Enhancement of Power Quality in Grid coupled DFIG based Wind System by using STATCOM and BESS with Fuzzy Controller

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ABSTRACT: By means of the increase in demand for electricity due to increase in population industrialization, the generation of power is really a challenge now a days. It is essential to meet the energy needs by utilizing the renewable energy resources like wind, biomass, hydro co-generation, etc. Addition of the wind power into an electric grid affects the power quality. The major power quality issues are voltage sag, swell, flickers, harmonics etc. During this future scheme Static Compensator (STATCOM) is linked at the point of common coupling with a battery energy storage system to mitigate the power quality issues. The STATCOM provides reactive power support to hybrid system and load. The Battery Energy Storage System (BESS) is generally required to compensate the fluctuation generated by hybrid system. The proposed Inverter control scheme to mitigate the power quality issues for power quality improvement in the grid connected hybrid power generation system is simulated using MATLAB/ SIMULINK in power system block set. The control scheme has a capability to cancel out the harmonic parts of the load current and maintains the source voltage and current in-phase. The performance of the system using PI and Fuzzy controller has been studied comparatively.

Key words: ***Battery energy storage system, DFIG, Power Quality, STATCOM, Wind Farm, Power Quality, Voltage Sag, fuzzy logic controller.***

INTRODUCTION:

The increasing number of Renewable Energy Sources and Distributed Generation (DG) requires new technique for the operation and management of the electricity grid to enhance power supply reliability and power quality. The distributed generation and in integration of Renewable Energy Sources into the grid provides power quality problems. By using renewable energy sources we can get pollution less environment and it is available enormously in nature. Power shortage is reduced by implementing distributed generation. The power electronic loads place a major role in industries. These nonlinear loads inject harmonic currents in the AC system and increase overall reactive power demand by the equivalent load. The major power quality problems are from system to load voltage sag/swell, voltage unbalance, voltage distortion and interruptions and from load to system are current harmonics, reactive current, current unbalance, voltage notching and voltage flickering [1-2]. These problems can be mitigated by using various techniques. Proportional Integral (PI) control instead of power converter is implemented to manage reactive power interchange between wind farm and grid. To control power converter, a new current sharing approach is proposed in [3]. Pulse Width Modulation (PWM) based controller operates the inverter circuit to give a desired output. When turbine starts high frequency current flows through rectifier circuit and then stores into the dc-link capacitor. Instead of using dc-link capacitor storage device [4], [5] separate Battery Energy Storage System (BESS) is proposed in [6]. By using State of Charge (SOC) technique BESS control is done. State of Charge (SOC) technique proposed in [7] investigates with cascade pulse width modulation are presented. The experimental system includes no voltage-balancing control because it uses nine NiMH battery units that have an almost flat charge/ discharge voltage profile. In [8] STATCOM based control scheme for power quality improvement in grid connected wind generating system and with nonlinear load is presented. This method reduces harmonic parts of load current. It maintains the current and source voltage in phase and also compensates reactive power demand only but produce harmonics [9]. The operation of the control system developed for the STATCOMBESS in MATLAB/SIMULINK for maintaining the power quality is simulated. To overcome these issues I proposed this paper.

Here proposing a STATCOM based control technology for mitigating the power quality issues when we are integrating wind farms to the grid. In the event of increasing grid disturbances, a battery energy storage system is required to compensate the fluctuation generated by wind turbine. Here two control schemes for STATCOM is designed and compared: Bang Current controller and fuzzy logic controller. PI controller plays an important role in reducing fluctuating voltage error signal efficiently. Simulation result shows that the proposed SVC and STATCOM with PI controller is efficient in mitigating voltage sags and thus improving the power quality of the power grid. Fuzzy logic technique has been used as it has advantage of robustness, easily adaptive fast technology is also used and best results are achieved when compared to conventional PI technique.

PROBLEMS RELATED TO POWER QUALITY & ITS AFTER MATH

A. Power Quality Issues of Grid Side:

Problems associated with power quality on the grid which affect the wind generators are generally troubled with the voltage quality that is being provided by the utility. In other words, the quality of voltage is a utility responsibility to supply “Worthy” voltage. Some of the voltage parameters that should be considered are:

1) Voltage variation:

Variation of voltage has several impacts on reactive and active power of grid connected wind farms. In low-voltage situation, most of the current will flow through the generator, power equipment and the line which leads to increasing the losses. On the other side low voltage also affects power factor. This effect occurs when capacitive VAR generated by installing capacitor, decreased by reduction of voltage. Voltage increment also affects systems operation; higher voltage will increase the stress on the insulation which leads to reduce the life of them and the magnetization VAR of transformer [4, 5].

