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Analysis of Fault Ride through Capabilities in Wind Plants using STATCOM and UPFC-A Case Study

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***Abstract*—Voltage dip is one of the major concerns related to quality of power in power system. The main objective of this paper is to analyze the stability issues related to wind plant connected to grid. The work flow goes in order by collection of real time data, study of existing methods employed to improve power quality enhancement of wind plant connected to grid. The wind plant connected to grid and the use of FACTS controller such as STATCOM and UPFC controller with consideration of their design and control levels, a grid interactive wind plant model is built using MATLAB/SIMULINK model.**

The developed SIMULINK model is studied for steady state analysis of reactive power compensation and voltage variation in wind plant. The system is analyzed with and without STATCOM and UPFC controller for different condition to study voltage variation and reactive power support.

Keywords— Cerc,Facts,Statcom,Upfc.

I. INTRODUCTION

The technical development and sophistication life style has increased the use of electricity. The growing demand of electricity, depletion of fossil fuels, global warming has been a concern. This has led to generate electricity using green energy which is gaining a momentum all over the world. Hence, low cost and reliable low carbon electricity generation has been given much attention in many countries. Wind plant which is a green energy has large penetration into the power system network and wind grid penetration is expected to be 20 percent by 2030.This major increase in the capacity of wind energy in power system may affect the grid performance.

Grid interactive wind plants are susceptible to the faults caused by lightning, failure of insulation, generation and load pattern in deregulated power system network, contingency and increase in loading of transmission line. These can lead to voltage dip due to increased consumption of reactive power in the power system. So the reactive power support during faulted conditions to wind plant is necessary and it must be fulfilled by wind plants connected to grid as per CERC grid codes.

II. FAULT RIDE THROUGH CAPABILITY REQUIREMENT

The Central Electricity Regulatory Authority of India has issued connectivity standards of wind plant interconnection to grid according to which wind plants should have fault ride through capability.ie at the point of common coupling whenever there is voltage dip on any phase up to 15% of its nominal voltage, wind plant should be able to remain connected to grid during this fault condition till the period of 300ms or when voltage starts recovering. This requirement during faulted condition needs external reactive power support using external reactive power source using FACTS device [1]. Thus, FACTS controller can be opted to mitigate the effects of voltage dip at the point of common coupling for wind plant connected to grid and also provide reactive power support to the wind plant which in turn fulfills fault ride through capability.

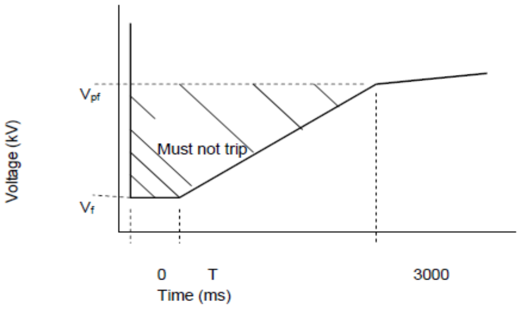

Fig. 1.Fault Ride Through Capability Profile

Vf - 15% of nominal system voltage.
Vpf - minimum voltage

III. SYSTEM UNDER STUDY

A case study system has 24 wind turbines. Analysis and simulation of the same is carried out in this work. Each unit is connected with 1.6 MVA 400V/33kV step-up transformer; units are grouped in 6 rows and fed by separate inter-farm lines up to pooling station. From pooling station generated power will be transmitted via 33/220kV 30MVA Power Transformer and a 220kV line for a distance of about 18kms up Substation.

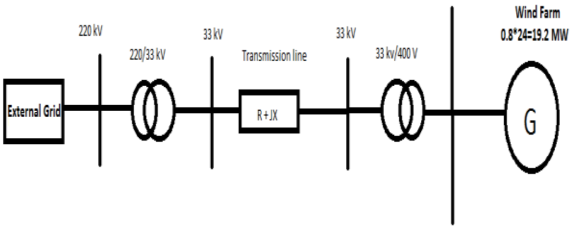

Fig. 2.Schematic diagram of system under study.

