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Effect of FACTS Devices on Stabilization of Power System Connected to Renewable Energy Units

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Abstract:
this paper deals with the effect of FACTS devices such as Unified Power Flow Controller (UPFC) and Static Synchronous Compensator (STATCOM) on stability of the system connected to wind turbine under normal and fault conditions. Simulink models are developed for 5 bus system with wind turbine with and without FACTS devices. Digital simulation using MATLAB/SIMULINK is done with these models and the results are presented. The effect of UPFC and STATCOM on real power, reactive power and the voltage is also presented.

الملخص:
يقدم البحث دراسة تأثير تركيب عناصر توصيل التيار المتردد المرنة على اتزان نظم القوى المتصلة بوحدات الطاقة المتجددة. وقد تم تركيب موحد حاكم سريان القدرة، ومعوض القدرة الغير فعال الاستاتيكي إلي توربينة رياح متصلة بنظام قوى ودراسة تأثير كل منها في حالة ظروف التشغيل العادية وفي حالة الأعطال. وقد تم استخدام شبكة مكونة من خمسة باسبارات مع توربينة رياح كنظام قوى لأختبار التقنية المقترحة، وقد أظهرت المحاكة الرقمية قدرة ودقة تركيب نظم توصيل التيار المتردد المرنة في تحسين أداء النظام وضبط جهده عند ظروف التشغيل العادية والغير عادية، وقد تم نمذجة النظام المقترح باستخدام حزم البرامج Matlab/Simulink

Keywords; FACTS, UPFC, STATCOM, System Stability, Wind Turbine, MATLAB, SIMULINK.

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I. INTRODUCTION

The problem of stability in the power system is considered to be a challenge for researchers. Stability is the ability of the system to remain in synchronism. When the fault occurs in any part it will result in an abnormal flow of power, affects the voltage and also cause the system to oscillate. To damp out the oscillations and enhance stability, various types of FACTS devices are used [1]-[3]. Since the birth of the AC system and the problem of stability, a group of mechanical switches comprises of capacitor and reactors were used [4]. But there use is avoided due to their slow response. To overcome the deficiency the family of FACTS devices is introduced by EPRI (Electric Power Research Institute) in 1980[5]. Nowadays FACTS devices can be used to control the power flow and enhance system stability. The main features of a FACTS device are its multiple control functions, such as power flow control, voltage control, transient stability enhancement, oscillation damping. A well designed FACTS Controller can not only increase the transmission capability but also improve stability of the power system [1,6]. The use of Wind Power for electricity generation is increasing, both worldwide and in Egypt too[7]. To meet the growing demand for electrical energy apart from conventional generation a large number of Wind Turbine Generating (WTG's) units are being integrated into the Grid. Increased penetration of wind power into the transmission grid gives rise to new challenges in maintaining reliability and stability for the transmission grid. Wind power affect the stability, causes oscillations in the system, the FACTS devices also able to damp oscillations in power system and improve transient stability in the system.

II. OPERATING PRINCIPLE OF UPFC AND STATCOM:

A. Unified Power Flow Controller:

UPFC is a combination of STATCOM and SSSC coupled via a common DC voltage link. The UPFC has capabilities of voltage regulation, series compensation, and phase shifting. It can and very rapidly control both real- and reactive power flows in a transmission lines. It is configured as shown in Fig. 1.

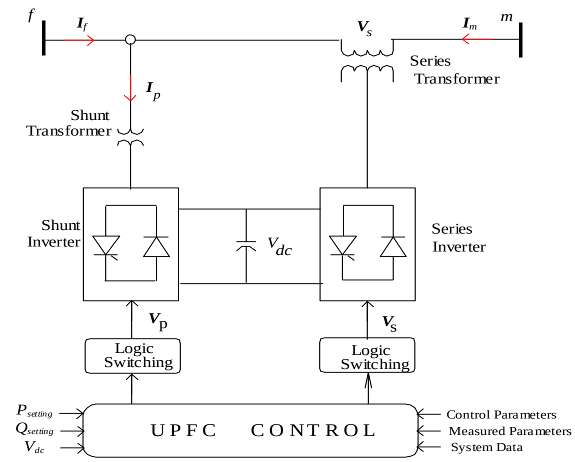

Fig. 1. UPFC configuration Model

The series converter exchanges both real and reactive power with the transmission line. Although the reactive power is internally generated/ absorbed by the series converter, the real-power generation/ absorption is made feasible by the dc-energy storage device that is, the capacitor. The shunt-connected converter 1 is used to supply the real-power demand of converter 2, which it derives from the transmission line itself. The shunt converter maintains constant voltage of the dc bus. Thus the net real power drawn from the ac system is equal to the losses of the two converters and their coupling transformers. As well as, the shunt converter functions like a STATCOM and independently regulates the terminal voltage of the interconnected bus by generating/ absorbing a requisite amount of reactive power. [8]