2) Voltage Transients:

Capacitor switching which uses mechanical switches may cause large voltage transient. These capacitors are provided as an essential part of the wind turbine generators (WTG) for compensation of reactive power. The frequency and amplitude of such transient are enormous, particularly when back to back switching is involved, for instance capacitor bank switching. When the voltage transient happens repeatedly it will damage insulation system, Moreover, sensitive electronic equipment of the generator control scheme thereby premature failure will happen. Turbine blades are highly susceptible to lightning strikes; thus lightning strike will cause damage the wind turbine. In addition, lightning strikes will cause an overvoltage in the electrical system of wind turbine.

B. Power Quality Issues of WTG Side

WTG power quality issues that affect the WTG are primarily troubled with the current quality which is being generated or drawn by the WTG's. It is the connected loads responsibility to provide an improvement due to the power quality of current injected or drawn into the grid. Some of the properties of current are:

1) Reactive Power Consumption:

Using induction generators for energy conversion cause reactive power consumption in a wind farm. Consumption of reactive power due to generating real power is the basic principle of induction generators, in addition the reactive power consumption will be extensively grown by step up transformers magnetization current. Reactive powers maintain the transmission line voltage which requires to deliver the active power. Reactive power is needed for different loads due to convert the flow of electrons into beneficial work. Reactive power should be enough to decrease the voltage sag.

2) Current Harmonics Generation:

Current harmonics are created as a result of the soft starting in induction machines during the mode of motoring. Huge generators concentrated on geographic locations that are small and huge sequel impedance linked to wind farms, thereby present harmonics would be changed to voltage harmonics. The whole line of consumers interconnected will get impacted because of this and due to the distortion of voltage on line. Current harmonics can also result in overheating the transformers. This can result in the capacitor's impulsive failure. The possibility of an intensification of the resonance harmonic as well stays alive with risks in the form of failures that are disastrous [6].

MODEL OF THE POWER GRID

The single line diagram of test system usd in this study is illustrated in Figure.1. The grid model consist of a 120 kV, 60 Hz, grid supply point, feeding a 25 kV distribution system through 120/25 kV, 47 MVA step down transformer, which is fed a 575V system through 25kV/575V, 12 MVA step down transformer. The system has 2 separate loads. There is a 2 MVA load with a lag of 0.9 pf at thirty kilo metres from the transmission line. The other one is a 500 kilo watts static load at 575 B bus. The line of 25 kV, thirty kilo metres is shown as a nominal-Π line. The DFIG based wind farm is made up of 6 wind turbines each with a 1.5 Mega Watts i.e. a total of 9 Mega Watts, that has a protection system monitoring voltage, current, the speed of the machine and the DC link voltage is connected at 575V bus. There is a gradual increase in the speed of the wind from 8 metres per second to 14 metres per second at 16 seconds, which is its stable state. All the tests here are studied after system reaches steady state i.e. after 16 sec. The GSC in DFIG preserves the DC link voltage nearly constant at 1200 V for the period of normal operating condition. To provide dynamic compensation of reactive power, the STATCOM is connected as a shunt reactive power compensator at the sending end bus (25kV bus). Table 1 shows the systems' factors' parameters [7].

A. DFIG-BASED WIND FARM

In this study doubly fed induction generator i.e. DFIG used in the wind farm. The DFIG known as a wound rotor induction generator which its stator winding connected directly to the three phase grid with constant frequency on the other hand a converter on the rotor side fed the rotor winding and grid side convertor connected back-to-back. Stator reactive and active power regulated independently by rotor side convertor (RSC) and while grid side convertor (GSC) tant from direction and magnitude of the rotor

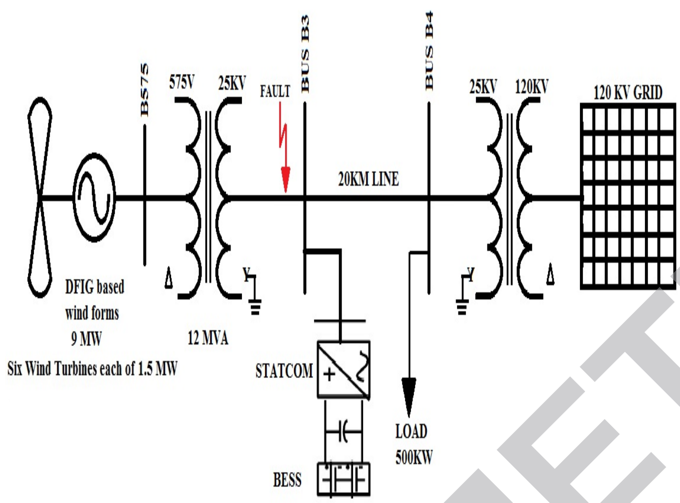


Figure.1.Single Line Diagram of the Test System.

