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Proportional Resonant Controlled Shunt Active Filter in IEEE Nine Bus System with Improved Dynamic Time Response

S. Dhandayuthapani[1], Dr. C. Sharmeela[2]
[1, 2] Dept of EEE, SCSVMV University, College of Engineering,

Abstract: This paper presents on improving the dynamic characteristics response of Permanent magnet synchronous generator (PMSG) used in wind energy conversion system (WECS) is connected to IEEE Nine bus system in closed loop controlled Active Power Filter with PR. Shunt active filter (SAF) is one of the popular device within the family of FACTS device and is implemented with Voltage Source Inverter (VSI) . Proportional Resonant controller is used to generate switching pulses. The simulation results with PI and Proportional Resonant Controller based SAF are compared and the corresponding time-domain parameters are presented. The results shows that Proportional Resonant Controller system gives better response than PI controlled system.

Index terms: Shunt Active filter, IEEE nine bus system, Proportional Resonant Controller, PI controller, Voltage Source Inverter, Reactive power, Time domain parameters, Mat lab.

I. INTRODUCTION

In recent years increase of power electronic systems in both industrial and domestic systems. So that lot of work has been done in power quality and custom power issues in the distribution side due to non-linear loads [1]. These non-linear loads are introducing low efficiency of power system, distortions in voltage or current ,losses in the distribution lines and reactive power problems. These power quality issues in the system induce several undesirable issues, such as increased heating losses in transformers, low power factor, torque pulsation in motors, poor utilization of distribution plant and also affects other loads connected at the same Point of Common Coupling (PCC). To improve the power quality conventional compensation method such as passive LC filters and fixed compensating devices with some degree of variation like thyristor switched reactors, thyristor switched capacitors were employed . The demerits of such devices are of fixed compensation, large size, ageing and resonance. Nowadays active power filters (APF's) , Power Line Conditioners are used for the power quality issues due to their dynamic and adjustable solutions[2]. Power Filters were developed to reduce the harmonics and reactive power compensation . The APF circuit can be connected in either series or parallel and combinations of both configurations[3]. The shunt active filter is prominent than the series active filter, because most industrial applications require the current harmonic compensation[4].

Voltage collapse creates voltage instability in the system. Voltage stability states that the power system maintain steady voltages at all buses in the system after being subjected to a disturbance from a given initial operating point. The system state enters the voltage instability region when a disturbance or an increase in load demand or alteration in system state moves in an uncontrollable state and drops in system voltage. A system is said to be in voltage stable state if at a given operating condition, for every bus in the system, the bus voltage magnitude increases as the reactive power injection at the same bus is increased. A system is voltage unstable if ,for at least one bus in the system, the bus voltage magnitude decreases as the reactive power injection at the same bus is increased. The active filter is implemented with VSI (Voltage source inverter) and switching patterns are generated with the help of proposed Proportional Resonant(PR) controller. A disturbance is given in bus 6 which means connected with additional load. Voltage stability[9] is improved in the bus 6 .Final results gives low steady state and settling time error .

In most of the papers discussed with the use of PI controllers. PI controller needs a linear mathematical model of the system and it is difficult to obtain parameter variations with the use of non-linear load disturbances. Conventionally, PI controlled three phase SAF for power quality improvement[7], Hysteresis band and DC voltage control in shunt active filter were implemented. FLCs were also proposed in active filter in various power electronic applications.

The overhead literature does not pact with PR controlled SAF system. This investigation suggests with PR controller for SAF system. The above papers do not report the comparison of PI and PR controlled SAF systems. This work compares the results of PI and PR controlled SAF systems.

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II. PRINCIPLE OF SHUNT ACTIVE POWER FILTER

The principle of the Shunt Active Filter is to generate harmonic currents equal in magnitude but opposite in-phase to those harmonics that are present in the grid. Fig. 1 shows the schematic representation of Active Filter. Shunt Active Filter can compensate reactive power and mitigate harmonics and distortions. Open loop systems sense the load current and harmonics and also they inject fixed amount of power in the form of reactive into the system which may compensate reactive power as well as harmonics. Since there is no feedback and there is no reference to check the accuracy and performance.

