STABILITY ANALYSIS AND IMPROVEMENTS FOR PMSG-BASED WIND POWER GENERATOR PERFORMANCE UNDER FAULTS

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Abstract—*This paper presents a novel application of continuous mixed -norm algorithm-based adaptive control strategy with the purpose of enhancing the low voltage ride through capability of grid-connected photovoltaic power plants. The PV arrays are connected to the point of common coupling 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 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 PCC through a vector control scheme. 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 proposed control strategy is compared with that obtained using Taguchi approach-based an optimal PI controller taking into account subjecting the system to symmetrical, unsymmetrical faults, and unsuccessful reclosing of circuit breakers due to the existence of permanent fault.*

Keywords— Adaptive Control; Low Voltage Ride Through (LVRT); Photovoltaic (PV) Power Systems; Power System Control; Power System Dynamic Stability

1. INTRODUCTION

Photovoltaic (PV) system will be one of the most promising renewable energy systems in the near future. The costs of the installed PV systems are continuously decreasing worldwide because of falling component average selling prices. Based on the statistics of the PV power plants 2014 industry guide report, the global PV system installations reached 136.7 GW at the end of 2013 and the cumulative market growth reaches 36%. Several factors affect the high penetration of the PV systems into electricity networks, such as environmental concerns, clean energy, 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 to the electric grid in the last few years. Because of this large integration with the electric grid, many problems arise and need to solve like low voltage ride through (LVRT) capability enhancement of such systems. With 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. As of late, the utilities have discharged medium voltage framework codes to the PV frameworks that force on these frameworks to add to and have a part in the matrix bolster amid lattice shortcomings. To satisfy these framework codes, the PV framework needs to fulfill the LVRT ability necessity and stays in the lattice associated mode quickly after an aggravation happens. Several methods have been used to study, analyze, and improve the LVRT capability of the PV systems. In the LVRT capability of single phase grid-connected PV systems was presented using an extensive control method, which depends on controlling both the real and reactive powers out of the PV system. The authors extended their research work to apply the same control technique to transformerless PV systems. In the impact of dynamic performance of the PV systems on short term voltage stability was introduced. A cascaded proportional- integral (PI) control scheme was proposed to control the grid-side inverter. Moreover, many studies have utilized the PI controller for LVRT improvement of grid-connected PV systems. However, in all these previous reported studies, 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 systems. Recently, different optimization techniques were implemented to solve this problem. Although 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 principle motivation of the author to apply the continuous mixed -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 newest 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. Recently, these algorithms were explored in electric power systems, since affine projection algorithm was utilized to adapt the PI controller parameters in a wind energy conversion system.

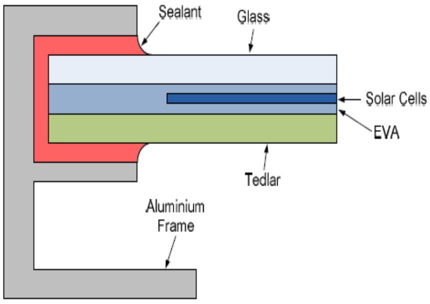

Figure 1- PV Module typical construction.

In these algorithms, a compromise should be taken into consideration between the algorithm complexity and the convergence speed. Many comparisons have been made among the proposed CMPN algorithm and other adaptive filtering algorithms. The outcomes have demonstrated the high merging pace of the CMPN calculation over these calculations for various applications. In this venture, a novel utilization of the CMPN calculation based versatile control methodology is exhibited for improving the LVRT ability of lattice associated PV control plants. The DC-DC help converter is utilized for a greatest power point following operation in view of the partial open circuit voltage strategy. The network side inverter is used to control the DC-connect voltage and terminal voltage at the point of common coupling (PCC) through a vector control plot. The CMPN calculation based versatile PI controller is utilized to control the power electronic circuits because of its quick joining. The proposed calculation refreshes the PI controller increases online with no compelling reason to calibrate or improvement. The PV control plant is associated with the IEEE 39-transport New England test framework. The viability of the proposed control methodology is contrasted and that acquired utilizing Taguchi approach-based an ideal PI controller considering subjecting the framework to symmetrical, unsymmetrical issues, and unsuccessful reclosing of circuit breakers because of the presence of changeless blame. The legitimacy of the versatile control system is broadly confirmed by the reproduction comes about, which are completed utilizing matlab/simulink programming. To the best of the creator learning, the proposed control procedure has not been so far specified in power system literatures.

