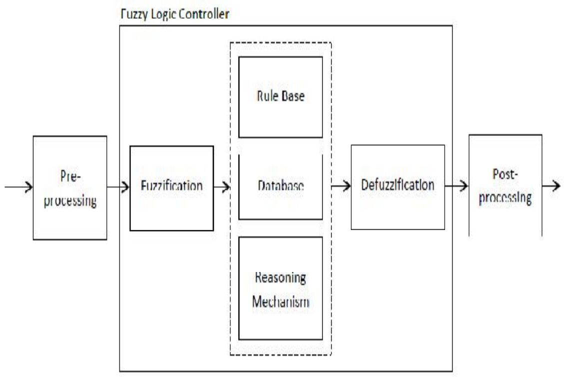

Fig.7.Fuzzy Logic Controller Structure

ii.DEFUZZIFIER

A defuzzifier performs the exact opposite function of a fuzzifier. It transforms the Fuzzy variables (which are obtained as output after processing of the inputs) to crisp sets. The defuzzifier is necessary because in the real world the crisp values can only be taken as inputs to the other systems.Adefuzzifier is generally required only when the MamdaniFuzzy Model is used for designing a controller.

a.Centroid of Area (COA):

It is one of the most popular techniques used for defuzzification, as it is reminiscent of the calculation of expected values of probability distributions. It can be defined as follows:

$$z_{COA} = \frac{\int_z \mu_A(z)\, z\; dz}{\int_z \mu_A(z)\; dz}$$

Where$\mu_A(z)$ is the total output MF.
Fuzzy membership functions:

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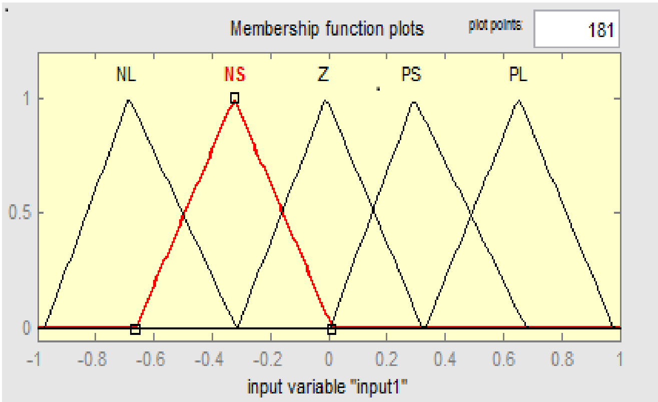