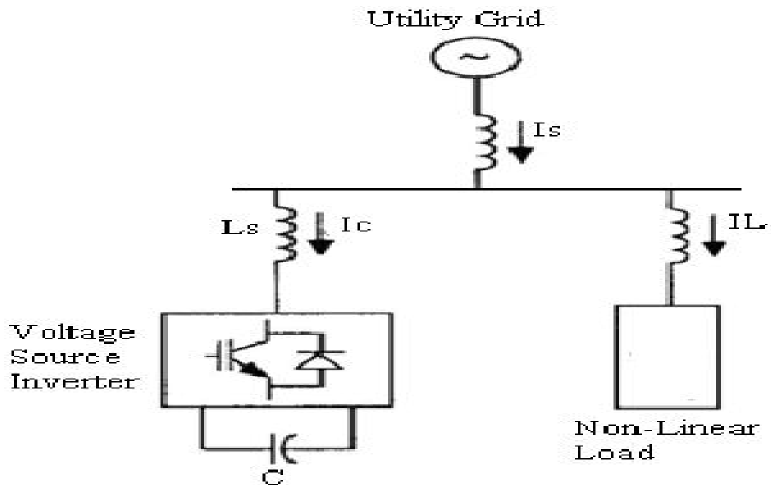

Fig. 1. Schematic Representation of Active Filter

The SAPF is a closed loop structure. Closed loop structure incorporate a feedback loop providing greater accuracy of current injection for compensation of harmonics and reactive power well over the open loop design.

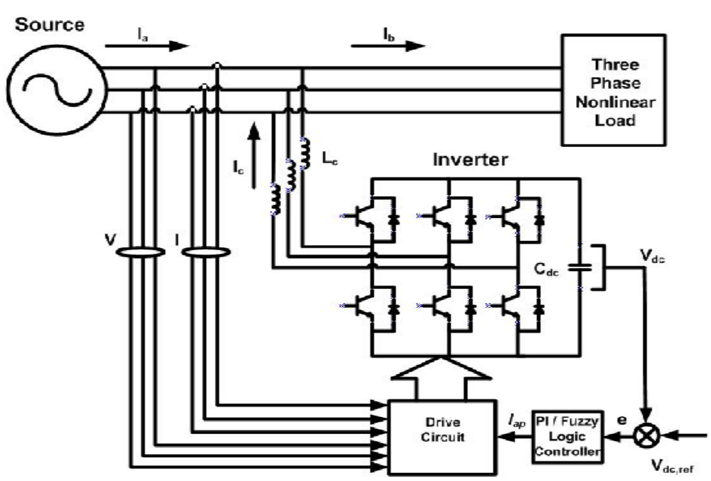

Fig. 1.1. Schematic Diagram of Shunt Active Filter

Fig.1.1 represents the schematic diagram of Shunt active filter. The shunt active filter is comprised by the controller block, the inverter block (IGBT module), the DC bus (with a single capacitor), and the coupling to the power system block (with an inductance for each phase and neutral wire).

The DC side capacitor serves two main purposes: (i) it maintains a DC voltage with small ripple in steady state, and (ii) serves as an energy storage element to supply real power difference between load and source during the transient period. In the steady state, the real power supplied by the source should be equal to the real power demand of the load plus a small power to compensate the losses in the active filter. Thus, the DC capacitor voltage can be maintained at a reference value.

The inverter is used to charge and to provide the required compensation current. The capacitor (C) is used to store energy and the inductance (Ls) is used to smooth and decrease the ripple of the harmonic current injected by the active power filter. The AC supply provides the required active power and the capacitor of active power filter provides the reactive power for the load.

A three phase MOSFET based bridge with an energy storage capacitor on the DC side is connected in parallel with the load and acts as a voltage fed inverter. The three phase inverter is built by six MOSFETs that are chosen according to their rating. Anti parallel diodes are connected across these power switches for protection and provides power conversion in reverse direction in order to recharge the DC capacitor whenever its level goes lower than a reference value. The large size capacitor is connected to the inverter so that a constant level of voltage can be maintained over each switching cycle.

An inductor, when connected in series circuit with the inverter circuit will provide better isolation for high frequency components. Control of the injected current wave shape is limited by the switching frequency of the inverter and the available driving voltage across the interfacing inductance.