2. SOLAR CELL

2.1 OPERATING PRINCIPLE

Solar cells are the necessary apparatus of photovoltaic panels. Most are produced using silicon despite the fact that different materials are additionally utilized. Sun based cells exploit the photoelectric impact: the capacity of a few semiconductors to change over electromagnetic radiation straightforwardly into electrical current. The charged particles produced by the occurrence radiation are isolated helpfully to make an electrical current by a proper plan of the structure of the sunlight based cell, as will be clarified in short beneath. A sunlight based cell is essentially a p-n intersection which is produced using two distinct layers of silicon doped with a little amount of debasement iotas: on account of the n-layer, particles with one more valence electron, called benefactors, and on account of the p-layer, with one less valence electron, known as acceptors. At the point when the two layers are consolidated, close to the interface the free electrons of the n-layer are diffused in the p-side, deserting a territory emphatically charged by the contributors. Likewise, the free openings in the p-layer are diffused in the n-side, abandoning a district adversely charged by the acceptors. This makes an electrical field between the two sides that is a potential hindrance to additionally stream. The harmony is come to in the intersection when the electrons and gaps can't outperform that potential obstruction and thus they can't move. This electric field pulls the electrons and openings in inverse ways so the current can stream in one way no one but: electrons can move from the p-side to the n-side and the gaps the other way. A chart of the p-n intersection demonstrating the impact of the specified electric field is represented in Figure 1.

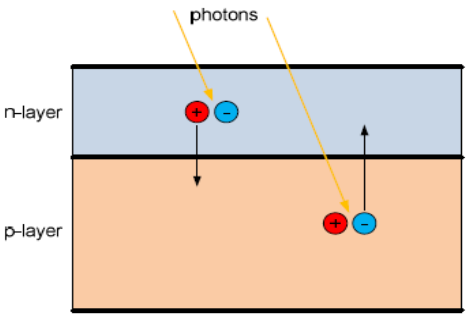

Figure 2 - Solar cell.

Metallic contacts are added at the two sides to gather the electrons and openings so the current can stream. On account of the n-layer, which is confronting the sunlight based irradiance, the contacts are a few metallic strips, as they should enable the light to go to the sun oriented cell, called fingers. The structure of the sun powered cell has been portrayed up until now and the working guideline is next. The photons of the sun oriented radiation sparkle on the cell. Three distinct cases can happen: a portion of the photons are reflected from the best surface of the cell and metal fingers. Those that are not reflected enter in the substrate. Some of them, ordinarily the ones with less vitality, go through the cell without bringing about any impact. Just those with vitality level over the band crevice of the silicon can make an electron-gap combine. These sets are produced at the two sides of the p-n intersection. The minority charges (electrons in the p-side, gaps in the n-side) are diffused to the intersection and cleared away in inverse ways (electrons towards the n-side, openings towards the p-side) by the electric field, producing a current in the cell, which is gathered by the metal contacts at the two sides. This can be found in the figure above, Figure 1. This is the light-produced current which depends specifically on the illumination: in the event that it is higher, at that point it contains more photons with enough vitality to make more electron-gap sets and therefore more present is created by the sun oriented cell.