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The electrical power generated by wind turbine is given by the following expression

$P=0.5\rho AV^3$.. [1.1]

Where
P - Power in watts.
ρ - Air density (standard air density is 1.2 kg/ m³).
A- Area Swept by turbine blades in m².
V- Wind speed in meter/second.

IV. STATIC SYNCHRONOUS COMPENSATOR

A STATCOM is a controlled shunt connected reactive power source. By processing voltage and current waveforms in voltage source converter, a required generation and absorption of reactive power to the system to which it is connected is done. The design is compact since it is an adjustable voltage source behind a reactance. It indicates that reactive power generation and absorption do not need capacitor bank and reactors [2].

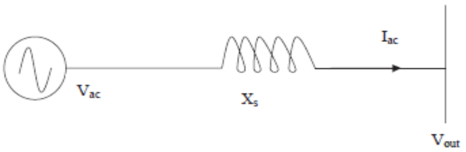

Fig. 3.Equivalent diagram of STATCOM

A STATCOM is a controlled reactive power source as its voltage can be controlled to desired output. The STATCOM consists of voltage source converter and it is connected to bus through shunt transformer as shown in figure 3.

In block diagram we can observe
V_{ac} - Bus Voltage
I_{ac}- STATCOM Injected Current
V_{out}- VSC output voltage
V_{dc} -DC side voltage
I_{dc}- Dc side current

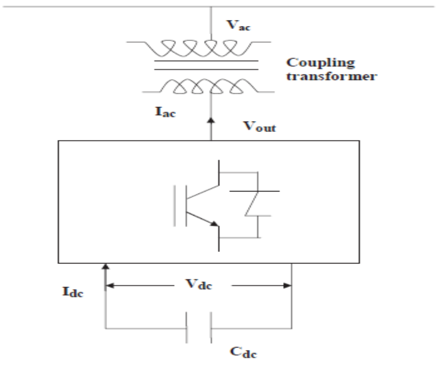

Fig. 4.Schematic representation of STATCOM.

The VSC consists of IGBT with a back to back diode which indicates three arm IGBT bridge present in voltage source converter and voltage source converter has two operations[4]

a. Inverter operation- when IGBT conducts.
b. Converter operation – when Diode conducts.

A STATCOM power exchange characteristics is shown in figure below and by controlling V_{out} of the converter we can control the exchange of reactive power between converter and ac system to which it is connected. If the amplitude of V_{out} is greater than V_{ac} then reactive current flows from converter to the AC system i.e. reactive power flows from converter to AC system. When amplitude of V_{out} is less than V_{ac} then the reactive power flows from AC system to converter [3].

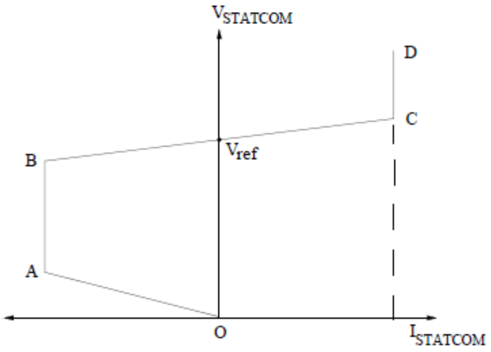

Fig. 5.VI characteristic of STATCOM

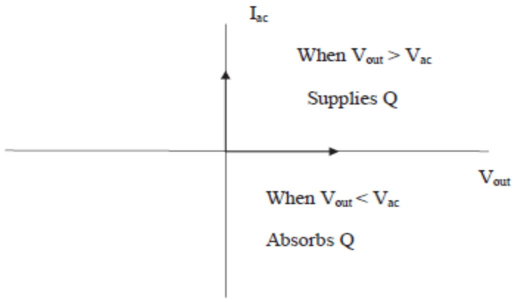

Fig. 6.Power Exchange Characteristic

The STATCOM control strategy consists of

a. PHASE LOCK LOOP: It synchronizes the positive sequence component of three phase primary voltage V_1.The output of phase lock loop is used in computing D axis and Q axis components of three phase voltage and currents.

b. AC and DC REGULATOR: The AC regulator generates reference current $Iqref$ for current regulator. Likewise DC regulator generates reference current $Idref$ for current regulator.

c.PULSE WIDTH MODULATION: It is used to generate gate pulses for IGBT of voltage source converter. It generates a sine wave of 50 Hz and a triangular wave of 20 kHz where both waves are compared to produce gate pulses which are in turn given as gate pulses to IGBT.

d.CURRENT REGULATOR: The reference current $Iqref$ and $Idref$ generated AC and DC regulator are used by current regulator to control magnitude and phase of the voltage generated by pulse width modulation converter.

