FRT Improvement by Fractional order PID Controller of a Grid-Tied PV System

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Abstract: ***Now a days in Power Systems, the addiction on renewable energy sources is increasing rapidly. The grid connected applications are important with the deficiency in Non Renewable energy sources due to fuel shortage. As the PV plants penetration increasing rapidly, the fault ride through [FRT] improvement has become a critical issue. In this paper a Fractional order PID Controller based Sliding Mode Control is presented for FRT Improvement. The proposed control system improve the voltage of DC-Link Capacitor and injected Reactive power under fault conditions. The Reliability of the FOPID controller is extensively demonstrated by the simulation results, which are brought out using MATLAB-/SIMULINK Software. By the presented FOPID based sliding mode control, the fault ride through capability of such system can be Improved.***

Keywords: Fault ride through[FRT], Grid connected PV array, Control system, Photovoltaic System, Fractional order PID controller.

1. INTRODUCTION

To overcome the problems related to Environmental pollution and fuel shortage, the generation of electrical power from various Non-conventional energy sources has been Increasing rapidly. Electricity Generation from Solar and Wind power sources can be used appropriately, which are pollution free and has turn out to be the most widely used for the distributed generation in recent years. In recent years, the efforts are going on to integrate the photovoltaic systems into the grid to meet the essential demand of pollution free and reliable electrical power generation. The high penetration of PV systems into Electrical Utilities made to think over the grid code requirements. As the usage in the solar energy increases rapidly, to meet the demand integration is need. This integration influences in the stability and security issues mainly. Thus, the countries which are investigating to maximize solar energy initiated new requirements for grid code for solar photovoltaic to address the issues in stability and security. The following conditions should be considered while discussing about stability:

System management: Security analysis, availability analysis and information about temporary limitation for present and forecasted situations should performed by production unit.
Frequency stability: To keep the balance in demand and generation, power plants should monitored with controlling action.
Voltage stability: To maintain the stability in voltage profile, reactive Power is needed.
Robustness of System: In any perturbation occurs, power Plants should be robust.
Restoration: After a disturbance, the Power plant should restore the voltage or operate voltage in control mode.

Several methods were presented in literature for intensifying the FRT capability of PV arrays which are connected to grid. A sliding mode controller is presented to improve the FRT of GCPA by controlling grid side converter. But there is a problem of mismatching of power drawn out from the PV array and the power supplied to grid remains to be solved. To improve the FRT capability, a new system is proposed for 2-stage GCPA’s[1]. According to this new system, the boost converter switches to a PID controller that controls the voltage of DC-link capacitor on the occurrence voltage sags. First order sliding mode control is used for boost DC/DC converter to control the voltage of DC Link capacitor. But zero dynamic stability was lost by effect of DC link voltage operation. So that inductor current in the converter is maintained as the controlling variable. A next order sliding mode controller is presented to verify response and stability.

In this paper, FTSMC is used to have a fast and stable operation of boost converter during voltage sags[2]-[5]. A FOPID based PBSMC is introduced in this paper for the Grid side inverter to speed up the recovery of the system after fault clearance. If any large disturbance occurred, the proposed FOPID based PBSMC controller provides smooth resuming of the system whereas in normal condition it provides fast response. The main contributions of this paper are:

1. During voltage sags and voltage recovery period, there is an improvement in the grid connected PV array. For this two controllers are introduced at Inverter and Boost converter side.
2. The FTSMC controller is employed at DC/DC converter which improves the performance of the system under voltage sags.
3. The proposed fractional order based PBSMC controller will enhance the system after clearance of fault.

The remaining content of the paper is organised like this mentioned below: In part II a discussion is carried on grid code requirement and problem description. The modelling of system is given in section III. A brief description on proposed FOPID controller is carried in the section IV. The simulation results are presented in section V. Finally, the conclusions are depicted in VI.

II GRID CODE REQUIREMENTS AND PROBLEM DESCRIPTION

Grid code requirements are elucidated by the system operators to define the rights and responsibilities of all the generators and loads that are connected to the power system. The variety of grid codes and norms which differ from country to country prove a major barrier for PV industry. According to the German grid codes, As indicated in fig.1 various amplitudes at the time of voltage sags with high and medium voltages of generating units are remain connected to grid. The limit shows the requirement of conventional systems. The area which is darken in the fig.1 represents the state of voltage sag for which the GCPA to be in contact with the grid[3]-[5]. To keep up the voltage of the grid during voltage sags, an injection in reactive current is needed from generating units.