Fig.8.input variable function of V_{PV}

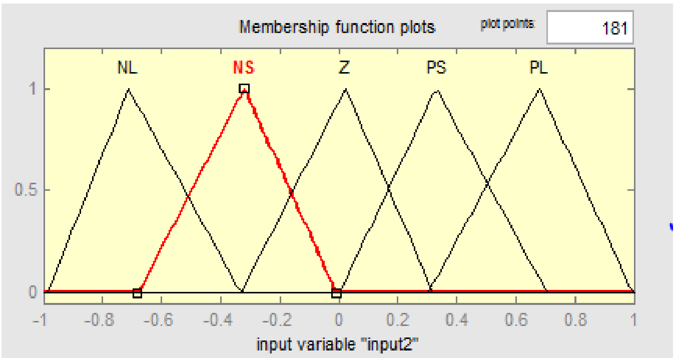

Fig.9.input variable function of rate of change of V_{PV}

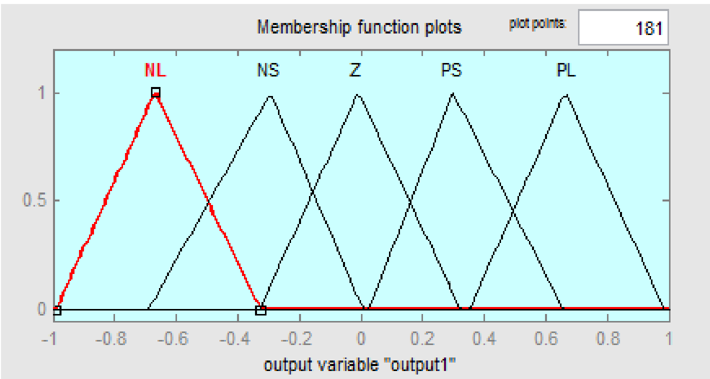

Fig.10.output variable function of triggering pulse

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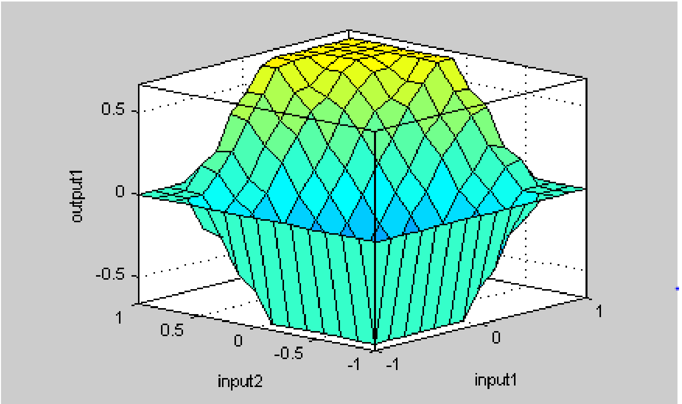

Fig.11.view of control surface in 3-D

IP \ OP	NS	NL	PL	Z	PS
NS	NL	NL	PS	NS	Z
NL	NL	NL	Z	NL	NS
Z	NS	NL	PL	Z	PS
PL	PS	Z	PL	PL	PL
PS	Z	NS	PL	PS	PL

Rule base

VI.SIMULATION RESULTS AND DISCUSSION

The point by point model of a grid-connected PV power plant is displayed. The model includes a total switching model of the power electronic circuits with the proposed adaptive control strategy for getting reasonable responses. The simulation time is chosen as 5 or 10 s, in light of the sort of study scenario, the time step is 10, and channel plot step is 200 µs for acquiring exact outcomes. The electrical characteristics of the PV modules.
Under the STC condition are executed. The medium voltage grid codes were released to the grid connected PV systems with emphasis on a contribution of these systems to the grid support during grid faults.
The effectiveness of the proposed Fuzzy controller is compared with the adaptive PI controller and considering subjecting the system to symmetrical, unsymmetrical faults, and unsuccessful reclosing of circuit breakers because of the presence of permanentfault as follows:

A. Successful Reclosure of Circuit Breakers (CBs)

In this situation, a three-line to ground (3LG) temporary fault happens at time t=0.1 s with term of 0.1 s to fault point F, outlined in Fig. 3(a). The CBs on the faulted lines are opened at t=0.2s to clear fault. At that point, the CBs are reclosed again at t=1s. Successful reclosure of the CBs implies reclosure under no fault condition.

TheVpcc drops immediately from the rated value (1 p.u) because of the effect of network disturbance and the grid side inverter conveys a good amount of reactive power that helps the Vpccto return back to the rated value, as showed in Fig. 12(a). It is worth to note here that Vpccthe reaction utilizing the Fuzzystrategy is preferable damped over that of utilizing PI controller-based an optimal PI control scheme, where it has lower maximum percentage undershoot, lower maximum percentage overshoot, lower settling time, and lower steady state error. Fig. 12(b) points out the real power out of the PCC. It can be understood that the proposed controlled DC-DC converter controls productively the maximum output power of the PV plant at 1 p.u. The reactive power out of the PCC, theVdc, what's

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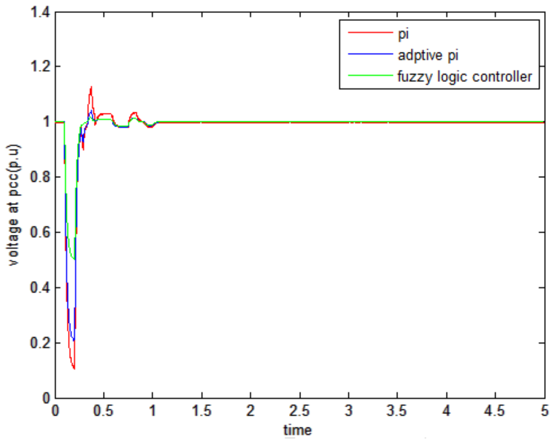
more, voltage at bus 18 are appeared in Fig. 12(c)–(e), respectively. It can be noticed that the reactions utilizing the proposed adaptive control strategy are quick with minimum fluctuations..