Wind turbine		Generator parameters		Transmission Line parameters (π Model)	
Rated capacity	(6 wind turbine × 1.5 MW) 9MW	P_{rated}	6G × 1.5MW	r_l	0.1153 Ω/km
Cut-in wind speed	3.5m/s	V_{rated}	575 V	r_o	0.413 Ω/km
Cut-out wind speed	25m/s	r_s	0.00706	l_l	0.00105 H/km
Rated wind speed	14m/s	r_r	0.005	l_o	0.00332 H/km
No. of blades	3	l_{ls}	0.171	C_l	11.33 F/km
Rotor diameters	82.5m	l_{lr}	0.156	C_o	5.01 F/km
Swept area	5346 m^2	L_m	2.9		
Rotor speed	10.1-18.7 rpm	pf	0.9		

Table.1.System Components' Parameters

Power generation can be achieved by means of DFIG leading to higher energy yield where the wind speed fluctuating between sub/super-synchronous speed. These days DFIG wind turbines are more broadly used particularly in large wind farms for the reason that they are capable to supply power at constant range of voltage and frequency while speed of rotor varies. Nowadays unity power factor operation preferred by several operators because it is the active power production that is rewarded. Reactive power is produced only if there are sufficient financial incentives although DFIG has the capability to control the overall system power factor within its capacity as its active and reactive power output can be controlled independently. The DFIG has some disadvantages during grid faults. DFIG stator is connected directly to the grid.

So during grid fault, some undesirable high current may be induced in the rotor windings and the protection system may block the RSC. DC-link capacitor voltage reaches high level during low terminal voltage because fault makes active power unbalance between RSC and GSC higher.
As a result, utilities disconnect the DFIG immediately for its protection. Hence to minimize effects of the grid side disturbances like 3-phase fault, abrupt load change, voltage swelling and sagging in DFIG-wind farm during and after fault, reactive power compensation is required because DFIG-based wind farm can't provide sufficient reactive power and voltage support due to its limited power capacity, for example 9 MW[7].

B. STATCOM

Static Synchronous Compensator is a Flexible AC Transmission System device. It consists of a Voltage Source converter, a dc energy storage device, a coupling transformer connected in shunt to the distribution network through a coupling transformer. The VSC converts the dc voltage across the storage device into a set of three-phase ac output voltages. It can continuously generate or absorb reactive power by varying the amplitude of the converter voltage with respect to the line bus voltage so that a controlled current flows through the tie reactance between the STATCOM and the distribution network. This enables the STATCOM to mitigate voltage fluctuations such as sags, swells, transient disturbances and to provide voltage regulation.

Rating	3 MVA
Operations' Mode	Voltage regulation
Point of Common Coupling's Reference Voltage	25 KV
Voltage DC Linked	4000 V
Capacitor inside DC Link	3.75 mF
Link Inductance that is Synchronous	6.6 mH, 0.04 Ω

Table.2.STATCOM Components' Parameters

The precise rating of the STATCOM is calculated depending upon many parameters and is mainly governed by amount of reactive power demanded by the system to recover and ride through typical fault or disturbances on the system so as to reduce the chances of losing synchronism with the power grid. Final decision of STATCOM rating is decided by financial analysis of the system. In this study, a 10 MVA STATCOM is selected which is found to be enough for protecting the wind farm from losing synchronism with the grid under different temporary disturbances studied below in the paper. [8]. Table.2 shows the STATCOMs' factors' parameters.

C. BESS- STATCOM

The BESS is adopted as an energy storage component to provide the voltage regulation. It will naturally preserve dc capacitor voltage constant and is best suited in STATCOM since it quickly injects or absorbed reactive power to stabilize the grid system. Moreover, it controls the distribution and transmission system in a very fast rate. When power fluctuation happens in the system, the BESS can be used to smooth the power fluctuation by charge/discharge process. The battery is connected in parallel to the dc capacitor of STATCOM. The STATCOM is a three-phase voltage source inverter having the capacitance on its DC link and connected at the PCC. The STATCOM injects a compensating current of variable magnitude and frequency component at the bus of common coupling [9].