B. Static Synchronous Compensator

STATCOM or Static Synchronous Compensator is a power electronic device using force commutated devices like IGBT, GTO etc. to control the reactive power flow through a power network and thereby increasing the stability of power network. STATCOM is a shunt device i.e. it is connected in shunt with the line.[9]

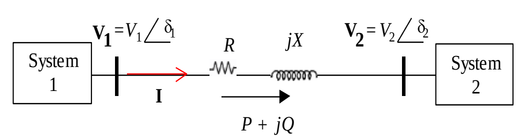

Fig .2 Single Line Diagram of a Simple Transmission Line

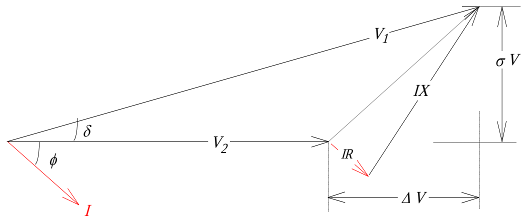

Fig. 3. Vector Line Diagram of a Simple Transmission Line

Fig. 2 shows a single line diagram of a simple transmission line with impedance $\mathbf{Z} = R + jX$ connecting between two generation systems. Assuming system 1 is a sending-end with voltage V1 and system 2 is a receiving-end with voltage V2. According to Fig. 2 and vector line diagram shown in Fig. 3, the real power (P) and reactive power (Q) flows at the receiving-end and sending end voltage sources are given by the follows.

$$P = \frac{V_1 V_2}{X}(\sin\delta)$$
$$Q = \frac{V_1 V_2}{X}\left(\frac{V_1}{V_2} - \cos\delta\right) \qquad (1)$$

From the above reactive power flow equation, angle δ is the angle between V1 and V2. Thus if angle δ = 0 then reactive power flow Q will become

$$Q = \frac{V_1}{X}(V_1 - V_2) \qquad (2)$$

And active power flow P will become

$$P = \frac{V_1 V_2}{X}(\sin\delta) = 0 \qquad (3)$$

We can say that if the angle between V1 and V2 is zero, the flow of active power becomes zero and the flow of reactive power depends on (V1 – V2). Thus for flow of reactive power there are two possibilities.

1) If the magnitude of V1 is more than V2, then reactive power will flow from source V1 to V2.

2) If the magnitude of V2 is more than V1, reactive power will flow from source V2 to V1.

III. DESCRIPTION OF THE SYSTEM

The system, connected in a loop configuration, consists of five buses (B1 to B5) interconnected through transmission lines (L1, L2, L3) and two 500 kV/230 kV transformer banks Tr1 and Tr2. Two power plants located on the 230-kV system generate a total of 1500 MW which is transmitted to a 500-kV 15000-MVA equivalent and to a 200-MW load connected at bus B3.