Also, the adaptive control strategy is broadly confirmed by subject the system to various sorts of unsymmetrical faults, such as double-line to ground (2LG), line-to-line (LL), and single-line to ground (1LG) faults. Fig. 13(a)–(c) appears the Vpccresponse under these types of faults.

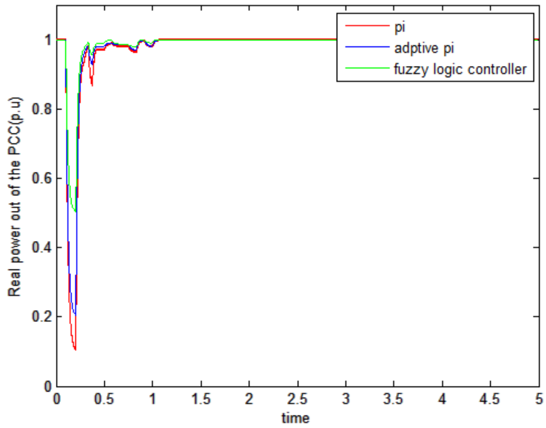
B. Unsuccessful Reclosure of CBs

This scenario proposes a 3LG permanent fault happening at point F in Fig. 3(a). The fault occurs at t=0.1 s and its duration is assumed to be 6.9 s. The CBs on the faulted lines are opened at t=0.2 s and reclosed again at t=1 s . Unfortunately,the CBs are closed on a permanent fault condition at this instant furthermore, this implies unsuccessful reclosureof CBs. Along these lines, the CBs are opened again at t=1.1 s and closed at t=7.1 s , which implies after the fault duration.

VII.SIMULATION RESULTS



(a)



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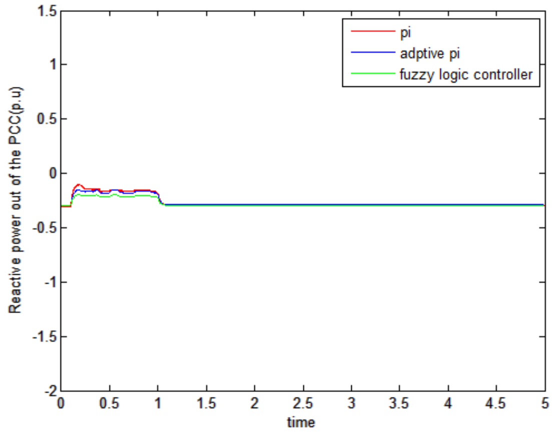
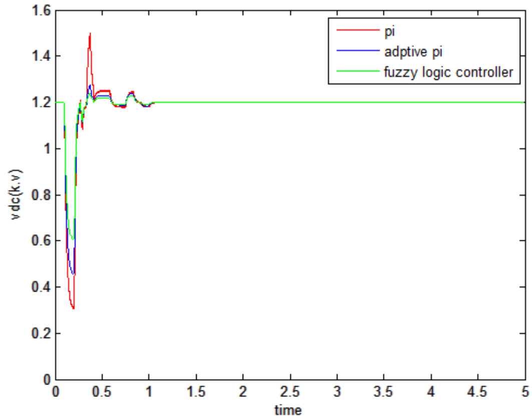
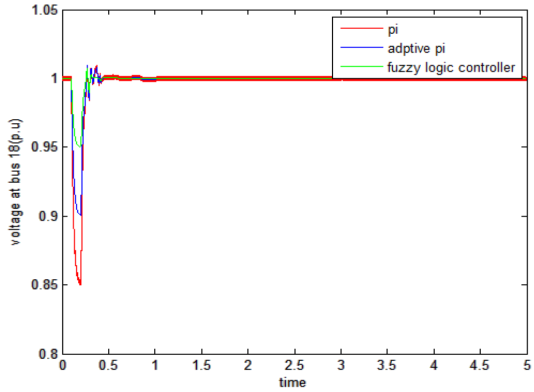