3. LVRT

3.1 Introduction

Grid dependability and security of supply are two imperative perspectives for vitality supply. Keeping in mind the end goal to maintain a strategic distance from control blackouts it is essential that power producing plants ought to have control capacities and assurance components. Before, these necessities were primarily satisfied by traditional power plants. Meanwhile, in any case, the offer of sustainable power sources in the aggregate power era has turned out to be significant to the point that these sources excessively should contribute, making it impossible to the lattice soundness. In this way the transmission framework administrators have built up purported lattice codes with certain basic esteems and control qualities that the producing plants need to satisfy. An essential piece of these prerequisites is the purported LVRT capacity of creating plants. Be that as it may, what precisely does this term mean? LVRT is short for Low Voltage Ride-Through and portrays the prerequisite that creating plants must keep on operating through brief times of low matrix voltage and not separate from the network. Here and now voltage plunges may happen, for instance, when extensive burdens are associated with the matrix or because of lattice shortcomings like lightning strikes or short circuits. Before, inexhaustible producing plants, for example, wind turbines were permitted to separate from the network amid such a blame and attempt to reconnect after a specific timeframe. Today, in light of the noteworthy offer of renewables, such a technique would be deadly. In the event that an excessive number of creating plants detach in the meantime the entire system could separate, a situation which is additionally called a "power outage". Consequently the LVRT prerequisite has been built up which is intended to ensure that the creating plants remain associated with the matrix. Also numerous matrix codes request that the network ought to be bolstered amid voltage drops. Producing plants can bolster the lattice by sustaining receptive current into the system thus raise the voltage. Instantly after blame leeway, the dynamic power yield must be expanded again to the an incentive preceding the event of the blame inside a predefined timeframe. These prerequisites which toward the starting just connected to wind turbines, now additionally must be satisfied by photovoltaic frameworks (PV) and most as of late, by combined heat and-power plants (CHP).

Fig. 3 demonstrates the aftereffect of a voltage drop test at a PV framework. As per the worldwide standard for the estimation of energy quality attributes of wind turbines (IEC 61400-21) for instance, an inductive voltage divider is prescribed

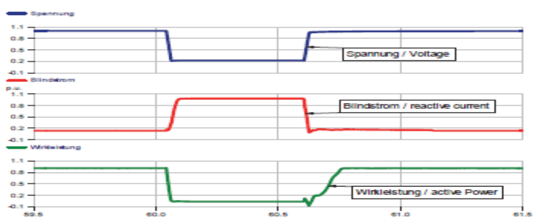

Fig. 3: Example of the results of a voltage drop test which is to be associated in front of the plant to be tried (see Fig. 4).

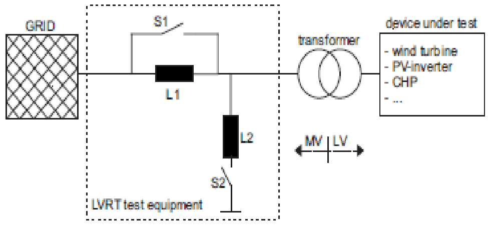

Fig. 4: Test equipment for the simulation of voltage dips

This voltage divider comprises of a longitudinal impedance (loop) L1 and a short out impedance L2. The figure demonstrates a rearranged perspective of the test gear. The impedances L1 and L2 can comprise of a few curls every (arrangement and parallel association). By changing the proportion L1 to L2 the profundity of the voltage plunge can be designed. Contingent upon the individual framework code, diverse profundities of voltage plunges must be reproduced, for wind turbines normally plunge to <5%, 25%, half and 75% of the evaluated voltage are required. The length of the plunge relies upon the profundity and extents from a few hundred milliseconds (profound plunges) to a few seconds (level plunges). At times the span can likewise reached out to a few minutes.

4. SYSTEM MODELING

The PV arrays are connected to 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 step up transformers, and double circuit transmission lines, as shown in Fig. 1(a). Fig. 1(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 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 at which generator 2 is connected, is defined as the slack bus. The total load and generation of the system is 6098.1 and 6140.81 MW, respectively. The load model is considered to be constant current and constant admittance load. 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.

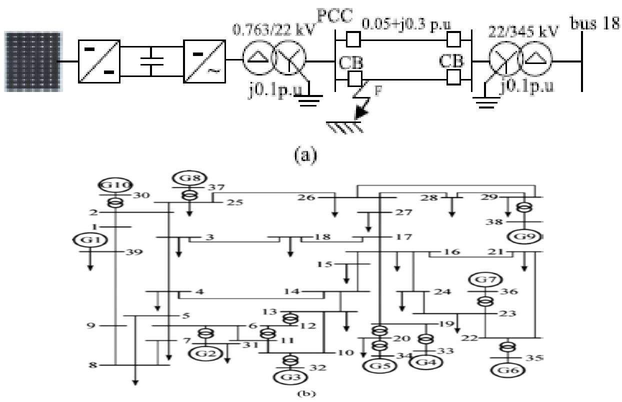

Fig. 5. Grid-connected PV power plant. (a) Connection of PV power plant. (b) single line diagram of the IEEE 39-bus New England test system under study

5. 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 in Fig. 2.