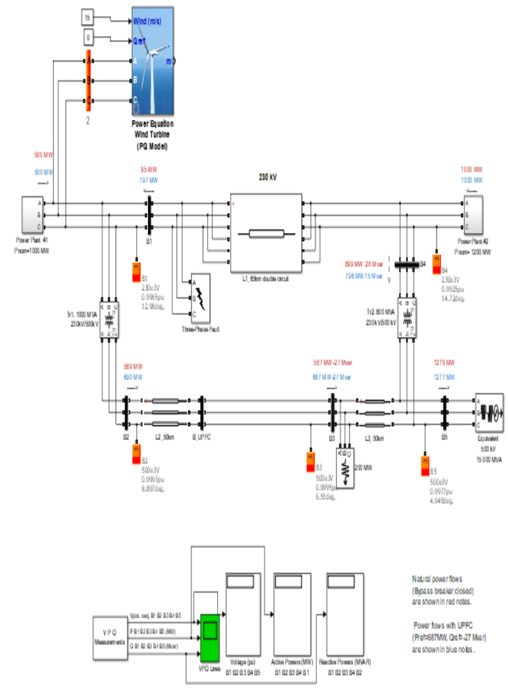

Fig.4. Simulink model of 5-bus system with wind turbine

In normal operation, most of the 1200-MW generation capacity of power plant #2 is exported to the 500-kV equivalent through three 400-MVA transformers connected between buses B4 and B5. We are considering a contingency case where only two transformers out of three are available (Tr2= 2*400 MVA = 800 MVA).Main system simulation model without FACTS devices with wind turbine has been created in MATLAB/ Simulink shown in Fig.4. As result of connecting wind turbine to the 5-bus system as shown in fig.4. Which was stable the wind turbine effects the stability of the system. The system becomes unstable in the beginning of the simulation (there are some oscillations) then return to be stable again. The active power, reactive power and voltage curves with respect to time at all five buses (B1 B2 B3 B4 B5) with and without wind turbine are shown in Figs.(5, 6 and 7)

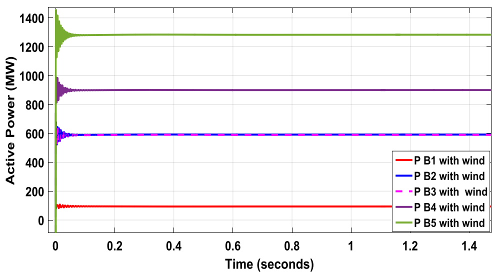

Fig.5. Active power of (B1B2B3B4B5) of the system

The wind turbine has much impact on the active power flow of the system as there is an increase in active power in B2, B3, B4, and B5 but in B1 the active power decrease.

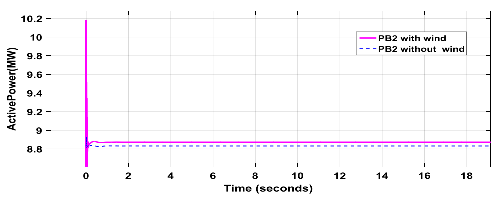

Fig.6. Active Power with &without wind at bus2

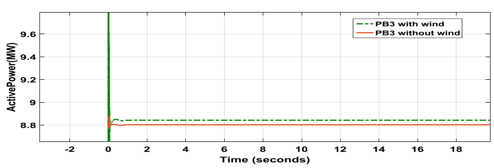

Fig.7. Active Power with &without wind at bus3

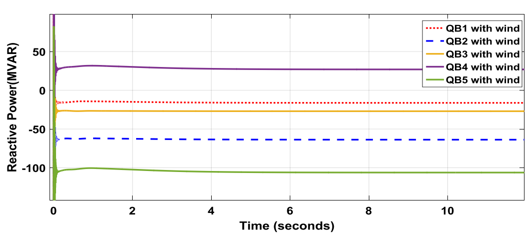

Fig.8. Reactive Power of (B1B2B3B4B5) of the system.