(c)



(d)



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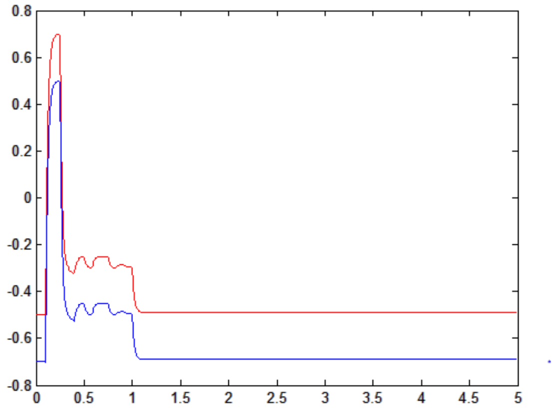
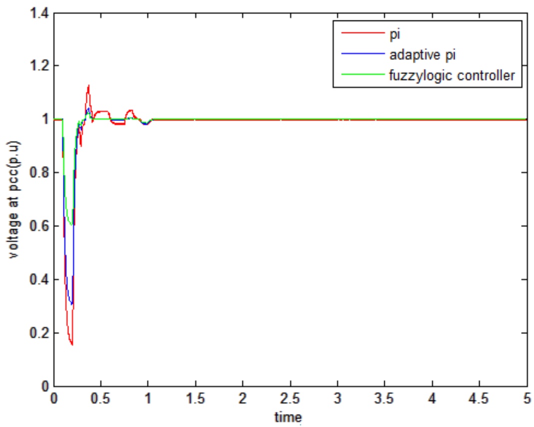
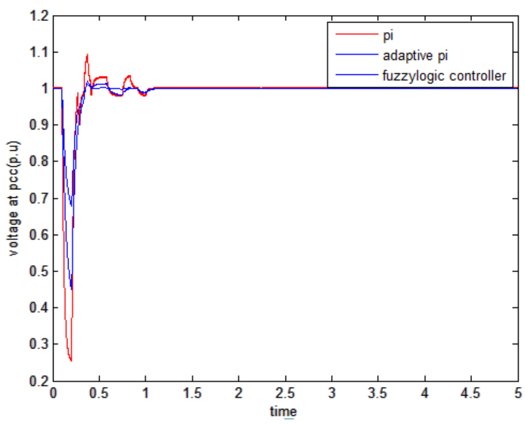


(f)

Fig. 12.Responses for 3LG temporary fault. (a) . (b) Real power out ofthe PCC. (c) Reactive power out of the PCC. (d) . (e) Voltage at bus 18. (f)Inverter currents with the proposed controller.



(a)