FUZZY LOGIC CONTROL

L. A. Zadeh presented the first paper on fuzzy set theory in 1965. Since then, a new language was developed to describe the fuzzy properties of reality, which are very difficult and sometime even impossible to be described using conventional methods. Fuzzy set theory has been widely used in the control area with some application to power system [5]. A simple fuzzy logic control is built up by a group of rules based on the human knowledge of system behavior. Matlab/Simulink simulation model is built to study the dynamic behavior of converter. Furthermore, design of fuzzy logic controller can provide desirable both small signal and large signal dynamic performance at same time, which is not possible with linear control technique. Thus, fuzzy logic controller has been potential ability to improve the robustness of compensator.

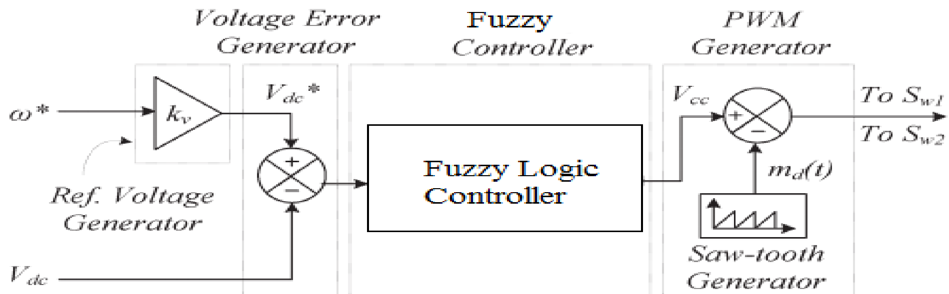


Fig. 2. Fuzzy logic Control of the PFC BL-CSC converter feeding BLDC Motor Drive.

The basic scheme of a fuzzy logic controller is shown in Fig 3 and consists of four principal components such as: a fuzzy fication interface, which converts input data into suitable linguistic values; a knowledge base, which consists of a data base with the necessary linguistic definitions and the control rule set; a decision-making logic which, simulating a human decision process, infer the fuzzy control action from the knowledge of the control rules and linguistic variable definitions; a de-fuzzification interface which yields non fuzzy control action from an inferred fuzzy control action.

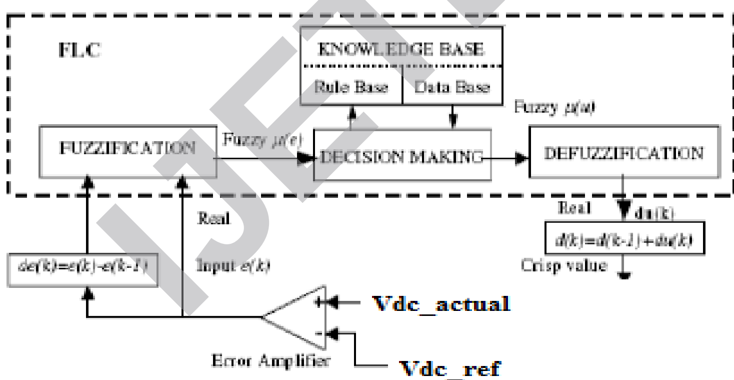
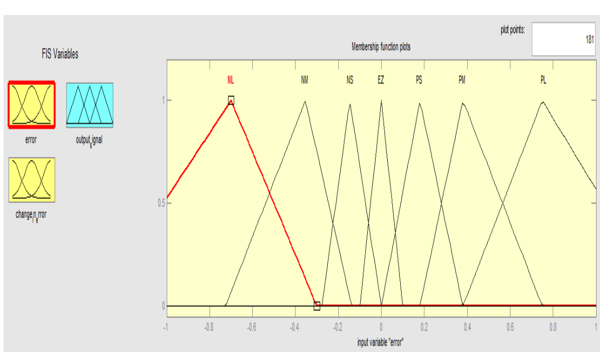


Fig.3. Block diagram of the Fuzzy Logic Controller (FLC) for proposed converter.



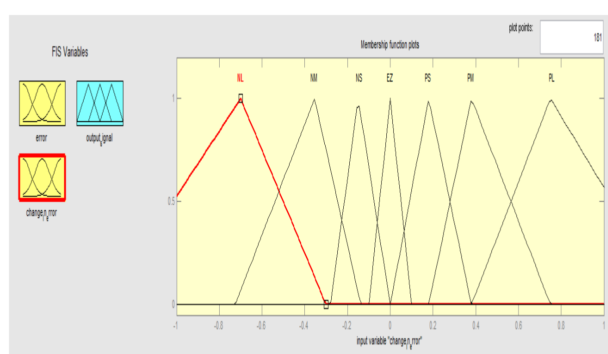


Fig.4 Membership functions for error.