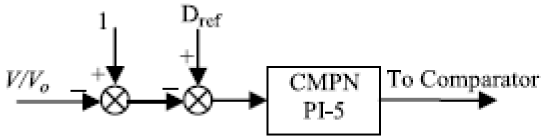

Fig. 2. Control of the DC-DC converter.

The duty cycle reference signal can be determined by the following equation:

$$D_{ref} = 1 - \frac{N_M K_M V_{oc-pilot}}{V_o}$$

An CMPN-based adaptive PI controller is used for this purpose. The controller output signal is compared with a triangular carrier waveform signal of 4-kHz frequency to generate the firing pulses of IGBT switch.

B. Grid-Side Inverter

A two-level, three-phase, six IGBT switches inverter is proposed in this study. The grid-side inverter is utilized to control the DC-link voltage and terminal voltage at the PCC through a vector control scheme, as illustrated in Fig. 3. The CMPN algorithm-based adaptive PI controllers are developed for this purpose. A phase locked loop (PLL) is dedicated to detect the transformation angle from the three-phase voltages at the PCC.

The output signals of the control scheme (Vq-ref and Vd-ref) are converted to three-phase sinusoidal reference signals , which are compared with a triangular carrier signal of 1-kHz frequency to produce the firing pulses of IGBT switches.

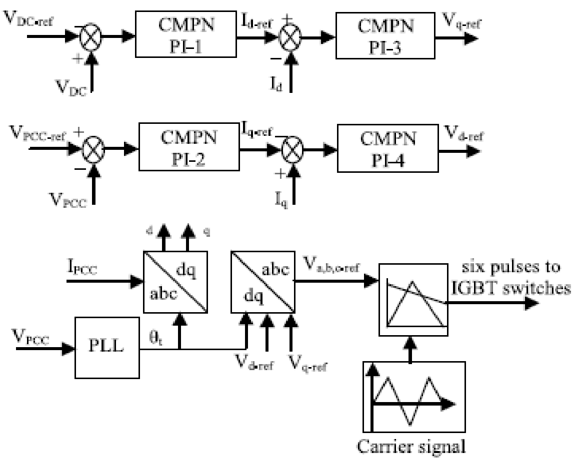

Fig. 6. Control block diagram of the grid-side inverter.

The is maintained constant at 1.2 kV through the simulation using this pulse width modulation inverter.

6. SIMULATION RESULTS

The detailed model of a grid-connected PV power plant is presented. The model involves a complete switching model of the power electronic circuits with the proposed adaptive control strategy for obtaining realistic responses. The effectiveness of the proposed adaptive control strategy is compared with that obtained using Taguchi approach-based optimal PI controllers, taking into account subjecting the system to symmetrical, unsymmetrical faults, and unsuccessful reclosing of circuit breakers due to the existence of permanent fault as follows:

A. Successful Reclosure of Circuit Breakers (CBs)

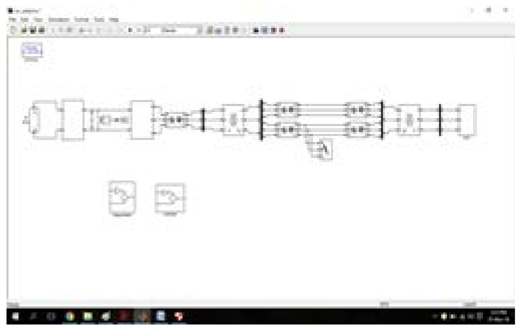

Fig:1- response of proposed system for 3LG temporary fault

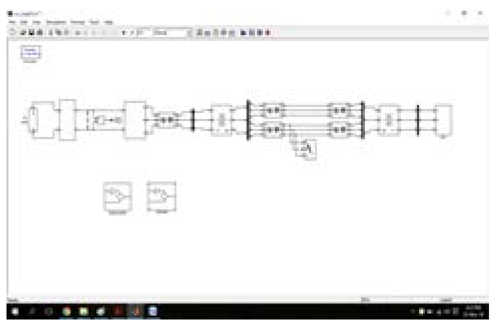

Fig:2- response of conventional system for 3LG temporary fault

In this scenario, a three-line to ground (3LG) temporary fault takes place at time t=0.1 s with duration of 0.1 s at fault point F. 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 reclosure of the CBs means reclosure under no fault condition.

