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Stability Analysis of Grid Connected Wind Farm Supported by SVC and STATCOM

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Abstract— *To create power at a low cost, non-conventional energy resources, particularly wind energy, are exploited. A wind turbine is used to create power that may generate or absorb reactive power to or from the grid during a grid outage. The objective is to analyze the impact on small signal and transient stability of wind turbines by introducing FACTS devices. Due to oscillations in voltage and frequency, a high penetration of wind turbines produces a stability problem in the power system, lowering the system's efficiency and power quality. Grid connectivity difficulties include power quality, the consequence of a low power factor, and inadequate grid stability. After a severe disturbance, the effects of the Static Var Compensator (SVC) and Static Synchronous Compensator (STATCOM) on the stability of wind farms based on fixed speed induction generators (FSIG) were investigated in this work. Because of the asynchronous nature of fixed speed induction generators, instability in FSIG-based wind farms is caused by the FISG's excessive reactive power absorption following a breakdown. This issue occurs as a result of FISG rotor slip, which rises during the fault, increasing reactive power consumption. The performance of a wind farm equipped with SVC and STATCOM to increase wind farm stability during and after a malfunction is compared. Both devices can improve system stability during and after a disturbance, according to simulation data, especially when the network is poor. It has been demonstrated that the STATCOM outperforms the SVC in terms of improving wind farm stability and providing greater reactive power assistance to the network.*

Keywords— *Wind Power, Rotor angle Stability, STATCOM, SVC, FACTS devices.*

I. INTRODUCTION

Higher per capita output of commodities, increased wealth and urbanisation, increased per capita consumption, and ease of energy access are all factors that have contributed to a large growth in overall power demand. When you look at the disparity between demand and supply for power, you'll notice that massive amounts of coal and furnace oil are required. These practises must be curtailed, since they result in significant expenses in the form of subsidies and an increase in the country's reliance on imports. Renewable energy sources have the potential to contribute significantly in these areas. As a result of all of these factors, renewable energy must be extensively researched and utilised. [1]. It has become an important element of the country's energy solution. As a result, commissioning wind power units in an existing grid might cause issues such as bus voltages exceeding the grid's specified limitations, power congestion, unexpected system losses, and voltage instability. Wind power offers a great deal of promise for supplying free and non-polluting electrical energy. Because of its efficiency as a source of electricity, several governments throughout the world have set lofty goals for wind power systems. The following are some of the advantages:

- No emissions of harmful gasses like CO_2
- Significant economically viable resource potential
- No impact on generation cost due to fuel supply price fluctuations.
- Increased security of supply
- Can be used as distributed generation Source
- Cost-effective energy production
- Improves sustainability
- Reduces global warming
- Improves energy security
- Requires no waste storage.

The below table shows the installed capacity of various generation systems of India.

TABLE 1: Installed capacity of various generation systems in India

Sr. No	**Resources**	**Cumulative Achievements (in MW) till 31.03.2021**
Grid connected renewable electricity		
1	Biomass Power	8701
2	Waste to energy	138
3	Solar PV power plants	21651
4	Wind Power	34046
Off-grid renewable energy		
5	Biomass Cogeneration	661.4
6	Solar PV system	539.13
7	Biomass Gasifiers	163.37
8	Waste to Energy	175.45
9	Hybrid Systems / Aero Generators	3.29