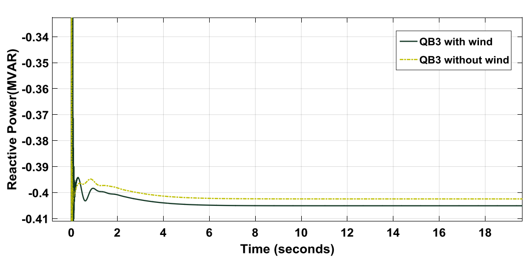

Fig.9. Reactive Power with& without wind at bus3

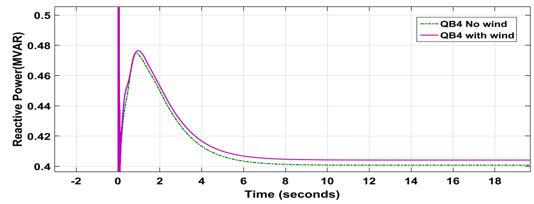

Fig.10. Reactive Power with& without wind at bus 4

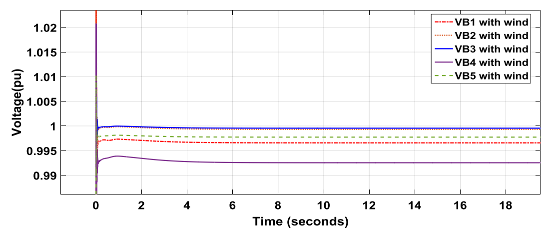

Fig.11. Voltage in Pu for (B1B2B3B4B5) of the system

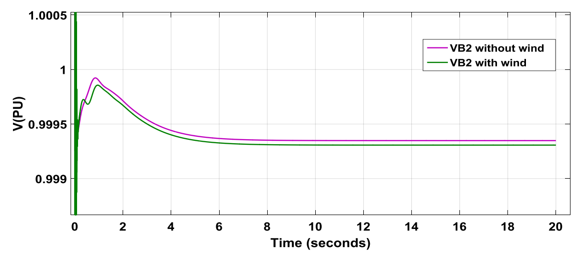

Fig.12. Voltage in Pu with &without wind turbine at bus2

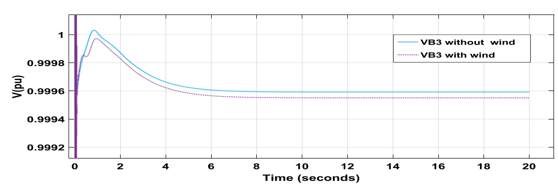

Fig.13. Voltage in Pu with &without wind turbine at bus3

For reactive power and voltage response the wind turbine has less effect where there is small decreasing in the value of each with wind turbine than without wind turbine**.** That can be illustrated in table (1, 2) which shows the voltage, active and reactive power of the system with and without wind turbine. The 5-bus system load flow parameters is given in Table 1. The system load flow parameters without and with wind is given in Table 2.

Table (1) Illustrate The 5-bus system load flow parameters

No Bus	V with wind	P with wind	Q with wind
B1	0.9966	93.75	-16.23
B2	0.9993	591.5	-63.77
B3	0.9996	589.5	-27.01
B4	0.9925	900	26.95
B5	0.9977	1283	-106.2

Table (2) Illustrate The 5-bus system load flow parameters without and with wind

NO.BUS	V without wind	P without wind	Q without wind
B1	0.9966	95.19	-16.73
B2	0.9998	588.8	-63.19
B3	0.9996	586.3	-26.83
B4	0.9928	898.6	-26.72
B5	0.9978	1279	-105.6

IV. Model with &without Unified power flow CONTROLLER (UPFC) during fault condition:

Main system simulation model with Unified Power Flow Controller (UPFC) FACTS devices has been created in Matlap/Simulink as shown in fig14 In this model UPFC is connected in between bus B2 and B3. Fault is created simultaneously near bus B1 with resistance of 0.001Ω a single line to ground fault and three lines to ground of 2sec duration are applied. The response of the voltage, active power and reactive power are analyzed

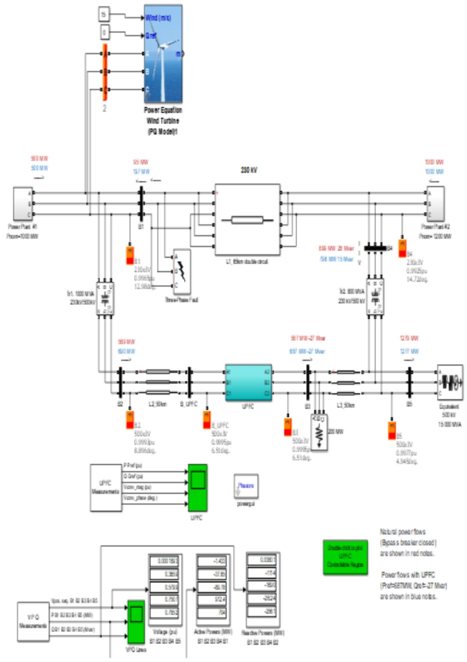

Fig.14.simulink model with UPFC

Study Case1, Single Line To Ground Fault: System performances with and without UPFC are shown from Fig (15) to fig ( ) in terms of Active power response, Reactive power response and Voltage response during single line to ground fault. The Active power of system with and without Upfc during single line to ground fault (L.G) is given in Table 3. The reactive power of system with and without Upfc during single line to ground fault (L.G) is given in Table 4.

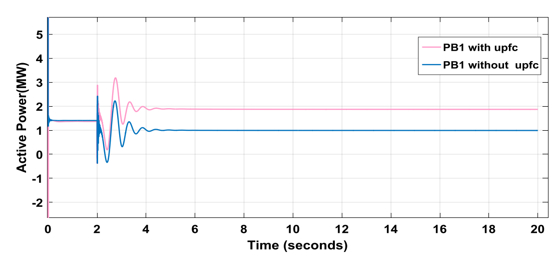

Fig (15) Active power response with& without UPFC during single line to ground fault at bus1

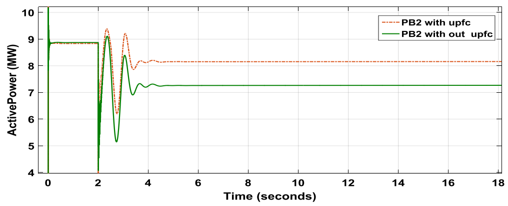

Fig (16) Active power response with& without UPFC during single line to ground fault at bus2