III. BLOCK DIAGRAM

A. Shunt Active Filter with PI controller

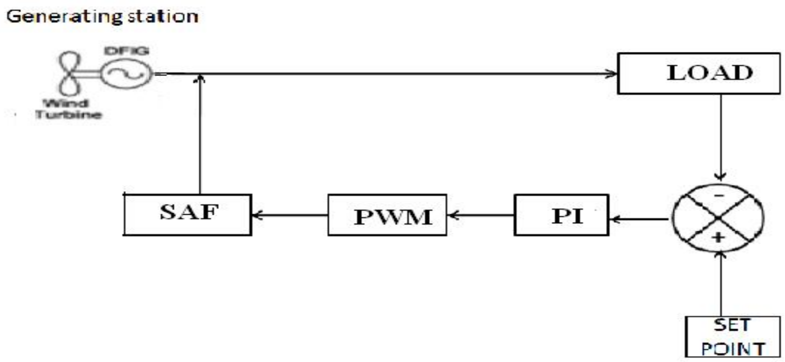

Fig.2. Block diagram of Shunt Active Filter with PI controller

Fig.2. shows the block diagram of the implemented PI control scheme of a shunt active filter. The block diagram consists of , PI controller.PWM converter, Shunt Active Filter, DFIG based Wind farm and Dc voltage regulator. The shunt active power filter mainly consists of DC link capacitor, filter inductor, PI controller.

1) *DC Link Capacitor:* The DC link capacitor mainly used for two purposes- (a) It maintain a Constant DC voltage (b) It supply real power difference between load and source during transients and also it act as a energy storage element In this scheme the role of the DC link capacitor is to absorb/supply real power demand of the load during transient.
2) *PI Controller:* The controller used is the discrete PI controller that takes in the reference voltage and the actual voltage and gives the maximum value of the reference current depending on the error as shown in fig 2.1

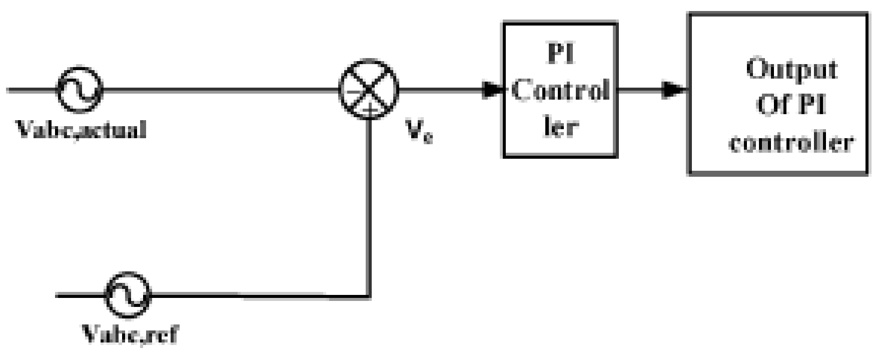

Fig. 2.1 Block diagram of PI controller

3) *PWM Controller:* The shunt active filter is controlled with the help of PWM logic controller. The modulation wave of the reference current is determined by the difference between the injected current and the reference current. These voltages are compared and generate switching pulses. PWM is a MOSFET inverter.

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B. Shunt Active Filter with PRC

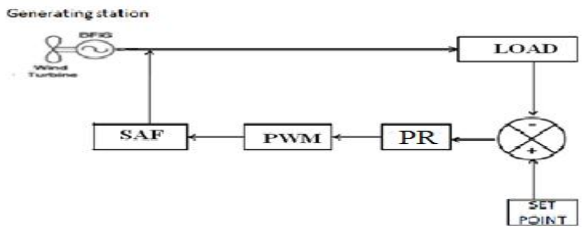

Fig. 3. Shunt Active Filter with Proportional Resonant Controller

The PR controller operation with shunt active filter is Source voltage and source current values are given to the reference generator. It will produce I_{ref} and given to PR controller. Using PR controller error should be compensated. The peak value of the reference currents is estimated by regulating the DC link voltage. The actual capacitor voltage is compared with a set reference value. The error signal is then processed through a PR controller .The reference currents and actual currents are compared to a PWM, which gives the error signal for the modulation technique. This error signal decides the operation of the converter switches. The inverter circuit triggering depends on the control circuit output. The proposed system use PWM control to produce the pulse to trigger gate of MOSFET.

The PR tool is a mathematical tool for dealing with uncertainty. It is important to observe that there is an intimate connection between PR and Complexity. The advantages of PR controllers over conventional controllers like PI controllers are that they do not need accurate mathematical model, they can work with imprecise inputs, can handle non-linearity, load disturbances etc.

