Application of Fuzzy Logic Controller for Grid Connected Photo Voltaic Power Plants to Overcome LVRT Problem

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Abstract—This paper presents an novel application of continuous mixed p-norm (CMPN) algorithm-based adaptive control strategy with the purpose of enhancing the low voltage ride through (LVRT) capability of grid-connected photovoltaic (PV) power plants. The PV arrays are connected to the point of common coupling (PCC) through a DC-DC boost converter, a DC-link capacitor, a grid-side inverter, and a three-phase step up transformer The DC-DC converter is used for a maximum power point tracking operation. The grid- side inverter is used to control the DC-link voltage and terminal voltage. The CMPN algorithm-based adaptive proportional-integral (PI) controller is used to control the power electronic circuits due to its very fast convergence. The proposed algorithm updates the PI controller gains online without the need to fine tune or optimize. The PV power plant is connected to the IEEE 39-bus New England test system. The proposed strategy is effective when the system is subjected to symmetrical, unsymmetrical faults, and unsuccessful reclosing of circuit breakers due to the existence of permanent fault. The performance of adaptive control strategy is verified by the simulation results, which are carried out using MAT LAB software. With the proposed adaptive-controlled PV power plants, the LVRT capability of such system can be improved.

Index Terms: Adaptive control, low voltage ride through (LVRT), photovoltaic (PV) power systems, power system control, power system dynamic stability.

I. Introduction

PHOTOVOLTAIC (PV) system will be one of the most promising renewable energy systems. The costs of the installed PV systems are continuously decreasing worldwide because of falling component average selling prices[1].Several factors affect the high penetration of the PV systems into electricity networks, some as clean energy environmental concerns , increase in fuel price, political issues, and PV system cost reduction. In addition, installations of the MW PV power plants take only a few months. Large scale PV power plants were connected and need to solve like low voltage ride through (LVRT) capability enhancement of such systems. The high level of penetration of the PV power plants in the electric grids, maintaining the grid stability and reliability represents a greater challenge to the network operators. The PV system needs to satisfy the LVRT capability requirement and remains in the grid-connected mode immediately after a disturbance takes place. Several methods have been used to study, analyze, and improve the LVRT capability of the PV systems. The LVRT capability of single phase grid-connected PV systems was presented using an control method, which depends on controlling the real and reactive powers out of the PV system. The same control technique can be applied to transformer less PV systems [5]. In [6], the impact of dynamic performance of the PV system on short term voltage stability was introduced.

A cascaded proportional integral (PI) control scheme is proposed to control the grid-side inverter. Many studies have utilized the PI controller for LVRT improvement of grid-connected PV systems [7]–[9].The design of the PI controller is based on the trial and error method which depends on the designer experience. Despite robustness of the PI controller and its usage in different industrial applications, it suffers from the sensitivity to parameters variation and nonlinearity of dynamic system different optimization techniques were implemented to solve this problem [10]–[13].These optimization methods are very effective to deal with such nonlinear systems, they require complex computational procedures, long times and significant efforts. This represents a principal to apply the continuous mixed p-norm(CMPN) algorithm-based adaptive PI controller to enhance the LVRT capability of grid-connected PV power plants.The CMPN algorithm is one of the modern adaptive filtering algorithms.

In this paper, an application of the CMPN algorithm-based adaptive control strategy is presented for enhancing the LVRT capability of grid- connected PV power plants. The DC-DC boost converter is used for a maximum power point tracking operation based on the fractional open circuit voltage method. The grid-side inverter is utilized to control the DC-link voltage and terminal voltage at the point of common coupling (PCC) through a vector control scheme.

The CMPN algorithm-based adaptive PI controller is used to control the power electronic circuits due to its very fast convergence. The PV power plant is connected to the IEEE 39-bus New England test system. The system is subjected to symmetrical, unsymmetrical faults, and unsuccessful reclosing of circuit breakers due to the existence of permanent fault. The validity of the adaptive control strategy is extensively verified by the simulation results, which are carried out using MAT LAB software. The PV module is represented by a current source, diode and resistance.