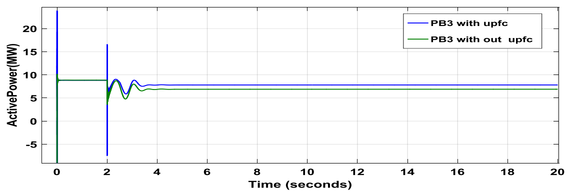

Fig (17) Active power response with& without UPFC during single line to ground fault at bus2

Table (3) Illustrate Active power of system with and without Upfc during single line to ground fault (L.G):

No .Bus	Active Power (MW) without UPFC	Active Power (MW) With UPFC
B1	66.06	124.7
B2	484.6	544
B3	459	520.7
B4	858.1	798
B5	1113	1110

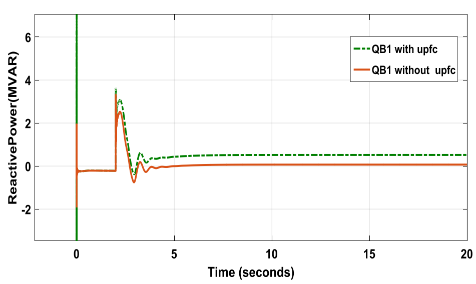

Fig (18) Reactive Power response of system with &without UPFC during single line to ground fault at bus1

Table (4) Illustrate Reactive power of system with and without Upfc during single line to ground fault (L.G):

No .Bus	Reactive Power (MVAR) without UPFC	Reactive Power (MVAR) With UPFC
B1	4.533	34.41
B2	-247.7	-56.2
B3	-326.4	-191.5
B4	34.31	-21.87
B5	-610.7	-479.8

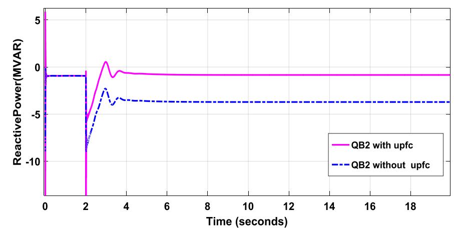

Fig (19) Reactive Power response of system with &without UPFC during single line to ground fault at bus2

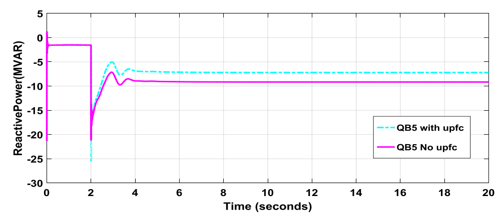

Fig (20) Reactive Power response of system with &without UPFC during single line to ground fault at bus3

Table (5) Illustrate bus voltages of system with and without Upfc during single line to ground fault **(L-G)**:

No .Bus	Voltage (pu) without UPFC	Voltage (pu) With UPFC
B1	0.7543	0.7402
B2	0.8487	0.8062
B3	0.9033	0.9283
B4	0.9341	0.9356
B5	0.9467	0.9599

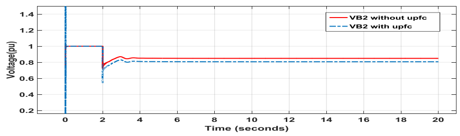

Fig (21) Voltage response of system with &without UPFC during single line to ground fault at bus2

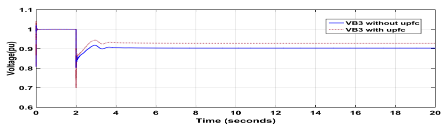

Fig (22) Voltage response of system with &without UPFC during single line to ground fault at bus3

Table (6) Illustrate Active power of system with and without Upfc during Three lines to ground fault (L.G):

No .Bus	Voltage (pu) without UPFC	Voltage (pu) With UPFC
B1	0.0003047	0.0005969
B2	0.3667	0.3315
B3	0.5814	0.6039
B4	0.7476	0.7508
B5	0.7872	0.7971

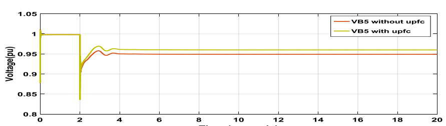

Fig (23) Voltage response of system with &without UPFC during single line to ground fault at bus5

Case study2,Three lines to ground fault: System performances with and without UPFC are shown from Fig (24) to (26) in terms of Active power response, Reactive power response and Voltage response during three lines to ground fault. And table 6,7and 8 illustrate P, Q and V. with and without UPFC.