IV. IEEE NINE BUS SYSTEM

The circuit of Active filter is shown in Fig. 4.1.A large DC capacitor is selected and it is added on DC side. The capacitor on the DC side and the inductor on the AC side are the elements of the filter. The filter is tuned to the frequency requires by the load. The single line diagram of nine bus system is shown in Fig.4. This has Three-generator buses and six load buses. The line data and load data is given in Table 1.The generators buses are bus-1, bus-2 (wind generator)and bus-3(wind generator) respectively. The buses ,4,5,6,7, 8,9represent load buses. Diode bridge RL load is taken as a nonlinear load.

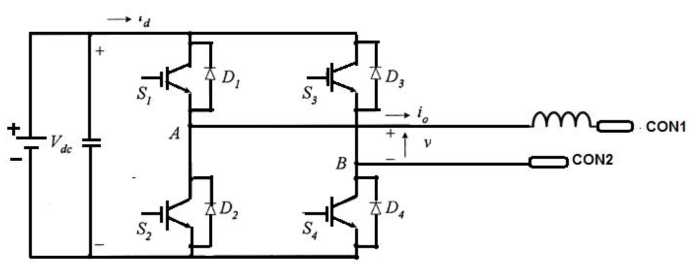

Fig. 4.1 Circuit of Shunt active filter

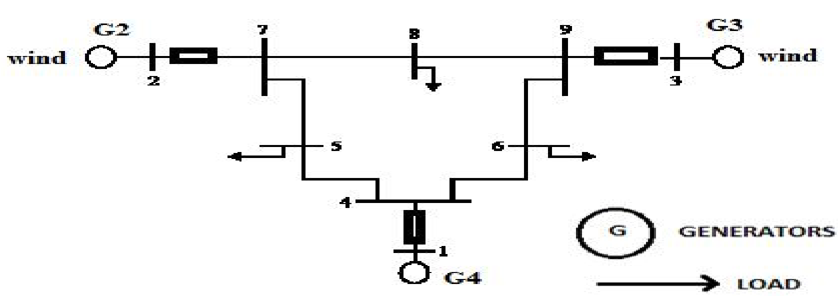

Fig. 4.2 IEEE Nine bus system-single line diagram

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V. SIMULATION RESULTS

A. Simulation Results with Pi Controller

Closed loop SAF system with PI controller is shown in Fig 5.1. The voltage at bus6 is shown in Fig 5.2 and its value peak value is 4000 V. The RMS voltage of bus6 is shown in Fig 5.3 and its value is 2900 V. The real power is shown in Fig 5.4 and its value is $2*10^5$ W. The reactive power is shown in Fig 5.5 and its value is 2000VAR.