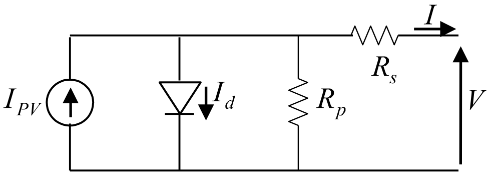


Fig.1.Equivalent circuit of the single diode model

II.SYSTEM MODELLING

The PV arrays are connected to bus 18 of the test system through DC-DC boost converter,DC-link capacitor of 15 mF, a grid-side inverter, three-phase step up,double circuit transmission lineFig.3(b)illustrates asingle line diagram of the IEEE 39-bus New England test system under study. This system is considered a compact version of the original New England System and it is used for realistic responses study. The IEEE 39- bus system includes 39 buses out of which 19 are load buses. There are 10 generators in the system. Bus 31 as generator 2 is connected, is defined as the slack bus. The load model is considered tobe constant current and constant admittance load [24]. In order to test the PV power plant with the IEEE 39-bus system, the PV power plant is connected to bus 18. All data of the IEEE 39-bus system is available in [24].

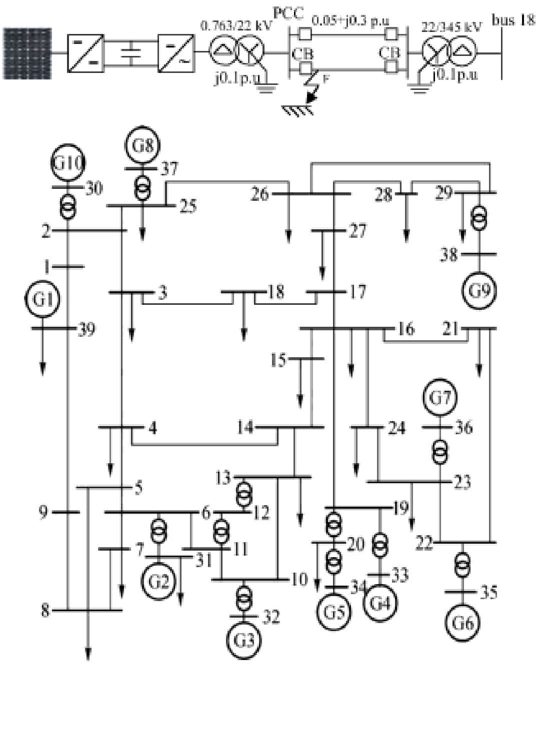


Fig. 2. Grid-connected PV power plant.(a) Connection of PV power plant. (b)Single line diagram of the IEEE 39-bus New England test

III. CONTROL STRATEGY OF POWER ELECTRONIC CIRCUITS

A.DC-DC BOOST CONVERTER

A DC-DC boost converter is used to control the output voltage of the PV plant in order to satisfy the maximum output power condition. This is done by controlling the duty cycle of insulated gate bipolar transistor (IGBT) switch of the converter, as indicated inFig.3. The fractional open circuit voltage method is applied to fulfill the maximum power condition.

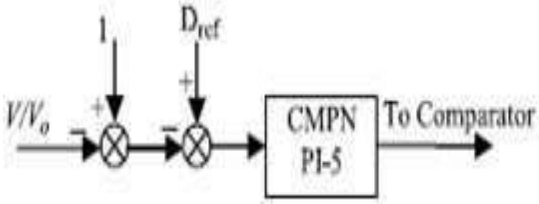


Fig.3.control of DC-DC Boost Converter

B. Grid-Side Inverter

A two-level, three-phase, six IGBT switches inverter is used here. The grid-side inverter is used to control the DC-link voltage and terminal voltage at the PCC through a vector control scheme, as illustrated in Fig.5.