V.UNIFIED POWER FLOW CONTROLLER

Unified power flow controller is a shunt series FACTS controller which is more versatile controller used to regulate voltage and power flows. The unified power flow controller is shunt series FACTS controller since it is combination of static synchronous compensator and static synchronous series compensator which are interconnected by a common DC capacitor. The UPFC has most fast response and decoupled active and reactive power compensations to connected system [5].

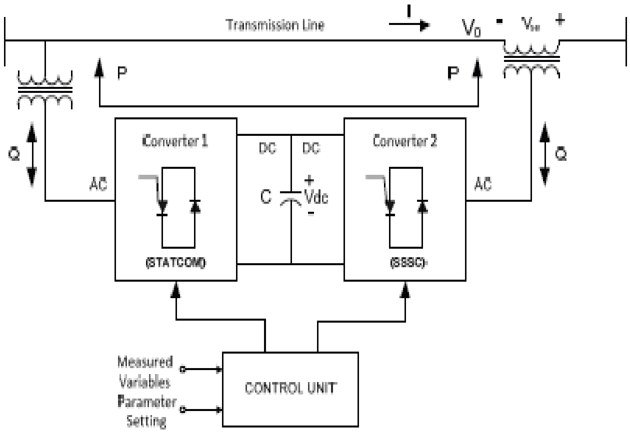

Fig. 7.Schematic representation of UPFC.

The UPFC control strategy consists of two converters i.e. STATCOM and SSSC converter the control strategy for statcom is same as explained in earlier section. In overall statcom performs control of AC voltage at it terminals and voltage of DC bus using inner current loop and outer loop. SSSC control scheme as shown in figure 8 can operate in two modes i.e. automatic mode and manual mode. In automatic mode power control is done by comparing measured values of active and reactive power with reference values to produce active and reactive power errors. The active and reactive power errors are used by PI controller to compute V_q and V_d components of voltage to be synthesized by the VSC.In manual mode reference values of injected voltage V_{dref} and V_{qref} are used to produce converter voltage[6].

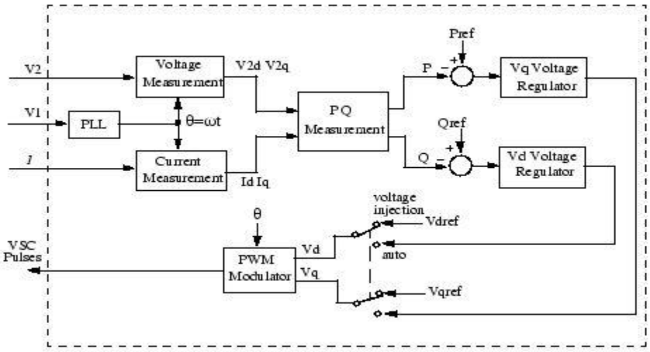

Fig. 8.Schematic representation of control strategy STATCOM.

VI. PERFORMANCE ANALYSIS OF CASE STUDY SYSTEM

The simulation of the system has been performed using the Simulink tool of MATLAB software.

(A) Matlab/Simulink model of DFIG Wind plant with STATCOM for different conditions

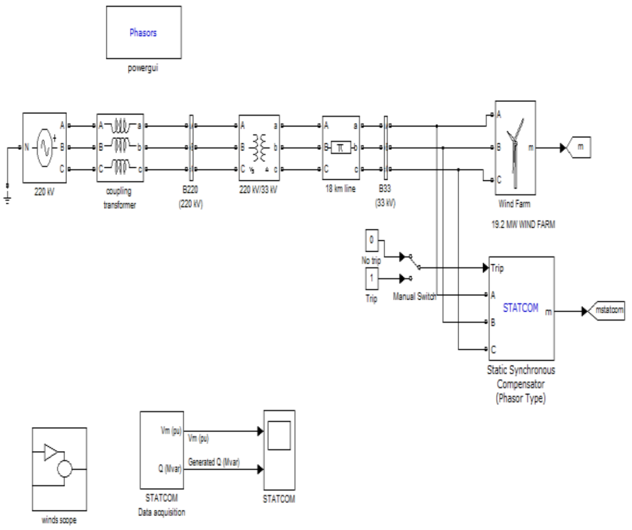

Fig. 9.Matlab/Simulink model of DFIG Wind plant with STATCOM.