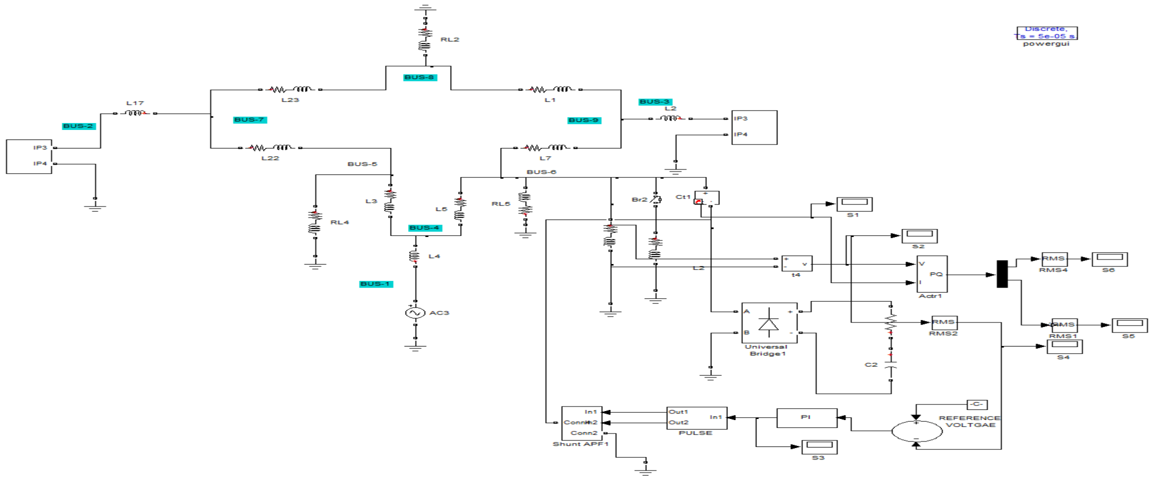

Fig 5.1 Closed loop SAF system with PI controller

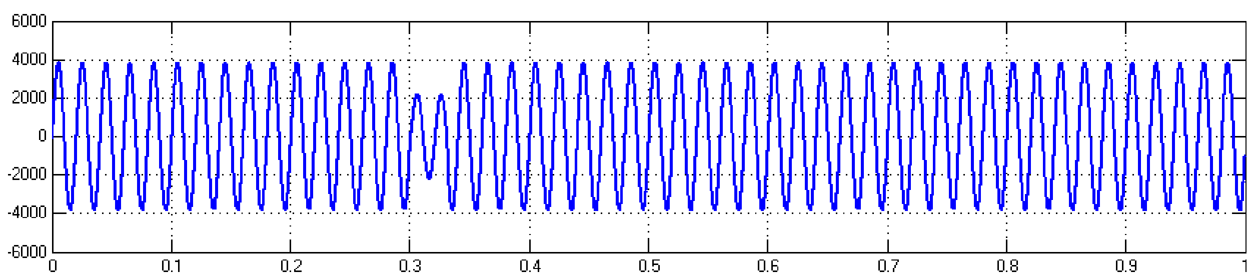

Fig 5.2 Voltage at Bus 6

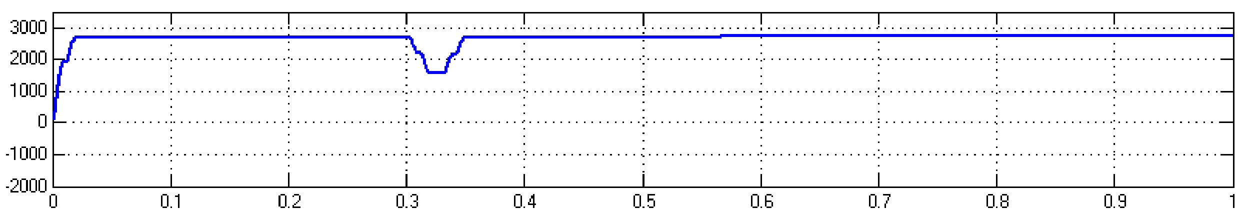

Fig 5.3 RMS Voltage at Bus 6

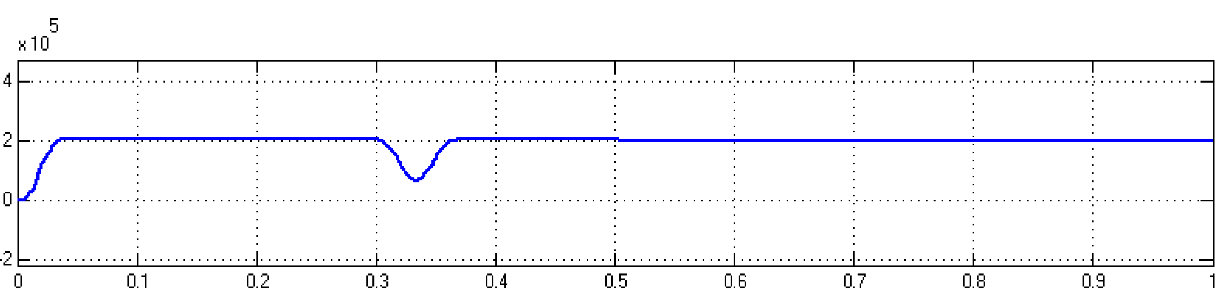

Fig 5.4 Real power

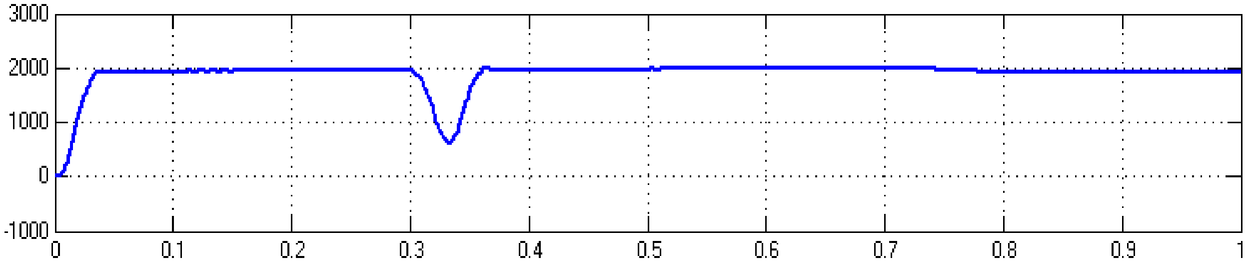

Fig 5.5 Reactive power

B. Simulation Results With Pr Controller

Closed loop SAF system with PR controller is shown in Fig 5.6. The output voltage is shown in Fig 5.7 and its value is 4000 V. The Output voltage of RMS is shown in Fig 5.8 and its value is 2750 V. The real power is shown in Fig 5.9 and its value is $2*10^5$VAR. The reactive power is shown in Fig 5.10 and its value is 2000 Watts. The Comparison of time domain parameters is given in Table-1.