The CMPN algorithm-based adaptive PI controllers are developed for this purpose. A phase locked loop (PLL) is used to find the transformation angle from the three phase voltages at the PCC. The output signals of the control scheme are converted to the three phase sinusoidal references which are compared with a triangular carrier signal to produce the firing pulses of IGBT switches.

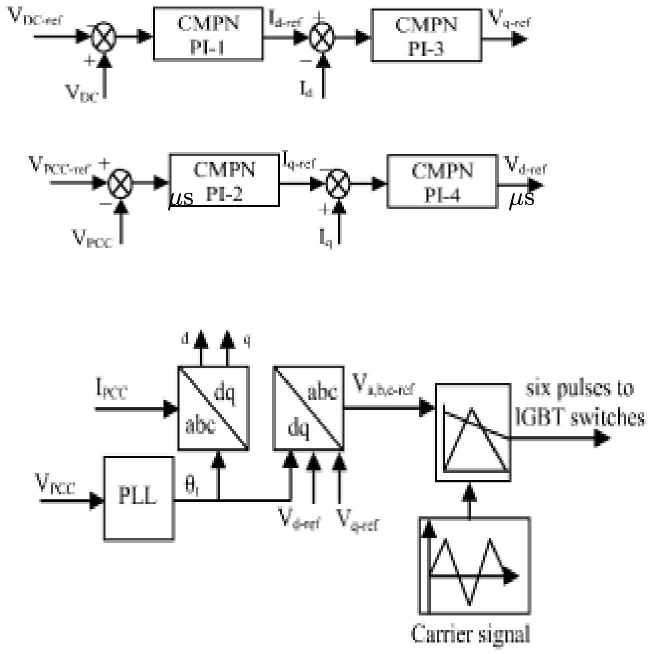


Fig.4.Control block diagram of the grid-side inverter.

IV. CMPN ADAPTIVE FILTERING ALGORITHM

One family of the adaptive filtering algorithms is the mixed-norm adaptive filters that have various forms. In [26], the least mean mixed-norm (LMMN) adaptive filter was presented, where it combined least mean square(LMS)and the least mean fourth (LMF) algorithms. In this study all the adaptive PI controllers of the control strategies are based on the CMPN algorithm, to adapt the proportion gain the integral gain of the PI controllers.

To guarantee the system stability, the initial values of the controllers' parameters are selected by using the black-box optimization technique[32]which is a powerful simulation-based optimization implemented on MATLAB environment. Table I illustrates the initial values of the PI controllers' parameters. Then, the propose adaptive algorithm can online update the controllers' parameters when a disturbance takes place.

TABLE- I

INITIAL VALUES OF PI CONTROLLERS PARAMETERS

Controller	k_p	k_i
PI-1	10	20
PI-2	10	20
PI-3	0.01	5
PI-4	0.01	5
PI-5	4.5	15

V.SIMULATION RESULTS

The detailed model of a grid-connected PV power plant is presented. Model involves switching model of the power electronics with the proposed adaptive control strategy for obtaining realistic responses. The simulation time is selected as 2s, based on the type of study scenario, the time step is 10 and channel plot step is 200 for obtaining accurate results.

The electrical characteristics of the PV modules under the STC environment implemented The PV system needs to satisfy the LVRT capability requirement and remains the grid-connected mode immediately after disturbance takes place. The LVRT characteristics are different from place to placewith small changes in voltage drop magnitude, fault time, voltage recovery time and final voltage magnitude.

The effectiveness of the proposed adaptive control strategy is checked with the system subjected to symmetrical, unsymmetrical faults, and unsuccesful reclosing of circuit breakers due to the existence of permanent fault as follows

A.Succesful Reclosure of Circuit Breakers

In this scenario, a three-line to ground (3LG) temporary fault takes place at t=0.1s with duration of 0.1s at fault point F, illustrated in Fig.5. The CBs on the faulted lines are opened at t=0.2s to clear fault. Then, the CBs are reclosed again at t=1s. Successful re closure of the CBs means re closure under no fault condition.