Fig.5. Membership functions for change_ in_ error.

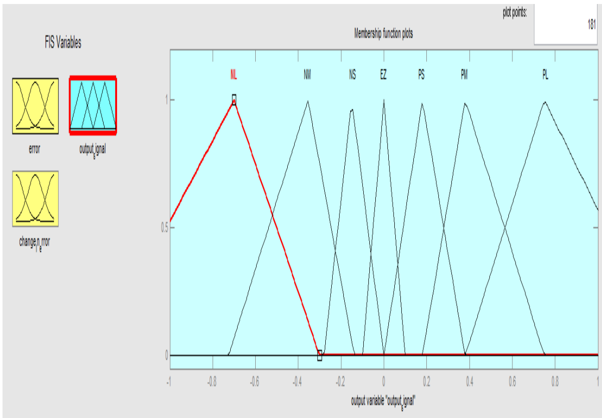


Fig.6. Membership functions for Output.

Change error \ Error	NL	NM	NS	EZ	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	NL
NM	NL	NL	NL	NM	NS	EZ	NM
NS	NL	NL	NM	NS	EZ	PS	NS
EZ	NL	NM	NS	EZ	PS	PM	EZ
PS	NM	NS	EZ	PS	PM	PL	PS
PM	NS	EZ	PS	PM	PL	PL	PM
PL	EZ	PS	PM	PL	PL	PL	PL

Table 3: Table rules for error and change of error.

MATLAB/SIMULATION RESULTS

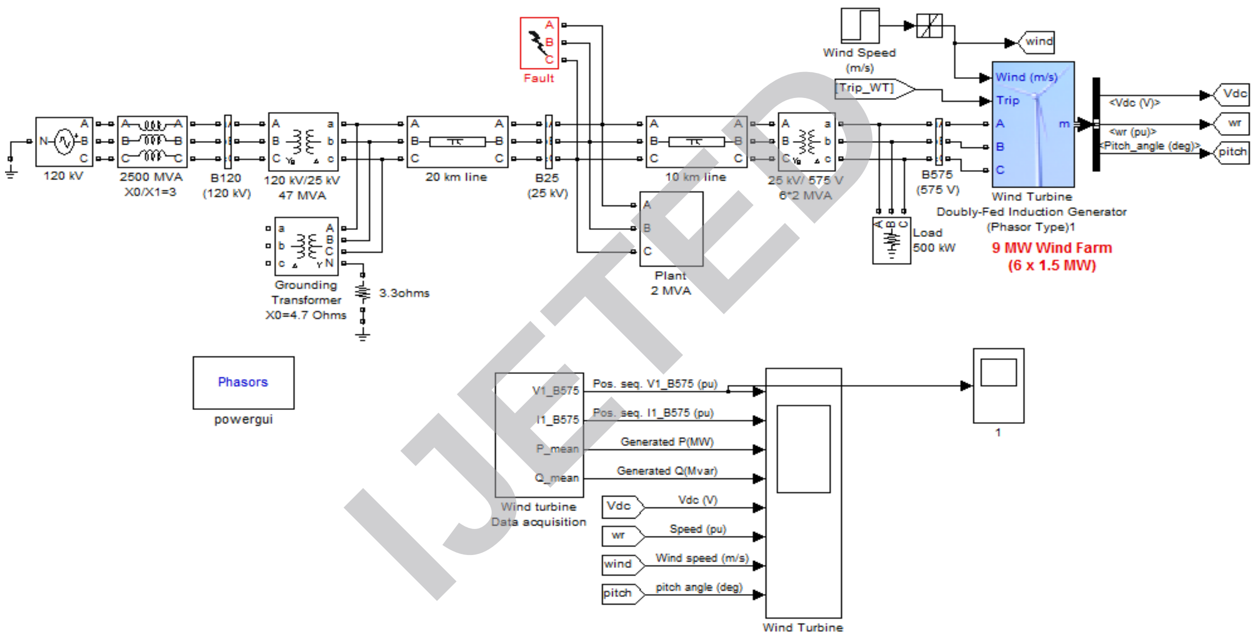


Fig.7.Matlab/Simulation model of Proposed Converter.