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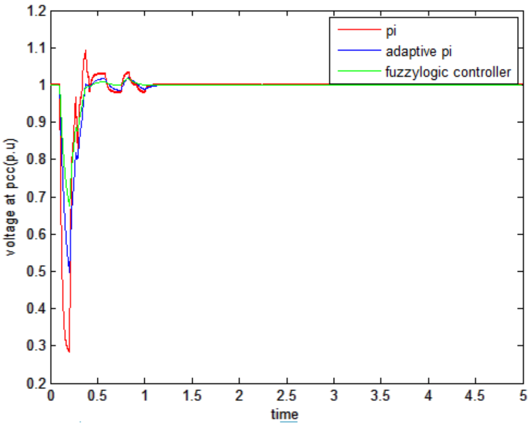
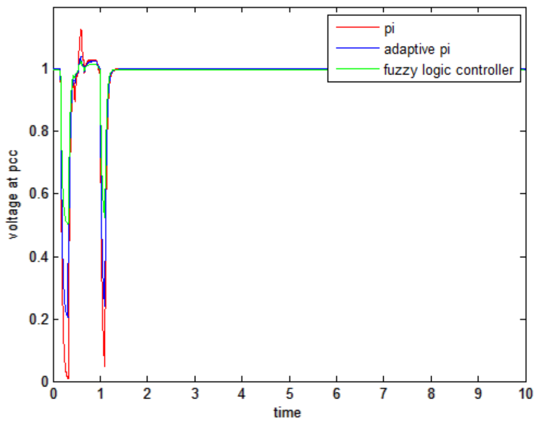
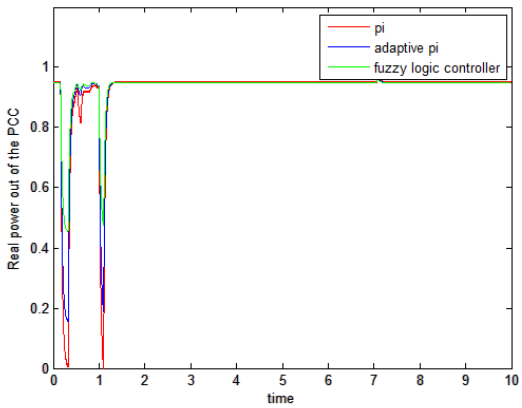


(c)

Fig. 13.Vpcc response for unsymmetrical faults. (a) 2LG fault. (b) LL fault. (c) 1LG fault.



(a)



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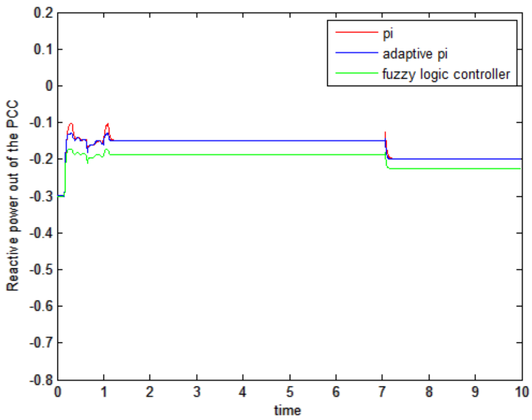
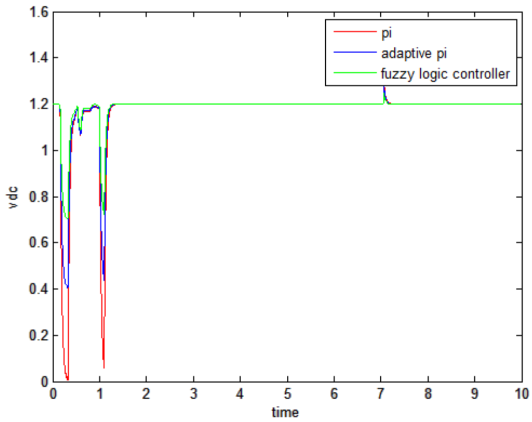


(c)



(d)

Fig. 14.Responses for 3LG permanent fault.(a)Vpcc. (b) Real power out of the PCC. (c) reactive power out of the PCC. (d)Vdc

VIII.CONCLUSION

This paper has presented a novel application of the Fuzzycontroller for improving the LVRT ability of grid-connected PV power plants. The proposed control strategy was applied to the DC-DC boost converter for a maximum power point tracking operation and furthermore to the grid-side inverter for controlling the Vpcc and Vdc..The PV power plant was connected to the IEEE 39-bus New England test system. The simulation results have demonstrated that the system responses utilizing the Fuzzy control methodology are quicker, better damped, compared with adaptive PI controlscheme during the accompanying cases:

1) Subject the system to a symmetrical 3LG temporary fault;
2) Subject the system to various unsymmetrical faults;
3) Subject the system to a symmetrical 3LG permanent faultfurthermore, unsuccessful reclosure of CBs.

It can be claimed from the simulation results that the LVRT capabilityof grid- connected PV power plants can be further enhancedutilizing the proposed Fuzzycontrol strategy whatever under grid temporary or permanent fault condition. By along this way, the PV power plants can contribute to the grid stability and reliability, which represents a greater challenge to the network operation.

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