Table (7) Illustrate bus voltages of system with and without Upfc during Three lines to ground fault (L.G):

No .Bus	Active Power (MW) without UPFC	Active Power (MW) With UPFC
B1	-4.729	-4.568
B2	-37.86	-30.93
B3	-90.35	-75.29
B4	712.7	711.7
B5	505.9	519.8

Table (8) Illustrate Reactive power of system with and without Upfc during Three lines to ground fault (L.G):

No .Bus	Reactive Power (MVAR) without UPFC	Reactive Power (MVAR) With UPFC
B1	0.7222	-0.7227
B2	-1120	-915.3
B3	-1700	-1659
B4	-93.87	-122.7
B5	-2539	-2453

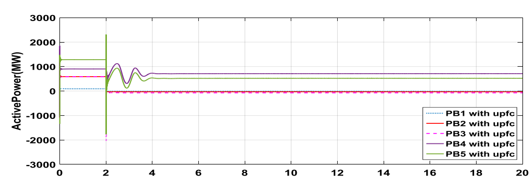

Fig. (24) Active power response of the system with UPFC during three lines to ground fault

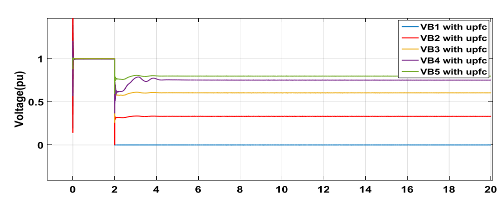

Fig. (25) Reactive power response of the system with UPFC during three lines to ground fault

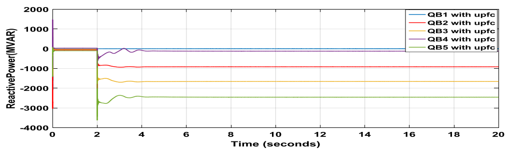

Fig. (26) Reactive power response of the system with UPFC during three lines to ground fault

V. MODEL OF THE SYSTEM WITH AND WITHOUT STATIC SYNCHRONOUS COMPENSATOR (STATCOM) DURING FAULT CONDITION:

Main system simulation model with Static Synchronous Compensator (STATCOM) FACTS devices has been created in Matlap/Simulink as shown in fig27. Fault is created simultaneously near bus B1 with resistance of 0.001Ω a single line to ground fault and three lines to ground of 2sec duration are applied. **CASE Study1, Single line to ground Fault:**

System performances with and without STATCOM are shown in Fig (28) to (33) in terms of Active power response, Reactive power response and Voltage response during single line to ground fault.

Table (9) shows System Active Power, ReactivePower and Voltage without STATCOM during single line to ground fault

No.BUS	P(MW)	Q(MVAR)	V(PU)
B1	64.74	8.137	0.7518
B2	483.3	-217.9	0.8423
B3	459.2	-383.3	0.8946
B4	859.6	45.88	0.9324
B5	1118	-663.6	0.9451

Table (10) shows System Active Power, ReactivePower and Voltage witht STATCOM during single line to ground fault

No.BUS	P(MW)	Q(MVAR)	V(PU)
B1	66.03	4.535	0.7543
B2	484.6	-247.7	0.8487
B3	459.3	-326.4	0.9033
B4	858.2	34.31	0.9341
B5	1114	-610.7	0.949