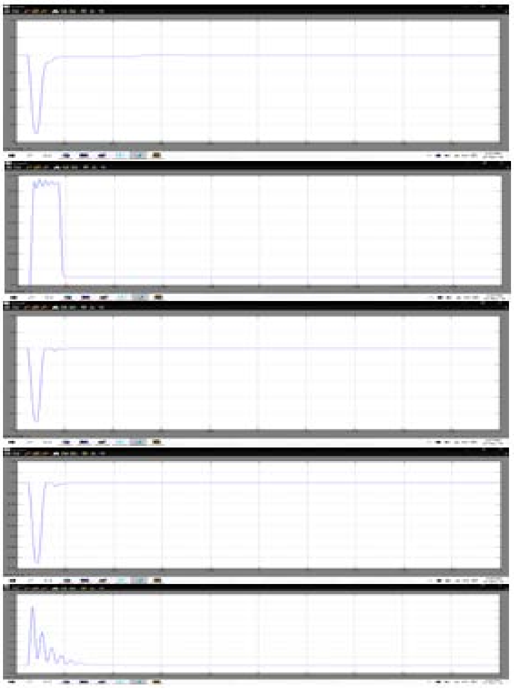

Fig. 3. Responses of proposed system for 3LG temporary fault. (a) Vpcc. (b) Real power out of the PCC. (c) Reactive power out of the PCC. (d) Vdc. (e) Voltage at bus 18. (f) Inverter currents with the proposed controller.

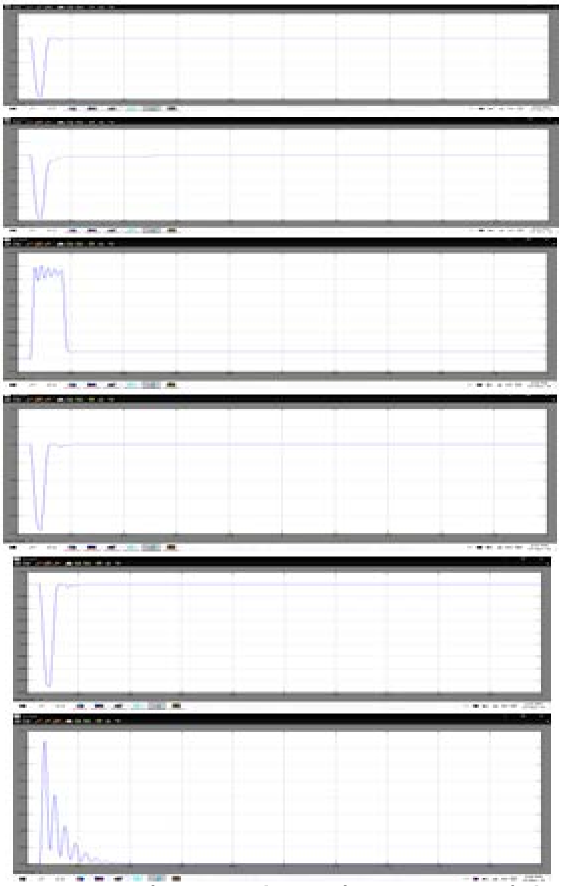

Fig. 4. Responses of conventional system for 3LG temporary fault. (a) Vpcc. (b) Real power out of the PCC. (c) Reactive power out of the PCC. (d) Vdc. (e) Voltage at bus 18. (f) Inverter currents with the proposed controller.

The Vpcc drops immediately from the rated value (1 p.u) due to the effect of network disturbance and the grid side inverter delivers a good amount of reactive power that helps the Vpcc to return back to the rated value, as indicated in Fig. 3 & 4 (a). It is worth to note here that the Vpcc response using the CMPN-adaptive PI control strategy is better damped than that of using Taguchi approach-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. 3 & 4 (b) points out the real power out of the PCC. It can be realized that the proposed controlled DC-DC converter controls efficiently 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 transformer losses. The reactive power out of the PCC, the Vdc , and voltage at bus 18 are shown in Fig. 3 & 4 (c)–(e), respectively. It can be noted that the responses using the proposed adaptive control strategy are very fast with minimum fluctuations.