CASE 1: NO LOAD CONDITION

TABLE I
NO LOAD CONDITION

33kV BUS VALUES						
WITHOUT STATCOM				WITH STATCOM		
T(S)	V (PU)	P (MW)	Q (MVAR)	V (PU)	P (MW)	Q (MVAR)
5	0.96	- 0.8	0.7	0.97	- 0.8	5.5
10	0.90	19.2	6.5	0.92	19.2	10.2

CASE 2: LOAD CONDITION -10 MW

TABLE II
LOAD CONDITION

33kV BUS VALUES						
WITHOUT STATCOM				WITH STATCOM		
T(S)	V (PU)	P (MW)	Q (MVAR)	V (PU)	P (MW)	Q (MVAR)
5	0.93	- 0.8	0.6	0.95	0.12	4
10	0.89	19.2	6.4	0.92	19.2	10.5

CASE 3: OVERLOAD CONDITION – 30MW

TABLE III
OVERLOAD CONDITION

33kV BUS VALUES						
WITHOUT STATCOM				WITH STATCOM		
T(S)	V (PU)	P (MW)	Q (MVAR)	V (PU)	P (MW)	Q (MVAR)
2.5	0.42	-2.5	0.95	0.64	4.9	1.2
5	0.45	3.2	1.2	0.51	8.8	3.9

CASE 4: FAULT CONDITION

TABLE IV
FAULT CONDITION

33KV BUS VALUES						
	WITHOUT STATCOM			WITH STATCOM		
T(S)	V (PU)	P (MW)	Q (MVAR)	V (PU)	P (MW)	Q (MVAR)
2.5	0.4	-8	0.6	0.8	-2.5	1.2
5	0.6	-1.5	0.8	0.92	6	1.3

(B) Matlab/Simulink model of DFIG Wind plant with UPFC for different conditions

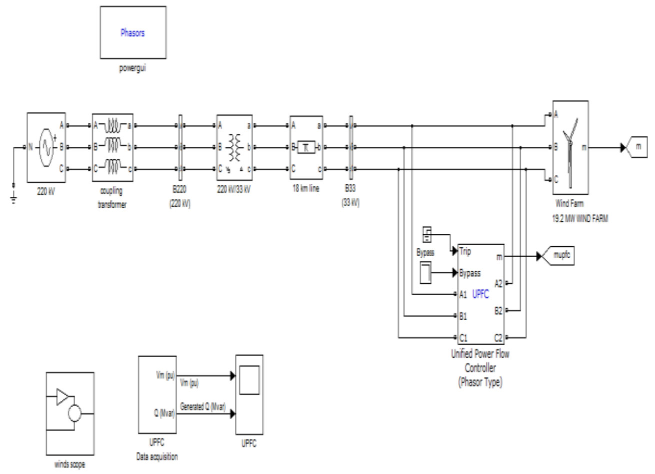

Fig. 10. Matlab/Simulink model of DFIG Wind plant with UPFC

CASE 1: NO LOAD CONDITION

TABLE V
NO LOAD CONDITION

33kV BUS VALUES						
	WITHOUT UPFC			WITH UPFC		
T(S)	V (PU)	P (MW)	Q (MVAR)	V (PU)	P (MW)	Q (MVAR)
5	0.96	-0.8	0.7	0.98	1.2	4.6
10	0.90	19.2	6.5	0.94	19.2	10.6

CASE 2: LOAD CONDITION – 10MW

TABLE VI
LOAD CONDITION

33kV BUS VALUES						
	WITHOUT UPFC			WITH UPFC		
T(S)	V (PU)	P (MW)	Q (MVAR)	V (PU)	P (MW)	Q (MVAR)
5	0.93	-0.8	0.6	0.96	0.15	4.5
10	0.89	19.2	6.4	0.94	19.2	11.2