The maximum power from PV arrays is generated by Maximum Power Point Tracking (MPPT) strategy. The power which is generated from the PV system by using MPPT technique is given to Boost converter. This boost converter will balance the voltage to obtain the maximum power from PV array. There are Several methods or techniques in MPPT strategy. Among all those methods, Perturb and Observe method and Incremental Conductance method are the most widely used strategies in MPPT techniques [6]-[10].

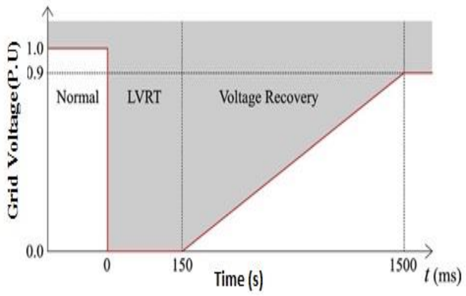

Fig.1: LVRT characteristics

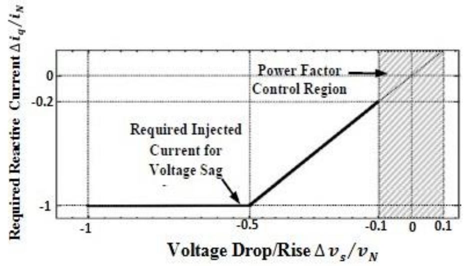

Fig.2: Reactive Power characteristics

To find the extremity of voltage sags, an easier method is used in this Paper. By using this method a quick decision will be taken when the voltage sag occurs. As per the requirement of grid code, we will calculate the direct axis and quadrature axis reference values. When voltage sag occur, the power supplied to the grid decreases significantly. There will be a very rapid increase in the DC Link capacitor voltage, if there is no balance between power extracted from PV system and power supplied to grid. Whenever this condition occurs we need to disconnect the PV array, so that we can protect our DC link Capacitor. To overcome this type of problems FTSMC controller is installed to control Boost converter from voltage sags[11]. If voltage sag is identified the system changes from MPPT Technique to FTSMC.

The objective of Grid Side Inverter is mainly divided into two tasks. The first one is the regulation of voltage. This is to supply the total power generated from PV system to grid. The other is to generate the needed reactive power or Power factor[12]-[14]. The regulation of reactive power is controlled by FOPID controller on the q-axis of grid side inverter current. In this paper FOPID is used to provide fast and smooth response. PBSMC has quick response in normal operating conditions while if any large disturbance occurs, FOPID produces very smooth and over-damped response [15]. Thus, FOPID controller exits saturation quickly, and also improves the performance of the system after the clearance of fault.

III MODELLING OF THE SYSTEM

The schematic diagram of the FOPID based system is shown in below fig.4. It mainly includes the PV array system for extraction of power from solar energy. A boost converter and 3 level grid side inverter is placed between grid and PV system. The signals from MPPT technique and FTSMC controller is given to boost converter while the signals from FOPID based PBSMC controller is sent to grid side inverter. Whenever there is a voltage sag is detected, the MPPT is disconnected from the system and switches to FTSMC controller. After the clearance of fault it switches to MPPT. While the proposed FOPID based controller exits the saturation smoother and faster after the clearance of fault.

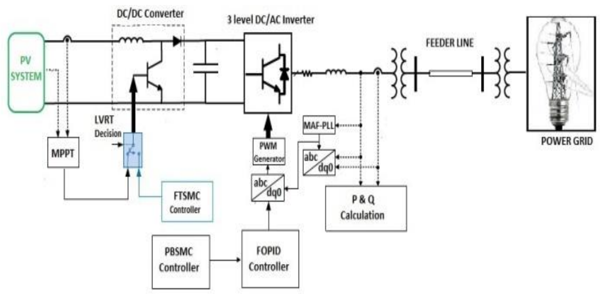

Fig.3: Block diagram of proposed configuration

PV ARRAY

The solar cell is a semiconductor device which converts the solar radiation into electric power. The output from a single cell is not suitable for practical cases. To acquire sufficient voltage the cells are connected in series and in parallel for sufficient current, to form a PV module. The PV array can be formed by connecting these modules in series and parallel with the required rated power. In this system, a 100 kW PV array is used. The equivalent electrical circuit of a PV cell is shown in Fig.4