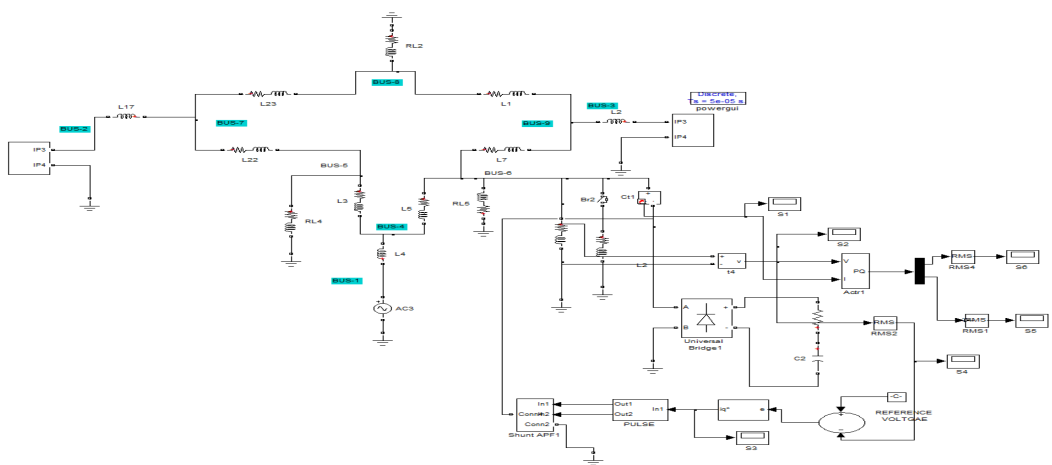

Fig 5.6Closed loop SAF system with PR controller

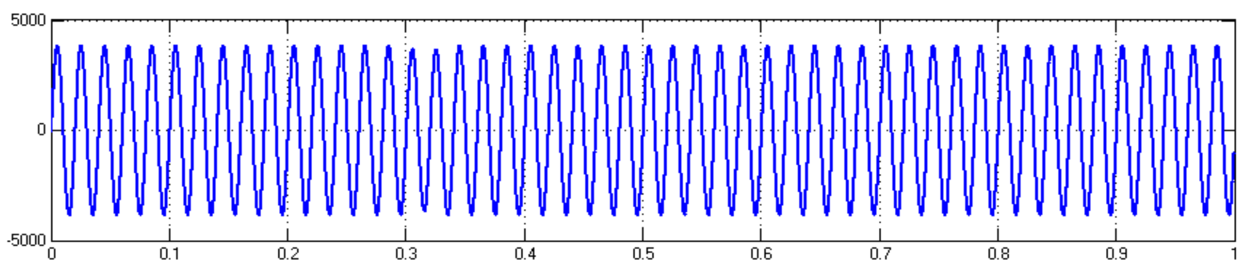

Fig 5.7Voltage at Bus 6

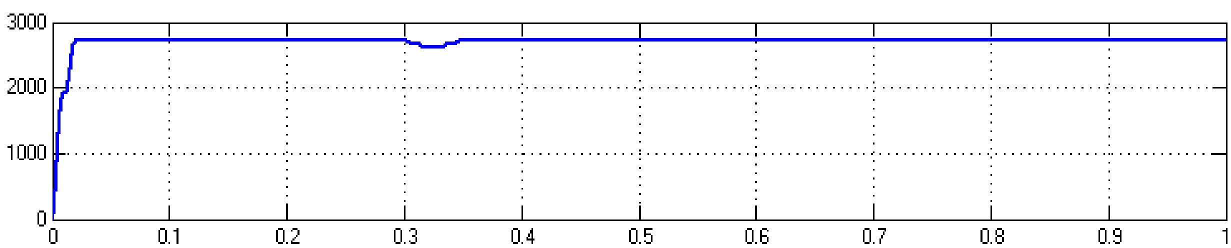

Fig 5.8Output voltage of RMS

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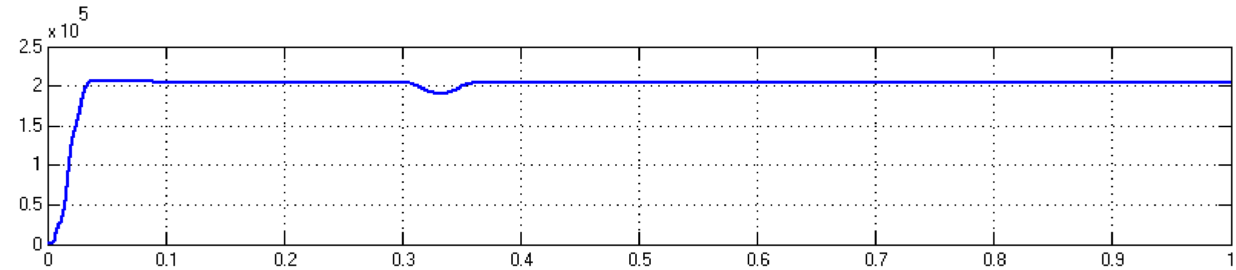

Fig 5.9Real power

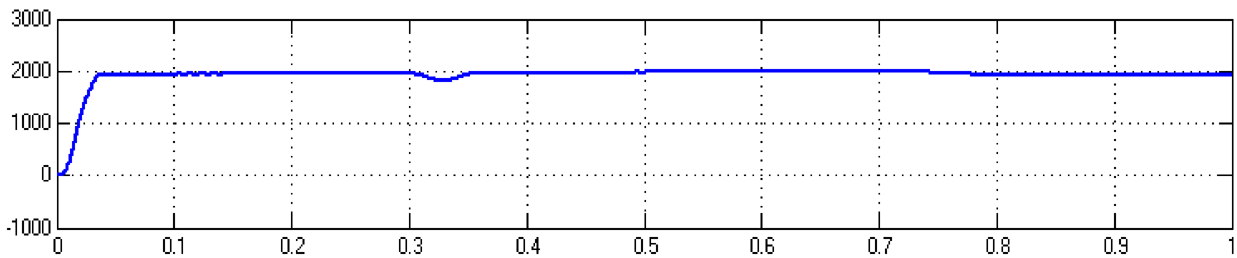

Fig 5.10Reactive power

Table-1
Comparison of time domain parameters

Controllers	Rise time (s)	Peak time (s)	Settling time (s)	Steady state error (V)
PI	0.32	0.34	0.35	4.53
PR	0.31	0.032	0.033	1.56

VI. CONCLUSION

Nine bus systems in closed loop are simulated and the results with PI and PR are presented. The steady state error is reduced from 4.53V to 1.56V. Therefore PRC based active filter may be a viable alternative to the existing controller. The reduction in settling time and steady state error are very high in the case of PRC system. The settling time is reduced from 0.35 seconds to 0.033 seconds. The advantages of proposed system are reduction in losses, line drop, steady state error and settling time. The disadvantage is that SAF requires large inductor and capacitor.

The present work deals with the investigation on nine bus system. The improvement in power quality of fourteen bus system using PRCSAF will be done in future.

APPENDIX –I
System Parameters

Sl.no	Parameters	Values
1	Frequency	50 Hz
2.	Wind generator	9 MW
2	Source voltage	6.3kv
3	Line impedance	3 Ω 10mh
4	PI controller	Kp-0.2 Ki-0.5
5	Load impedance	1Ω,70mh
6	Inductance of active filter	100mh
7	Output capacitance	100e-6
8	MOSFET	Irf840