The voltage drops immediately from the rated value (1p.u) due to the effect of network disturbance and the grid side inverter delivers a good time, and lower steady state error. The online CMPN adaptive distinguishes high speed convergence that updates the controller gains expedite way.It has lower percentage undershoot, lower maximum percentage overshoot, lower settling.The responses using the proposed adaptive control strategy are very fast with minimum fluctuations.PCC and voltage at bus 18 are shown in Fig. 5(c)–(e), respectively.

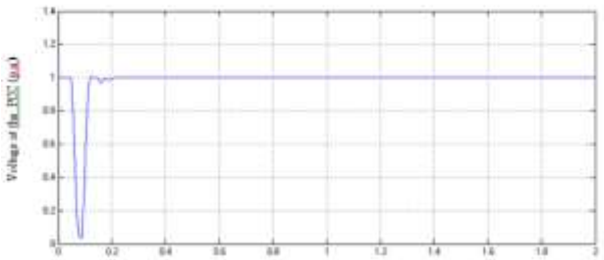
Fig. 5(f) indicates the direct axis and quadrature axis components of the inverter output currents. It can be realized that the proposed controller limits the rms inverter currents during the network disturbance to a value of 1.2 p.u, which lies in an acceptable range. the maximum output power of the PV plant at 1 p.u.

The real power out of the PCC reaches final 0.96 p.u due to the converter, inverter, and trans- former losses amount of reactive power that helps to return back to the rated value. The reactive power out of the proposed adaptive control strategy is extensively verified by subject the system to different types of un sym- metrical faults such as double-line to ground (2LG), line-to-line (LL), and single-line to ground (1LG) faults. Fig. 6(a)–(c) shows the response under these type of faults

B.Un successful reclosuer of circuit breaker .

This scenario proposes a 3LG permanent fault occurring at point F in Fig. 2(a). The fault happens at t=0.1s and its duration is assumed to be 6.9 s. The CBs on the faulted lines are opened at t=0.2s and reclosed at t=1s.Unfortunately, the CBs are closed on a permanent fault condition at this instant and this means unsuccessful reclosure of CBs. Therefore, the CBs are opened again at=1.1s and closed at t=7.1s which means after the fault duration.

Fig.7(a)–(d) indicates the responses of real and reactive power out of the PCC .All responses have faster and better damped adaptive PI control strategy through permanent fault period, the response lies in an acceptable range that agrees with the power plant grid codes. After Permanent fault clearance and CBs final closure.. All the system responses can return to their pre fault values.



(a)Time(s)