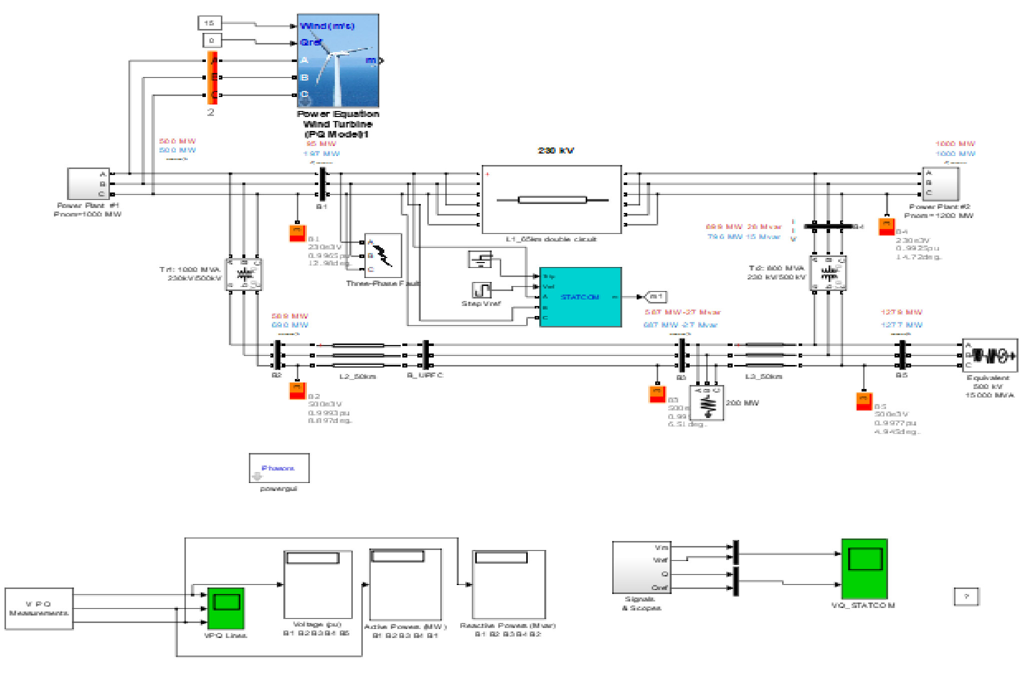

Fig. 27 Studied system Simulink

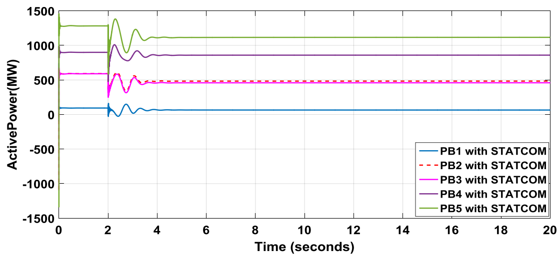

Fig.(28). ActivePower Response of the system with STATCOM during single line to ground fault

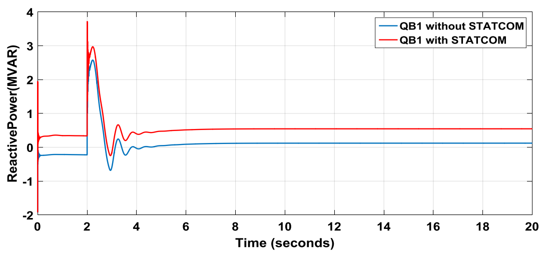

Fig (29) Reactive Power response of system with &without STATCOM during single line to ground fault at bus1

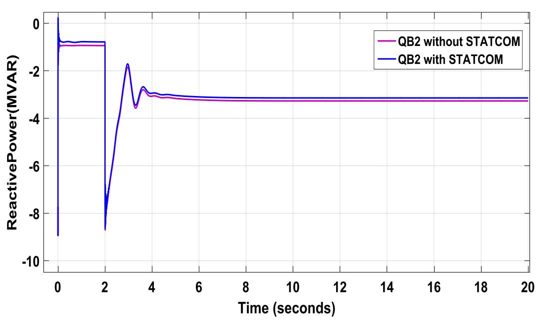

Fig (30) Reactive Power response of system with &without STATCOM during single line to ground fault at bus2

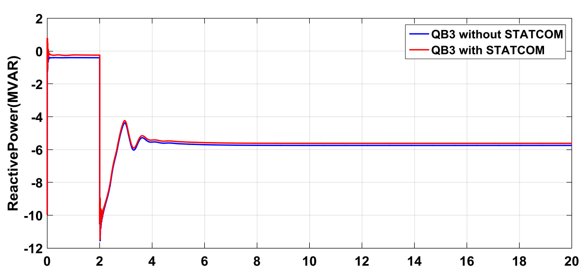

Fig (31) Reactive Power response of system with &without STATCOM during single line to ground fault at bus3.

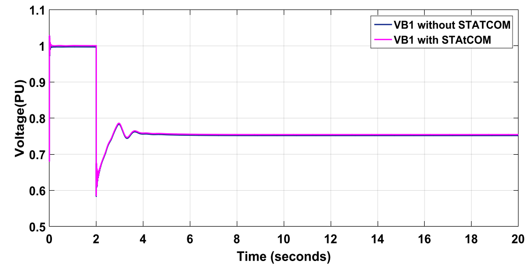

Fig (32) Voltage response of system with &without STATCOM during single line to ground fault at bus1.