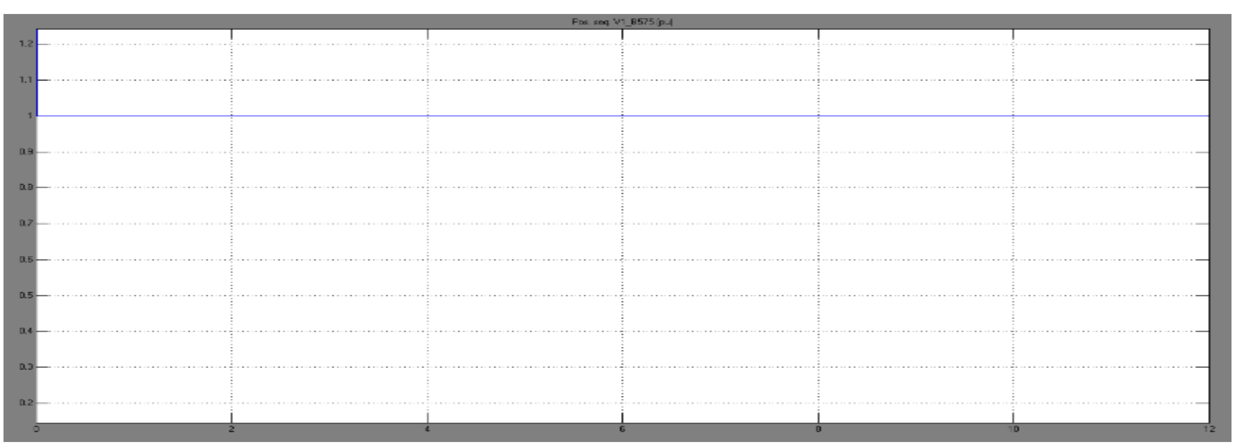


Fig.8.PCC (Bus B575) voltage under no fault Condition. (1 PU)

A. Single Line to Ground Fault with static synchronous compensator and RSC Blocking

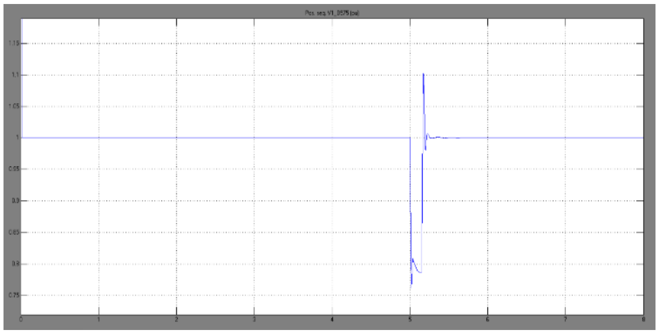


Fig.9.PCC (Bus B575) voltage during SLGF without compensation.