CASE 3: OVER LOAD CONDITION – 10MW

TABLE VII
OVER LOAD CONDITION

33kV BUS VALUES						
	WITHOUT UPFC			WITH UPFC		
T(S)	V (PU)	P (MW)	Q (MVAR)	V (PU)	P (MW)	Q (MVAR)
2.5	0.42	-2.5	0.95	0.64	-0.16	0.92
5	0.45	3.2	1.2	0.6	9.7	4.2

CASE 4: OVER LOAD CONDITION – 10MW

TABLE VIII
FAULT CONDITION

33kV BUS VALUES						
	WITHOUT UPFC			WITH UPFC		
T(S)	V (PU)	P (MW)	Q (MVAR)	V (PU)	P (MW)	Q (MVAR)
2.5	0.4	-8	0.6	0.82	-1.5	1.2
5	0.6	-1.5	0.8	0.97	7.2	2.1

VII. COMPARISION OF PERFORMANCE OF STATCOM AND UPFC

CASE 1: NO LOAD CONDITION

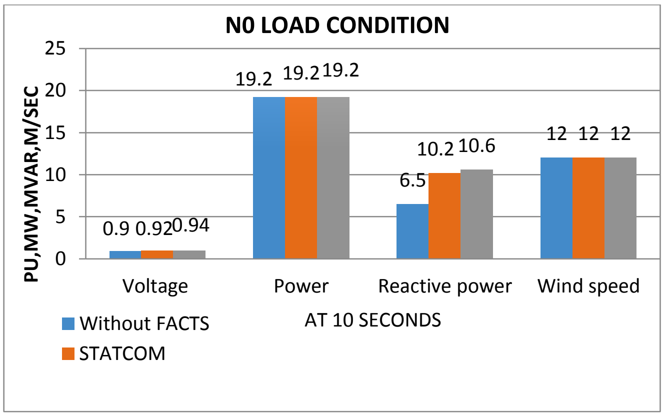

Fig. 11. Voltage, power, Reactive power, wind speed in STATCOM and UPFC at No load condition

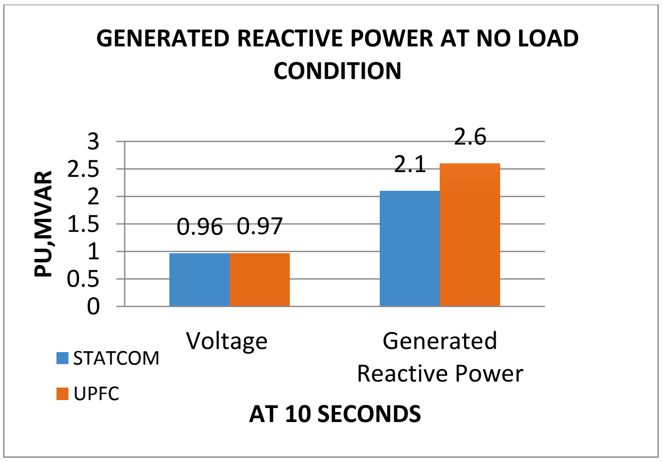

Fig. 12. Generated reactive power in STATCOM and UPFC at No load condition.

CASE 2: LOAD CONDITION -10MW

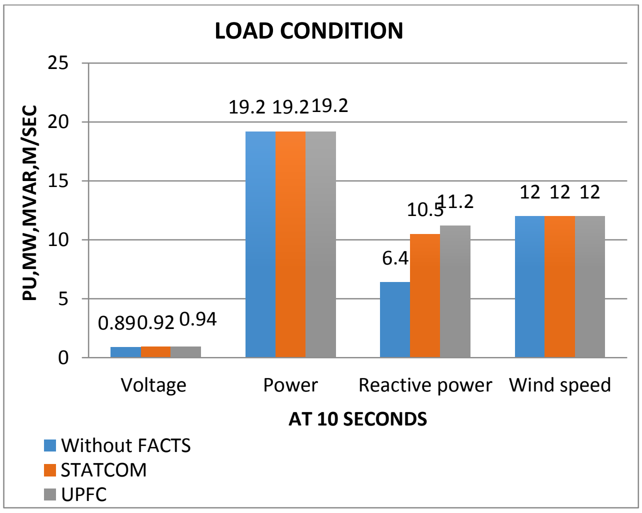

Fig. 13. Voltage, power, Reactive power, wind speed in STATCOM and UPFC at Load condition