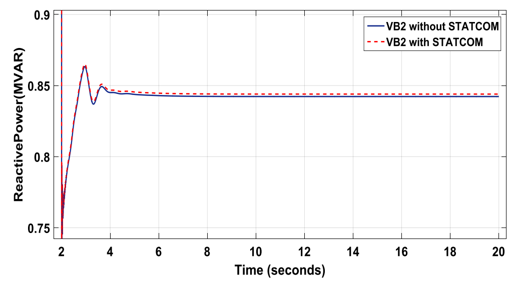

Fig (33) Voltage response of system with &without STATCOM during single line to ground fault at bus2.

CASE Study2, Three lines to ground Fault:

System performances with and without STATCOM are shown in Fig (34) to (39) in terms of Active power response, Reactive power response and Voltage response during Three lines to ground fault.

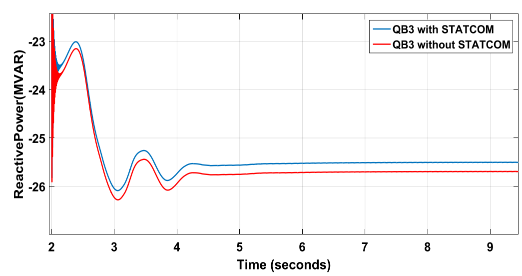

Fig (34) Reactive Power response of system with &without STATCOM during Three lines to ground fault at bus3

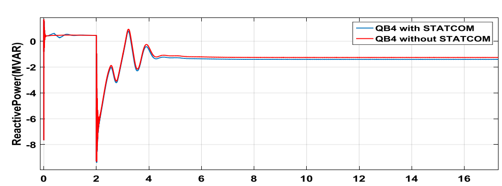

Fig (35) Reactive Power response of system with &without STATCOM during Three lines to ground fault at bus4

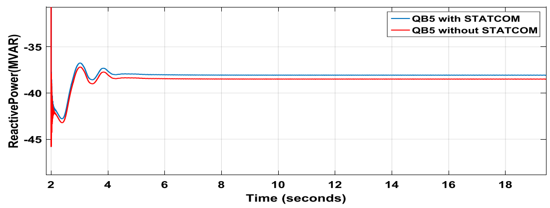

Fig (36) Reactive Power response of system with &without STATCOM during Three lines to ground fault at bus5

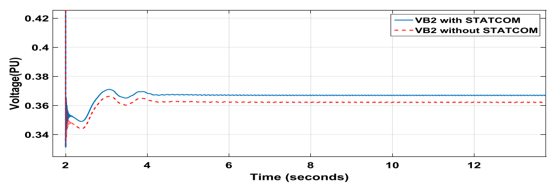

Fig (37) Voltage response of system with &without STATCOM during Three lines to ground fault at bus2.

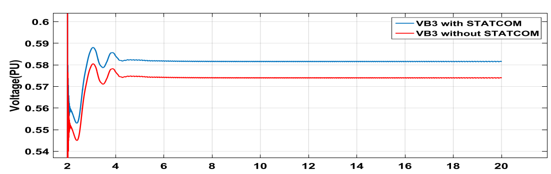

Fig (38) Voltage response of system with &without STATCOM during Three lines to ground fault at bus3.

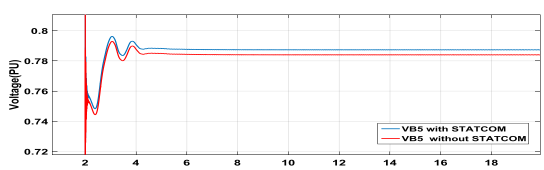

Fig (39) Voltage response of system with &without STATCOM during Three lines to ground fault at bus5.

From the above mention results it is noted that in all cases the voltage profile, Active power and Reactive power under different fault condition have improved by using STATCOM and UPFC. The voltage profile of the system has improved. Transient stability is also improved by UPFC and STATCOM. And faster steady state stability is achieved.

VI Conclusion

The system with FACTS devices and without FACTS devices is presented. When awind turbine is connected to the system ,it is necessary to provide efficient power and voltage control during different abnormal operating conditions. The FACTS devices which are used are STATCOM and UPFC . voltage profile,Activepower and Reactivepower of bus (1,2,3,4,5) are observed. The waveforms clearly show that FACTS devices help in improving voltage stability. The simulation result shows the effectiveness of UPFC to control the real and reactive power as well as STATCOM to generate and to absorb reactive power makes it suitable for power oscillation damping and hence power control. System become stable at short time. And the results indicate that the STATCOM and UPFC FACTS devices improves effectively power quality and reduces power losses as compared to system without FACTS devices.

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