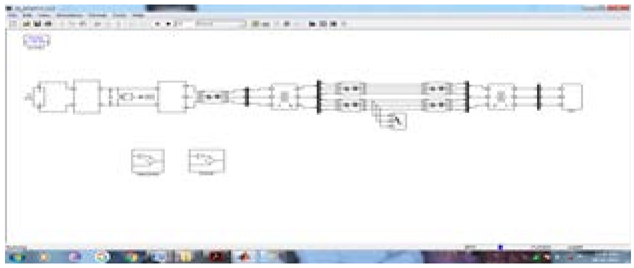

Fig:5- response for unsymmetrical faults of proposed system

The online CMPN adaptive algorithm distinguishes a high speed convergence that updates the controller gains in an expedite way. Fig. 3 & 4 (f) indicates the direct axis and quadrature axis components of the inverter output currents (Id and Iq). 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.

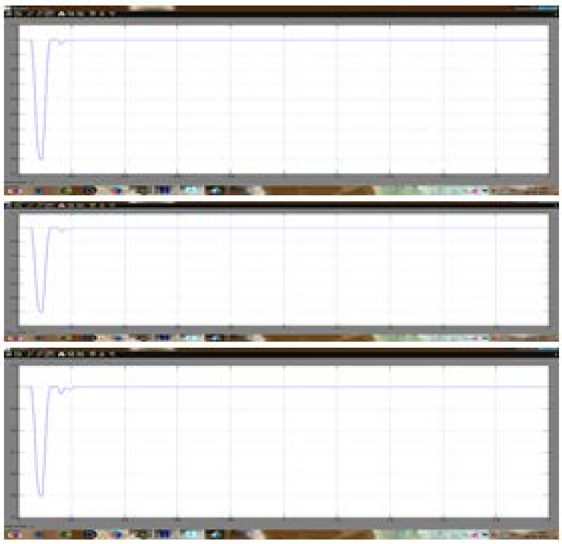

Fig. 6. Vpcc response for unsymmetrical faults of proposed system. (a) 2LG fault. (b) LL fault. (c) 1LG fault.

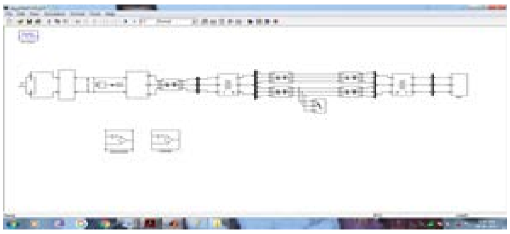

Fig:7- response for unsymmetrical faults of conventional system

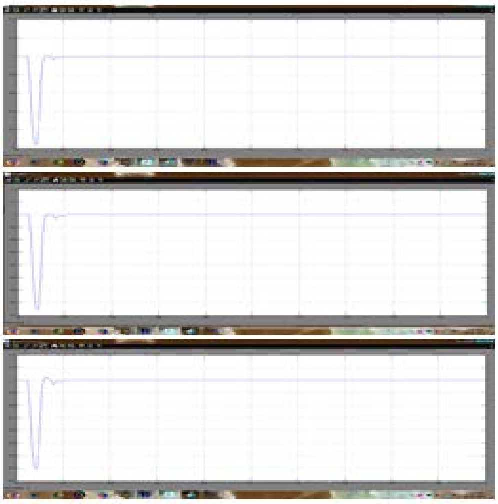

Fig. 8. Vpcc response for unsymmetrical faults of conventional system. (a) 2LG fault. (b) LL fault. (c) 1LG fault.

Moreover, the proposed adaptive control strategy is extensively verified by subject the system to different types of unsymmetrical faults such as double-line to ground (2LG), line-to-line (LL), and single-line to ground (1LG) faults. Fig. 6 & 8(a)–(c) shows the Vpcc response under these types of faults. All the transient responses using the proposed control strategy are superior to that obtained using Taguchi approach-based an optimal PI control scheme. Therefore, the LVRT capability of the grid connected PV power plants can be further enhanced using the CMPN algorithm-based adaptive PI control strategy.

B. Unsuccessful Reclosure of CBs

This scenario proposes a 3LG permanent fault occurring at point F in Fig. 3(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 again at t=1s.