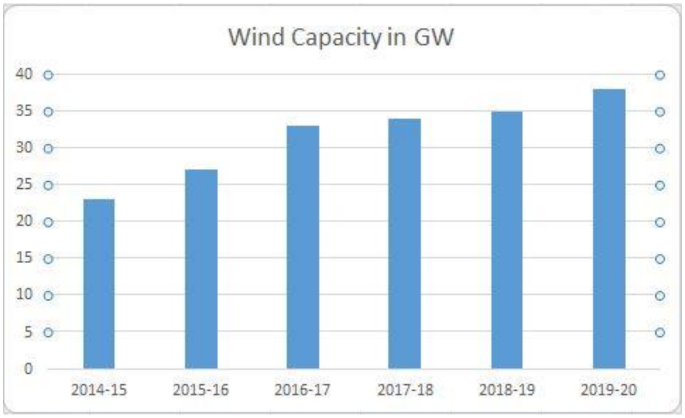

Fig. 1. Development of wind industry over the years

The most challenging problem in capturing electricity from wind turbines is their unpredictable nature. The wind turbine is the initial component in harvesting this renewable energy, followed by the electrical generator. These generators' primary job is to transform mechanical energy into electrical energy. Electrical equipment such as doubly fed induction machines, induction machines, PMSM, and others may accomplish this process. PMSM has a few unique characteristics:

- Simple construction
- Small size
- High efficiency
- Low Maintenance
- No need of DC excitation
- No need of brushes and slip rings

The generator fails to provide a steady electrical voltage due to the fluctuating nature of the wind, resulting in grid imbalance. Maximum power point trackers are used to solve this problem. After passing through appropriate filters, the three phase ac supply from the wind farm may be fed into a matrix converter. The input three-phase supply will be converted into a variable voltage variable frequency supply by this matrix converter. An induction motor and a PMSM may both be driven with this variable supply.

The use of either the Static Var Compensator (SVC) or the Static Synchronous Compensator (STATCOM) to increase the stability of a wind farm connected to the power grid is proposed in this study. The stability study of the FSIG based on a wind turbine is first discussed. MATLAB-SIMULINK also develops wind farm models based on FSIG, equipped with SVC and STATCOM, and connected to the power grid. Following that, the effects of SVC and STATCOM on the power system during and after a fault are examined. After that, the influence of these devices' ratings and the network's Short Circuit Ratio (SCR) on system recovery is investigated. Finally, the performance of SVC and STATCOM under disturbances is compared as a conclusion.

II. WIND TURBINE SYSTEM

In the diagram below, the wind turbine system [8] includes the generator, turbine rotor, gearbox, power electronic system, and a transformer for grid connection. Wind turbines capture wind energy and convert it to mechanical energy via turbine blades. During increased wind speeds, it is necessary to manage and restrict the converted mechanical power. A gearbox and a standard-speed generator are commonly used to convert low-speed, high-torque mechanical power to electrical power. The gearbox connects the turbine rotor's low speed to the generator's high speed. The generator then turns mechanical energy into electrical energy, which is delivered into the grid via power electronic converters and a transformer with the necessary protection and metering devices. In wind turbines, induction generators and synchronous generators are commonly utilised.

When the shaft of an induction generator [8] rotates faster than the induction motor's synchronous frequency, it generates electrical power. These generators are suitable for use in wind turbines because they can provide electricity at various rotor speeds. The building of induction generators is straightforward. They are also more durable in construction, thus no brushes or commutators are necessary. Because these generators are not self-exciting, they require an external source to create a spinning magnetic flux. When the generator starts producing electricity, the external source might come from the electrical grid [9] or from the generator itself. The current induces a magnetic field in the rotor, which produces the magnetic field. When the rotor rotates slower than the spinning flux, the machine operates as an induction motor; when the rotor turns faster, the machine acts as a generator, producing electricity at synchronous frequency. In freestanding generators, the magnetising flux is controlled by a capacitor bank linked to the machine, but in grid-connected generators, the magnetising current is drawn from the grid. It is most suited for wind-generating [10] stations since speed is always a variable component in this instance.