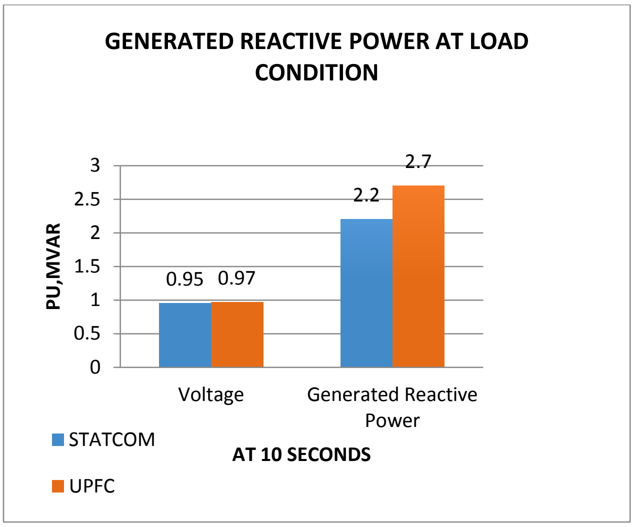

Fig. 14. Generated reactive power in STATCOM and UPFC at Load condition.

CASE 3: OVERLOAD CONDITION-30 MW

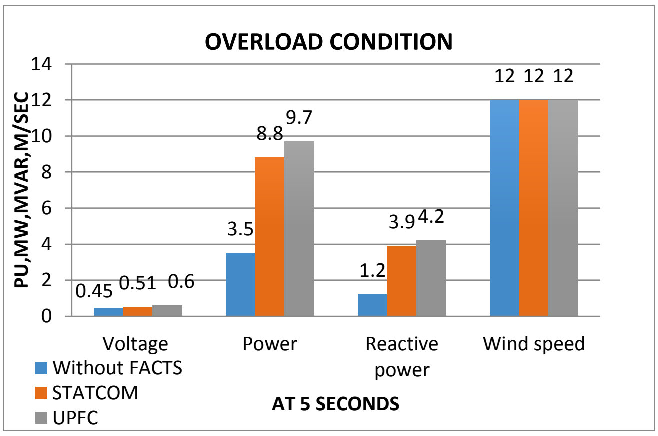

Fig. 15.Voltage, power, Reactive power, wind speed in STATCOM and UPFC at overload condition.

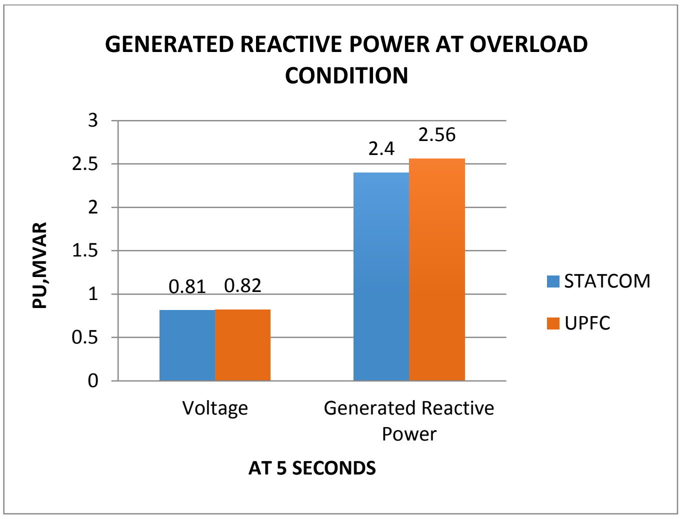

Fig. 16. Generated reactive power in STATCOM and UPFC at overload condition.