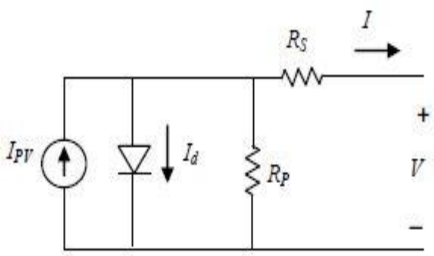

Fig.4: Circuit Diagram of PV cell

The current and voltage which were obtained from the PV array have a non linear function. The temperature and Irradiance may influence the current obtained. The obtained current from every PV array is expressed as in terms of voltage is given by the eq.(1):

$$i_{pv} = n_p \left(I_{sc} - I_{sat}\left[\left[e^{((q/kT).(v_{pv}/n_s))} - 1\right]\right]\right) \quad (1)$$

Where q is the electric charge, k is the boltzmann constant and T denotes the temperature. I_{sat} represents the saturation current of the diode. Where as n_p and n_s denotes the number of cells connected in parellel and series. I_{sc} can be calculated by using the eq. (2):

$$I_{sc} = \left[I_{ss0} + k_i\,(T - T_{ref})\right]\frac{S}{1000} \quad (2)$$

Where k_i denotes the co-efficient of temperature, T_{ref} is the reference ambient temperature and I_{ss0} is the short circuit current at 25 deg.C and 1000 W/m^2. If the PV panel is at MPP, the following condition holds:

$$\frac{di_{pv}}{dv_{pv}} = -\frac{i_{pv}}{v_{pv}} \quad (3)$$

Table.1: PV Module Parameters

Open circuit Voltage(V_{oc})	64.2 V
Short circuit current (I_{sc})	5.96 A
Voltage at Maximum Power (V_{mp})	54.7 V
Current at Maximum Power (I_{mp})	5.58 A
Parallel modules(n_p)	66
Series Modules(n_s)	5
Maximum output Power	100 KW

SLIDING MODE CONTROLLER

Sliding mode control (SMC), a nonlinear method which changes the dynamics of a nonlinear system by the use of a discontinuous control signal. Two controllers namely FTSMC and FOPID based PBSMC are used under voltage sags and fault conditions. If any voltage sag is detected, the FTSMC controller is used to maintain the DC link capacitor voltage constant.[11]-[15]. The FTSMC Controller trace the reference value of the current which keeps the voltage of DC link capacitor to be constant. Two cases are given to prove the stability of the FTSMC :

Case(A): If $S_{FTSMC} > 0 \Rightarrow u = 1 \Rightarrow \bar{u} = 0$:

$$\dot{S}_{FTSMC} = \left[-\frac{dG(i_{pv})}{di_{pv}} + \alpha_1 + \alpha_2.\alpha_3.|e_1|^{\alpha_3 - 1}\right].\dot{e}_1 \quad (4)$$

Case(B): If $S_{FTSMC} < 0 \Rightarrow u = 1 \Rightarrow \bar{u} = 0$:

$$\dot{s}_1 = \left[- \frac{dG(i_{pv})}{di_{pv}} + \propto_1 + \propto_2 . \propto_3 . |e_1|^{\propto_3 - 1}\right] . \dot{e}_1 - \frac{1}{LC} e_1 + \frac{i_{pv}^*}{LC} - \frac{i_{dc}}{LC} > 0$$

$$\left[- \frac{dG(i_{pv})}{di_{pv}} + \propto_1 + \dot{\propto}_2 . \propto_3 . |e_1|^{\propto_3 - 1}\right] . e_1 > \frac{1}{LC} e_1 + \frac{i_{pv}^*}{LC} - \frac{i_{dc}}{LC} \tag{5}$$

Where S_{FTSMC} denotes the sliding surface.