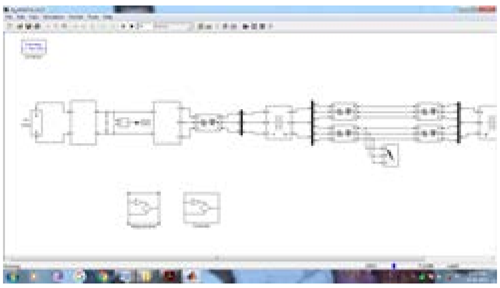

Fig:9- response for 3LG permanent fault of proposed system.

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 t=1.1s and closed at t=7.1s, which means after the fault duration.

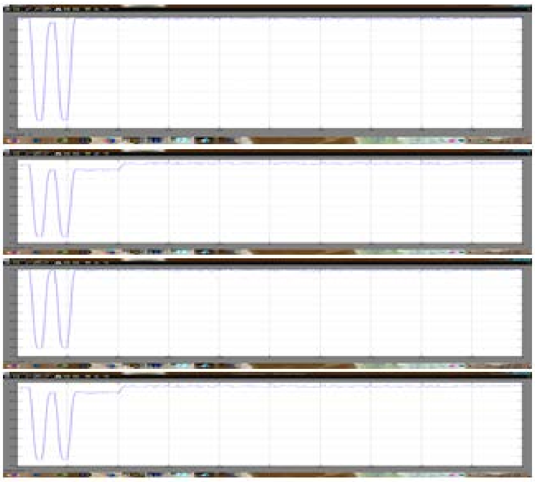

Fig. 10. Responses for 3LG permanent fault of conventional system. (a) Vpcc. (b) Real power out of the PCC. (c) Reactive power out of the PCC. (d) Vdc.

Fig. 10 & 12(a)–(d) indicates the responses of Vpcc, real and reactive powers out of the PCC, and Vdc, respectively. All responses have faster and better damped using the CMPN-based adaptive PI control strategy. Moreover, through permanent fault period, the Vpcc response lies in an acceptable range that agrees with the PV power plant grid codes. What's more, after changeless blame leeway and CBs last conclusion, the profits back with a quick reaction to its appraised esteem.

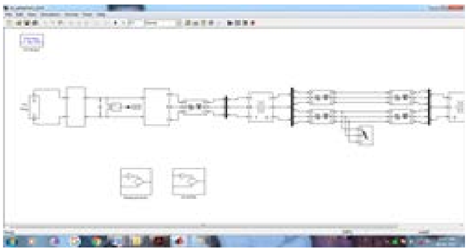

Fig:11- response for 3LG permanent fault of conventional system

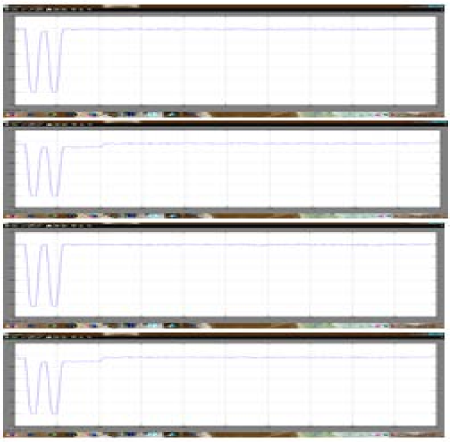

Fig. 12. Responses for 3LG permanent fault of conventional system. (a) Vpcc. (b) Real power out of the PCC. (c) Reactive power out of the PCC. (d) Vdc.

All framework reactions can come back to their pre-blame esteems. Thusly, the proposed control methodology brings about an improvement of the LVRT ability of framework associated PV control plants whatever under lattice impermanent or lasting issue condition. The high performance, accuracy, and superiority of the proposed CMPN algorithm-based adaptive PI controller to Taguchi-based an optimal PI controller are due to its proper design, its high convergence speed, and its flexibility to update the controller gains automatically online to minimize the error signals obtaining better results.

7. CONCLUSION

This project 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 procedure was connected to the DC-DC help converter for a most extreme power direct following operation and furthermore toward the framework side inverter for controlling the Vpcc and Vdc. The CMPN versatile sifting calculation was utilized to refresh the corresponding and indispensable additions of the PI controller online without the need to calibrate or upgrade. For sensible reactions, the PV control plant was associated 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 reclosure of CBs.

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