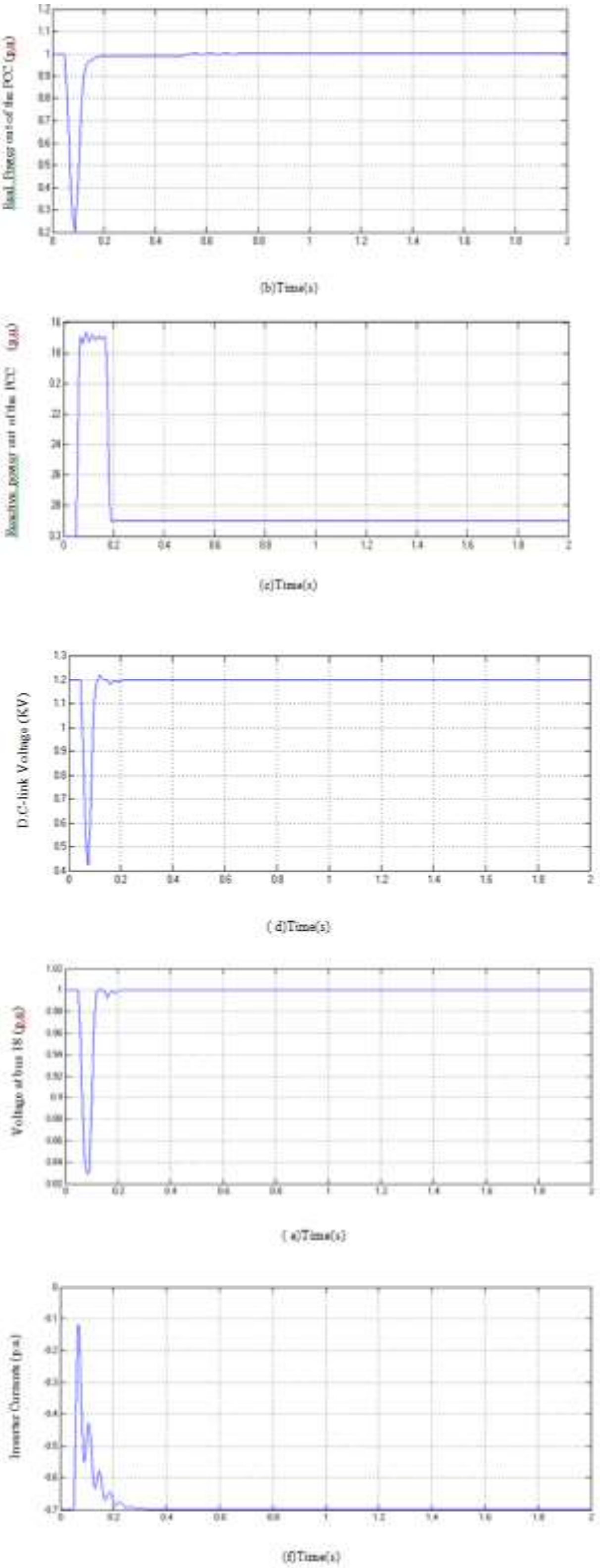


Fig. 5 .Responses for 3LG temporary fault. (a) *VP C C* . (b) Real power out of the PCC. (c) Reactive power out of the PCC. (d) *VD C*. (e) Voltage at bus 18 . (f) Inverter currents with fuzzy proposed controller.

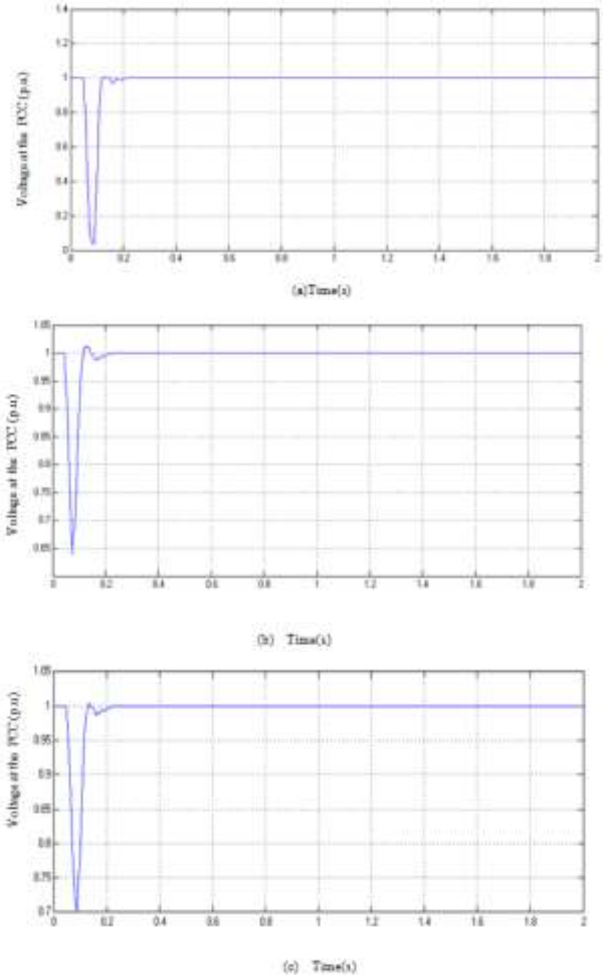
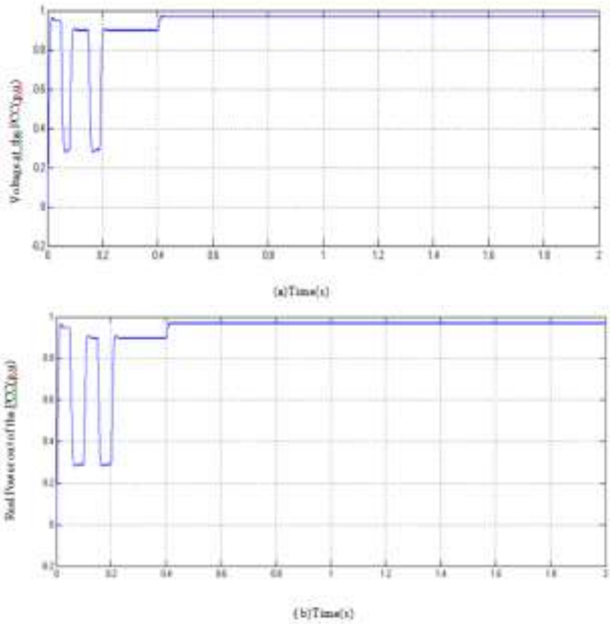