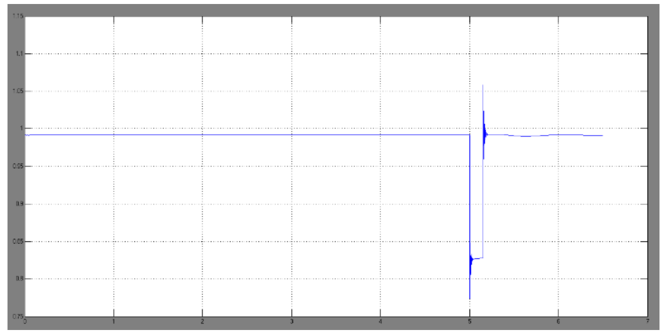


Fig.10.PCC (Bus B575) voltage during SLGF with the STATCOM

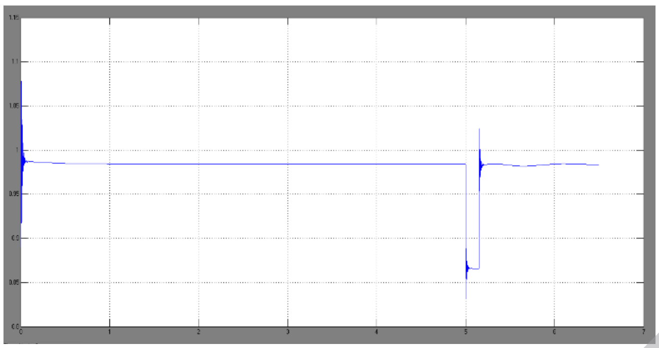


Fig.11.PCC (Bus B575) voltage during SLGF with a STATCOM & BESS

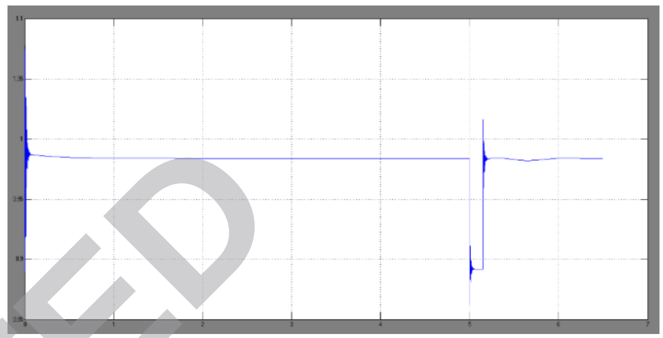


Fig.12.PCC (Bus B575) voltage during SLGF with Fuzzy Logic Controller

B. Line to Line Fault (L-L) with static synchronous compensator and RSC blocking

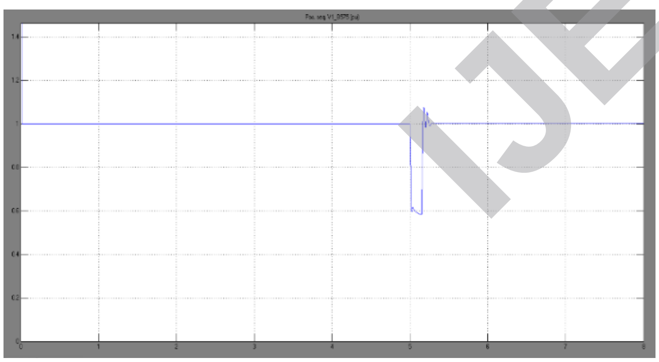


Fig.13.PCC (Bus B575) voltage during L-L fault.