CASE 4: FAULT CONDITION

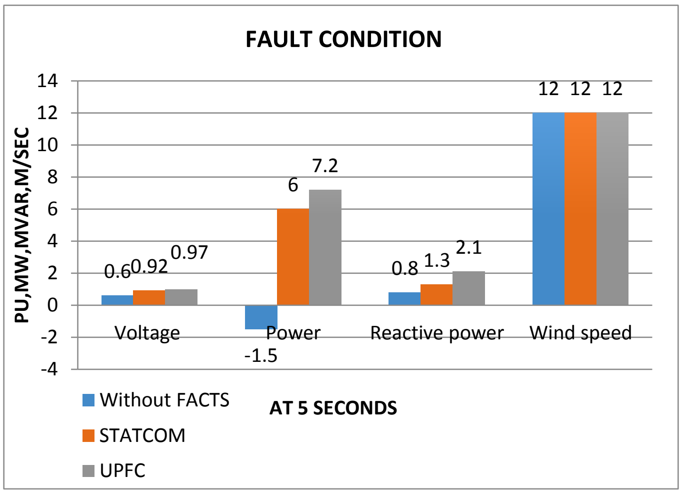

Fig. 17.Voltage, power, Reactive power, wind speed in STATCOM and UPFC at Fault condition.

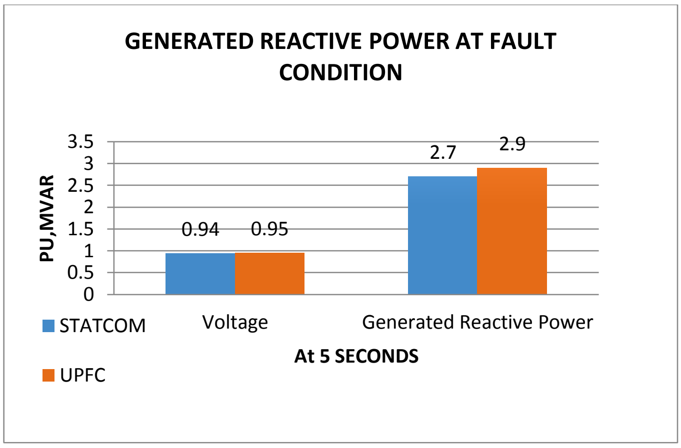

Fig. 18.Generated reactive power in STATCOM and UPFC at Fault condition.

VIII.CONCLUSION

This paper investigates the application of FACTS devices to improve the fault ride through capability of wind plants to meet the grid code. Results obtained show that without FACTS devices, wind plants will be disconnected from the grid due to voltage dip at the point of common coupling. The presence of FACTS devices will improve voltage, fault ride through capability of wind plants and with adequate reactive power support the connectivity of wind plants to grid is guaranteed.

The FACTS devices such as STATCOM and UPFC are used in this study to provide reactive power support which ensures improvements in power system stability and fulfilling requirements of grid code standards.

The results obtained by use of two FACTS devices STATCOM and UPFC show that UPFC has improved reactive power support, improved voltage profile and stability. Hence, the results obtained encourage using UPFC in wind plants connected to grid for improved reactive power support and voltage profile to enhance fault ride through capability to meet grid code standards.

Following inferences can be drawn from the results obtained through performance analysis of UPFC and STATCOM.

1. Improved voltage profile and reactive power at the bus as shown in graphs at different operating conditions shows that UPFC is better as compared to STATCOM.
2. The improvement in the Stability associated issues such as Power, rotor speed, pitch angle and reactive power shows that UPFC is better as compared to STATCOM.
3. At different operating conditions, voltage profile and reactive power support improvement by UPFC is better as compared to STATCOM.

At overload and fault condition without FACTS devices, the voltage dips at point of common coupling violates safety margins of grid codes. Application of FACTS to wind plant connected to grid at overload and fault condition improves voltage at point of common coupling. The presence of FACTS will improve fault ride through capability and hence wind plant connection to grid can be maintained by adequate reactive power support at overload and fault conditions using FACTS to ensure connectivity of wind plants to grid. From the results obtained at overload and fault condition with STATCOM and UPFC shows that UPFC has better performance as compared to STATCOM to maintain voltage and reactive power support. Hence presence of UPFC has better performance to ensure connectivity of wind plants to grid.

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