PROXY BASED SLIDING MODE CONTROL

PBSMC is used to track the virtual of the object namely "Proxy". The Proxy is operated with a sliding mode control to obtain required position. The proxy, an imaginary object which exert force to maintain it's length to zero. A simple approach for proxy based sliding mode control is shown in the fig.5

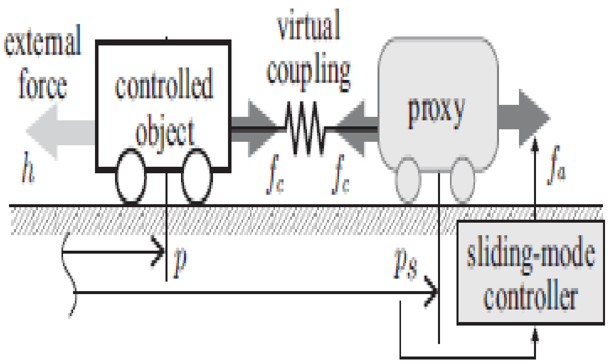

Fig.5: Schematic diagram of PBSMC

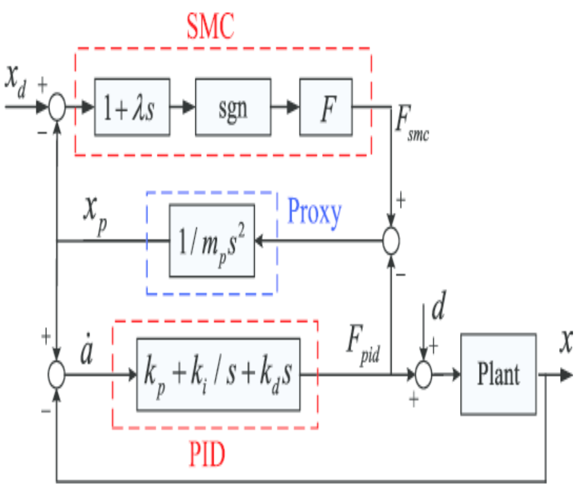

Fig.6: Block diagram of PBSMC

The fig.6 is the block diagram of the PBSMC controller. The PBSMC is the extension for the PID controller[16].In this paper the PBSMC based FOPID controller is installed at grid side inverter. The main objective is to set the voltage of DC Link and compare with the reference value[18]. The control law for the PBSMC is given by:

$$f = F . sat\left[\frac{k_d}{F} . \left[\frac{\sigma - \frac{d\rho}{dt}}{K} + \frac{k_i . \rho + k_p \frac{d\rho}{dt}}{k_d}\right]\right] \tag{7}$$

IV PROPOSED FOPID CONTROLLER

PID controller is the most widely used controller for industrial appliances because of its easy construction and parameters. Though the complexity in control systems increased, improvement in PID controllers is needed. The improvement in fractional order PID calculus has brought fractional order PID controller. FOPID controller is extension of normal PID controllers. The integer order (λ) and derivative order (μ) being fractions, improves the flexibility and robustness which will give better Performance. The PID controller rectifies the error between a measured variable and desired set point. It calculates the value and will output a corrective action and alter the process which we need actually. The Transfer function of Integer PID controller is given by:

$$G_C(s) = k_p + k_i s^{-1} + k_d s \tag{8}$$

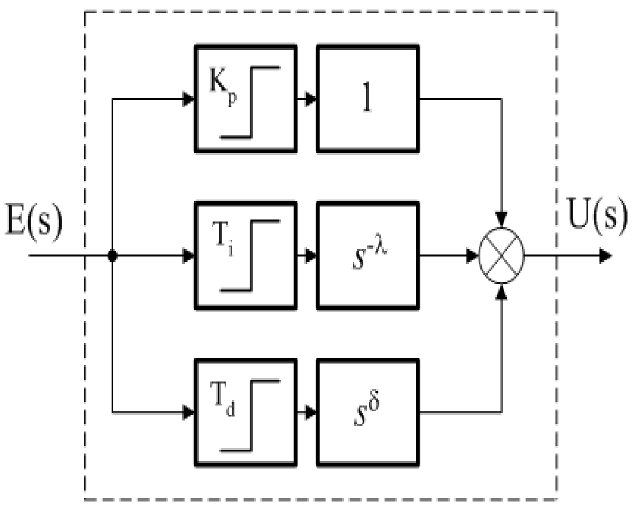

Fig.7: Block diagram of Fractional order PID Controller

Table.2: System Configuration Parameters

Boost DC/DC Converter Parameters	**FEEDER line Parameters**
Rated. Voltage 500V Max. Voltage 700V Min. Voltage 300V Inductance (L) 5mH DC link capacitance 36mF	L_{filter} 0.25mH R_{filter} 0.0019Ω L_{line} 5.25mH C_{line} 0.0565μF R_{line} 0.5765Ω
FTSMC Controller	**PBSMC Controller**
α_1 2.05 α_2 50 α_3 5.85	K 0.01 F 1.25
Transformer1	**Transformer2**
Voltage 260V/25Kv Power Rating 150KVA X,R,L 0.06,0.005,500 .p.u	Voltage 25kV/120kV Power Rating 150KVA X,R,L 0.16,0.005,500 .p.u
Grid Side DC/AC Inverter Parameters	**FOPID Controller**
Rating 125kVA Max. Current 563A Max. Volatge 320 V	k_p 2.6 k_i 1.8 k_d 0.25 λ, μ 0.9, 0.6
Current Regulator	**Voltage Regulator**
k_p 0.3 k_i 20 k_d 10^{-7} Current Limit 2 p.u	k_p 7 k_i 800 k_d 10^{-4} Voltage Limit 1.25 p.u

First time Podlubny in 1999 initiated a concept to generalize PID controller. He proposed it as $PI^{\lambda}D^{\mu}$ controller where as λ denotes the integer order and μ denotes the differential order. By using the Fractional order systems, he compares the concept of his proposed one to the conventional PID controller and expressed his view that his proposed controller has better response. In industrial applications, the PI, PID controllers are the most widely used controllers. The extension in integer order PID controller leads to a new advancement called fractional order PID controller. The FOPID controller is derived by using Fractional order calculus(FOC)[19]. FOC includes the differentiation and integration of the complex and real functions. The applications of FOPID includes in the field of robotics, control systems, biotechnology, Electronics research e.t.c., The transfer function of FOPID controller in continuous mode is given by:

$$G_C(s) = k_p + T_i s^{-\lambda} + T_d s^{\mu}, (\lambda,\mu > 0) \quad (9)$$

A point to plane analysis of FOPID controller is shown in the fig.(6). The extension in PID give more flexibility for designing the controllers and gives the accurate results.

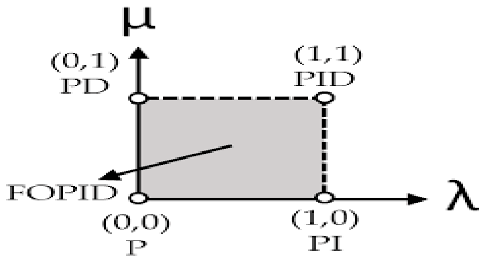

Fig.8: Point to plane analysis of FOPID

V SIMULATION RESULTS

In this simulation results, the results of presented Fractional-order PID (FOPID) controller and the conventional PID controller are compared by considering single phase and three phase faults at the Grid for a time period of 150ms. The FTSMC controller will maintain the DC link voltage with in limits under the voltage sags. While the proposed FOPID based sliding mode controller at the DC/AC inverter improve the recovery performance after the fault clearance. And also resumes the voltage with smooth and less distortions. Primarily the results which are obtained by the single phase fault are presented and later the results which are generated from three phase fault are Presented.

Performance under Single Phase fault:

In the first case, the Proposed FOPID controller is applied to single phase fault. The 3-Phase voltages of the grid during voltage sag is shown in the fig.9. The DC Link voltages are shown in fig10..In fig.11 the injective reactive current is presented. The d-axis and q-axis currents are obtained in fig. 12(a) & 12(b)