APPENDIX – II Line and Load data

	VOLTAGE (v)	LOAD IMPEDANCE	
		R (Ω)	X (mh)
BUS 1	6350	-	-
BUS 2	6350	-	-
BUS 3	6350	-	-
BUS 4	-	5Ω	60mh
BUS 5	_	3Ω	35mh
BUS 6	-	100 Ω	50mh
BUS 7		100 Ω	50mh
BUS 8		50Ω	50mh
BUS 9		100Ω	50mh

line	RESISTANCE (Ω)	INDUCTANCE (mH)
1-2	3Ω	10mH
2-3	5Ω	15mH
3-4	3Ω	10mH
5-6	2Ω	8mH
6-7	3Ω	10mH
7-8	9Ω	50mH
8-9	3Ω	10mH

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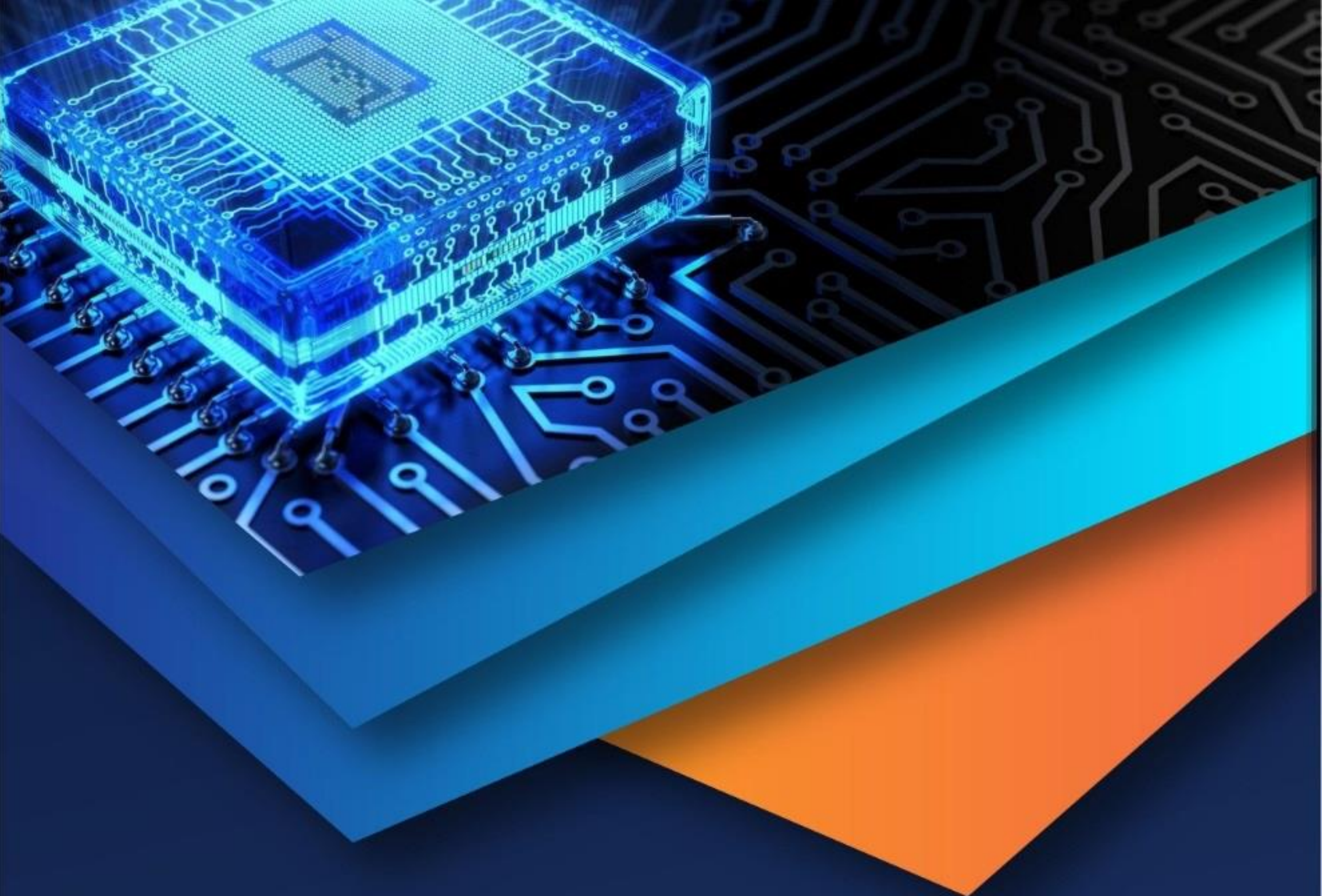

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