Fig. 6. V_{PCC} response for unsymmetrical faults. (a) 2LG fault. (b) LL fault. (c) 1LG fault.



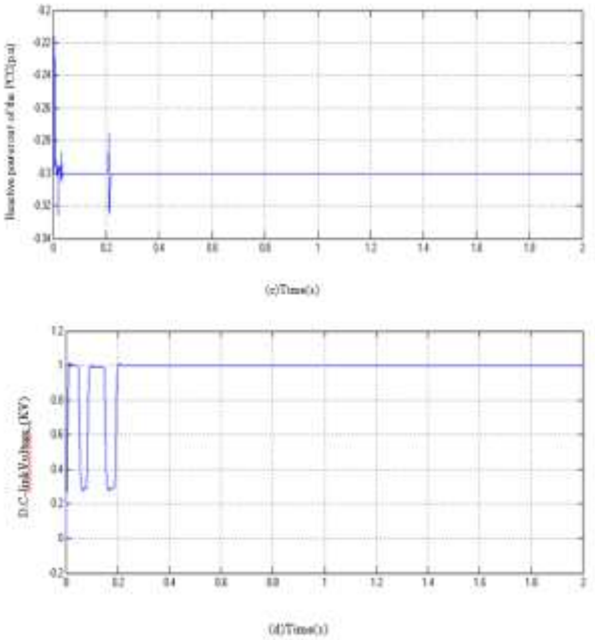


Fig. 8. Responses for 3LG permanent fault. (a). V_{PCC} (b) Real power out of the PCC. (c) Reactive power out of the PCC. (d) V_{DC}

VI.CONCLUSION

This paper has introduced a novel application of the CMPN algorithm-based adaptive PI control strategy for enhancing the LVRT capability 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 also to the grid-side inverter for controlling the D.C link voltage and terminal voltage at PCC. The CMPN adaptive filtering algorithm was used to update the proportional and integral gains of the PI controller online without the need to fine tune or optimize. For realistic responses, the PV power plant was connected to the IEEE 39-bus New England test system. The simulation results have proven that the system responses using the CMPN algorithm-based adaptive control strategy are faster, better damped, and superior to that obtained using Taguchi approach-based an optimal PI control scheme during the following cases:

1) subject the system to a symmetrical 3LG temporary fault;

2) subject the system to different unsymmetrical faults;

3) subject the system to a symmetrical 3LG permanent fault and unsuccessful re closure of CBs.

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