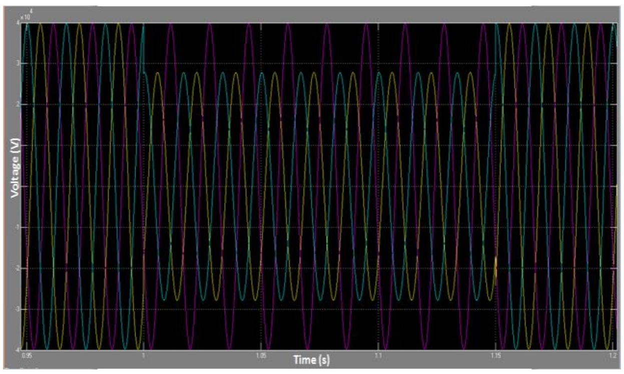

Fig.9: Line to line grid Voltage in Single Phase fault

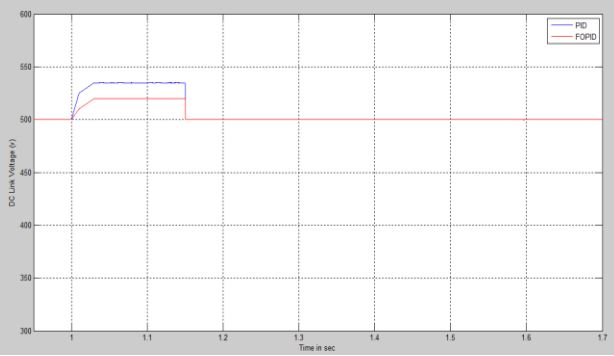

Fig.10: DC link Voltage of GCPA

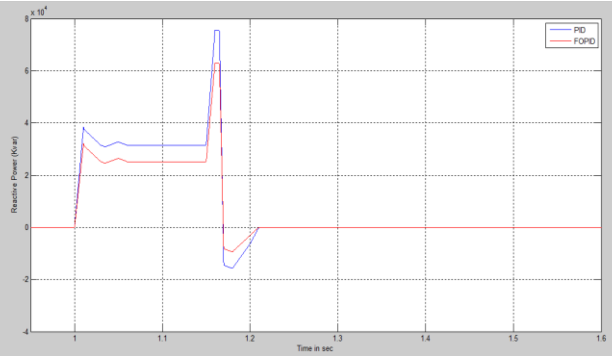

Fig.11: Injected reactive power of GCPA

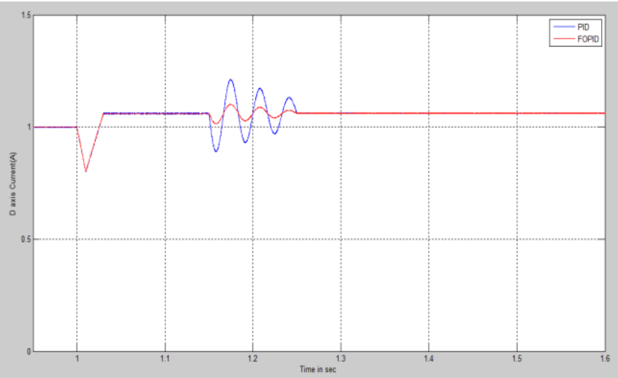

Fig.12(a): d-axis reference current

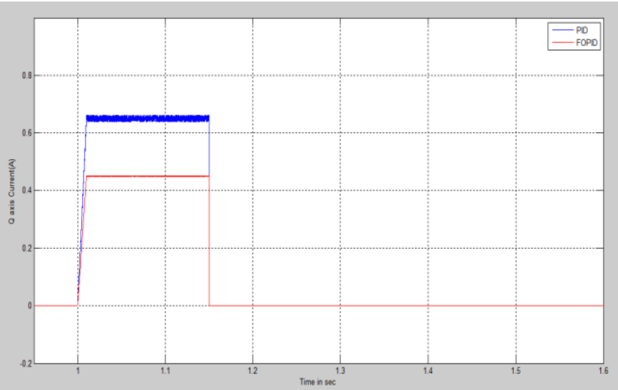

Fig.12(b): q-axis reference current

Performance under Three Phase fault:

In the second case, the Proposed FOPID controller is applied to Three phase fault also. In this the fault condition is studied for a time period of 150ms (1-1.15s). The three phase grid voltage for the GCPA is presented in fig.13. The voltage of DC link capacitor of the GCPA is shown in fig.14. In fig.15 the injected reactive power is shown. Finally the reference current generated by the controllers are shown in fig.16(a) & 16(b)

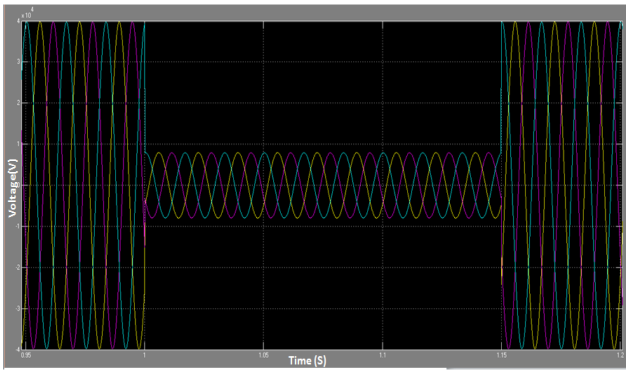

Fig.13: Line to line Grid voltage for Three Phase fault.