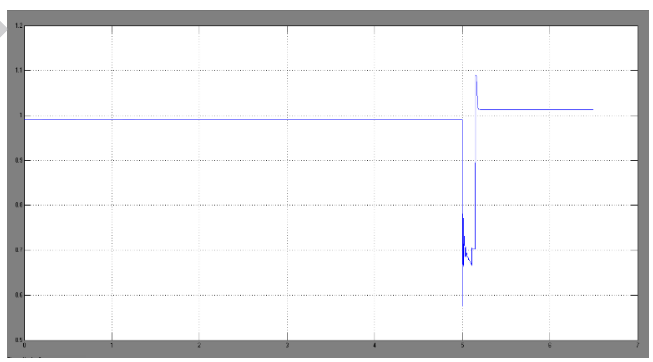


Fig.14.PCC (Bus B575) voltage during L-L fault with a STATCOM

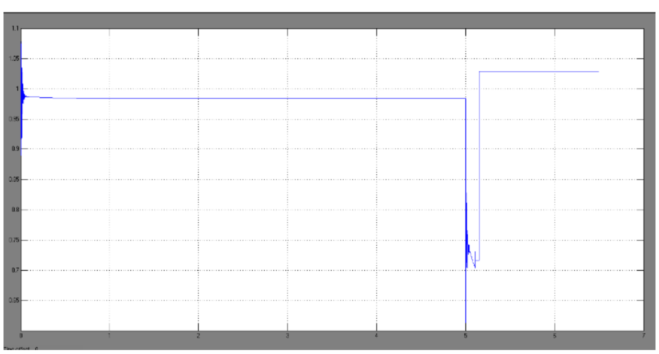


Fig.15.PCC (Bus B575) voltage during L-L fault with STATCOM - BESS

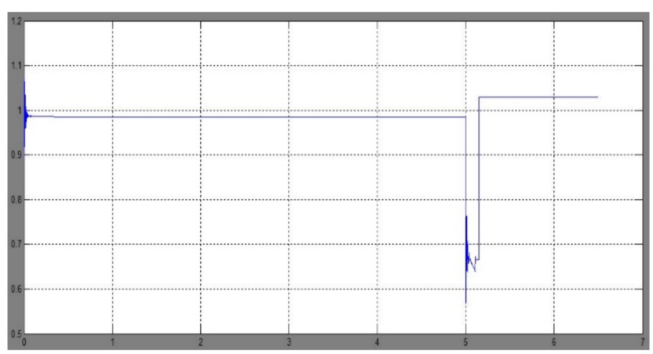


Fig.16.PCC (Bus B575) voltage during L-L with Fuzzy Logic Controller

C. Voltage Sag (30%) with static synchronous compensator and RSC blocking

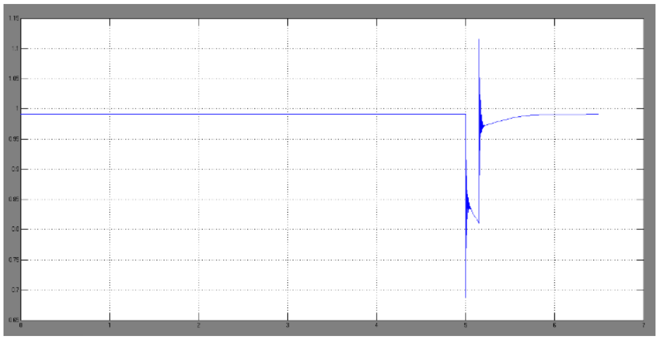


Fig.17.PCC (Bus B575) Voltage during voltage sag of 30% at Bus 120kV

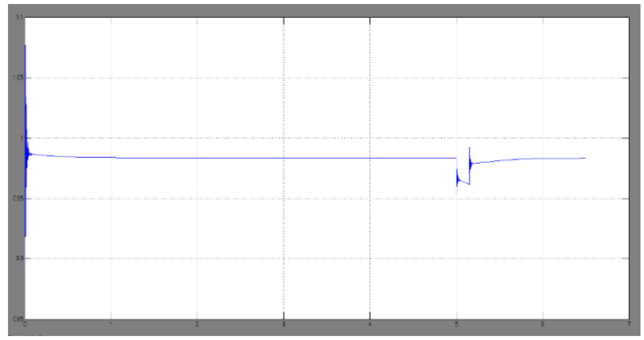


Fig.18.PCC (Bus B575) Voltage sag (30%) at Bus 120kV with a STATCOM

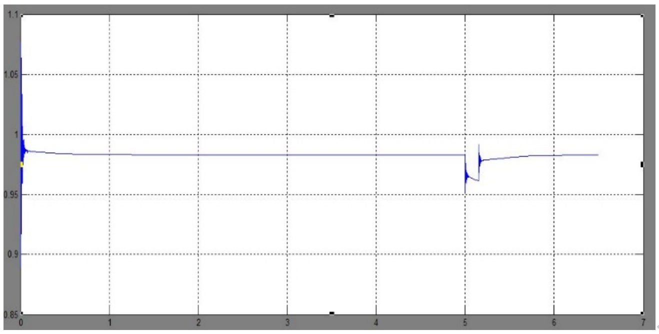


Fig.19.PCC (Bus B575) Voltage sag (30%) at Bus 120kV with a STATCOM-BESS

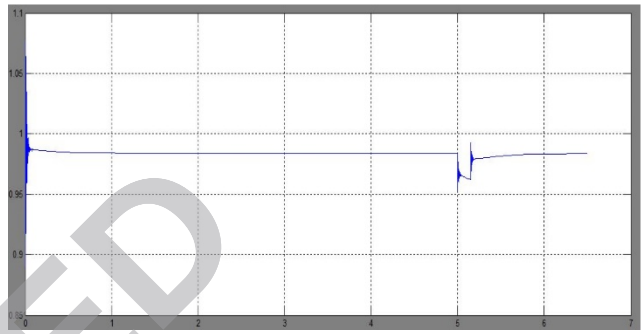


Fig.20.PCC (Bus B575) voltage during Voltage sag of 30% with Fuzzy Logic Controller

CONCLUSION

This paper presents the STATCOM-based control scheme for power quality improvement in grid connected wind generating system with nonlinear loads. The operation of the STATCOM is simulated using three controllers: PI controller, Fuzzy logic controller and HPF controller. STATCOM injects current to the grid and it cancel out the reactive and harmonic parts of the induction generator current and load current .When we are reducing the wind generating system output ,it will not affect the source current magnitude. It has a capability to cancel out the harmonic parts of the load current. It maintains the source voltage and current in-phase and support the reactive power demand for the wind generator and load at PCC in the grid system, thus it gives an opportunity to enhance the utilization factor of transmission line. The integrated wind generation and FACTS device with BESS have shown the outstanding performance.

TYPE OF FAULT	PCC (BUS 575) VOLAGE COMPARISION			
	Without STATCOM & BESS (PU)	With STATCOM (PU)	With STATCOM & BESS (PU)	With STATCOM, BESS WITH FUZZY LOGIC (PU)
Line to Ground (LG) Fault	0.76	0.78	0.83	0.88
Line to Line (LL) Fault	0.58	0.59	0.63	0.69
Voltage Sag (30%)	0.81	0.83	0.95	0.98

Table 4: Table showing the comparisons of voltages at PCC (BUS-575) with different compensation techniques under different fault Conditions

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