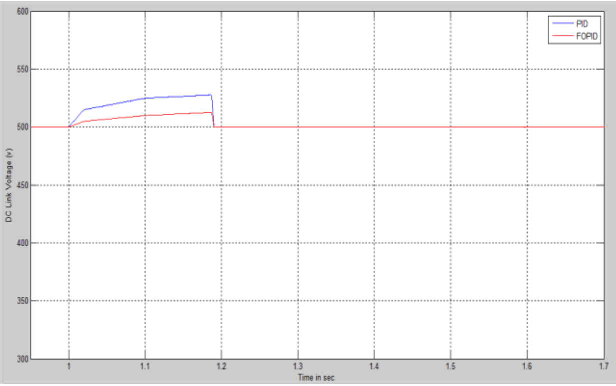

Fig.14: DC link voltage of GCPA

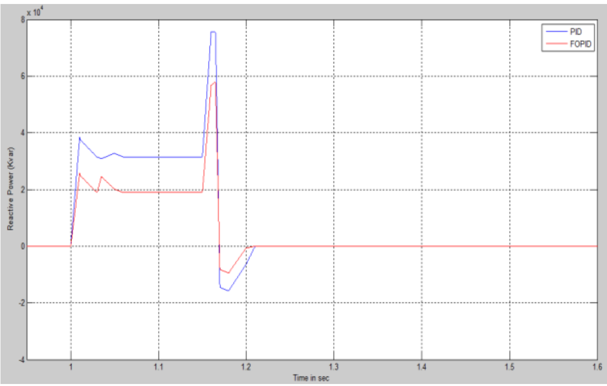

Fig.15: Injected Reactive power of GCPA

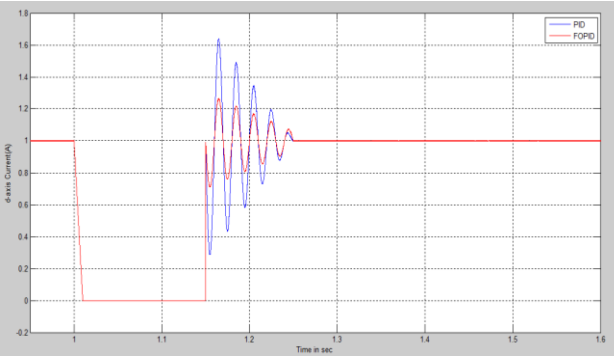

Fig.16(a): d-axis reference current

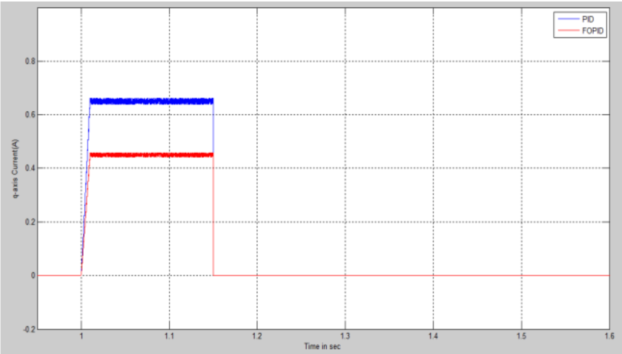

Fig.16(b): q-axis reference current

VI CONCLUSION

FOPID controller based PBSMC is presented in this paper to intensify the fault ride through and recovery performance after fault clearance of GCPA. If any voltage sag occurs, the boost DC/DC converter changes from MPPT technique to FTSMC controller. The FTSMC controller is used to keep the voltage of DC link capacitor constant. The proposed FOPID controller based PBSMC is employed to control the Grid side DC/AC inverter. After persistence of fault the PV system recovers very quickly. This happens due to the FOPID based PBSMC that will provide smooth resume to required value. The MATLAB simulation results will show the effectiveness of the presented FOPID controller for Grid connected PV arrays.

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