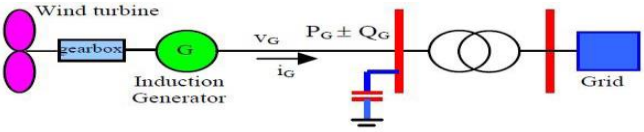

Fig. 2. Wind Turbine System Connected to Grid

Induction machines are frequently utilised as induction motors in the electrical power system, although they are not widely employed as generators. Despite their simplicity of manufacture, they are not as popular as synchronous generators. This is owing to the well-defined link between active power export [P] and reactive power absorption [Q]. Induction generators, on the other hand, have the advantage of producing a significant damping torque in the prime mover, making them suited for use in fixed-speed wind turbines. As illustrated in Figure 3, the fixed-speed wind turbine employs a squirrel cage induction generator that is connected to the power supply through a connecting transformer. A gearbox is used to match the differing working speeds of the wind turbine rotor and generator. The generator slip changes slightly depending on the quantity of generated power and is thus not completely constant. [11]

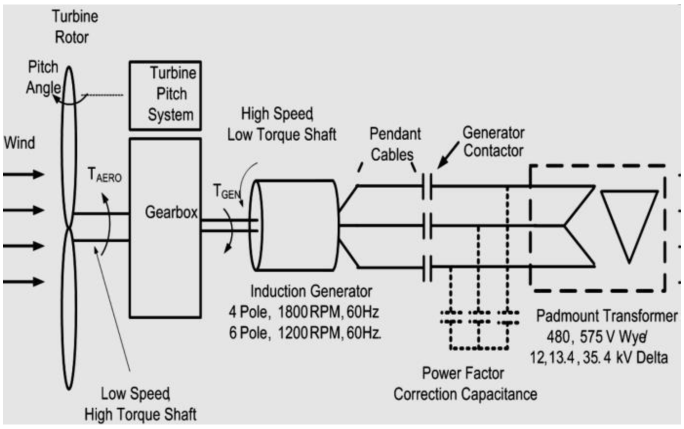

Fig. 3. Self-excited Induction Generator

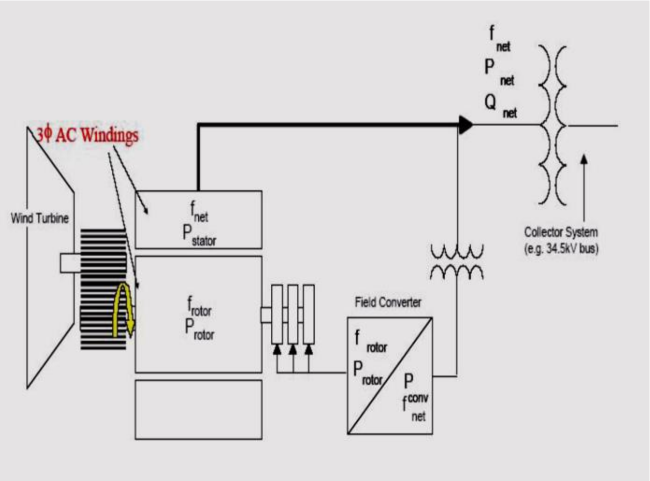

Fig. 4. Doubly-fed Induction Generator

However, because the speed changes are on the order of 1%, this wind turbine is commonly referred to as a constant speed wind turbine. Although pitch-controlled constant speed wind turbines have been produced in the past, this form of wind turbine is almost usually paired with stall control of the aerodynamic power nowadays. Due to the fact that these devices use reactive electricity, power factor correction capacitors are now installed at each wind turbine. These are usually rated at roughly 30% of the total capacity of the wind farm.. The connecting transformer of the wind turbine is required for connection to the distribution network and should be addressed when modelling the electrical interaction with the power system due to the low stator voltage of most wind turbine electrical generators.

III. INTRODUCTION OF STATCOM AND SVC

The SVC and STATCOM can offer dynamic reactive power compensation, which results in a network voltage rise during and after a malfunction. This increases the FSIG's electric torque, keeps the rotor from accelerating, and ultimately enhances system stability. One of the FACTS devices linked to the system is the STATCOM, which adjusts for reactive power. The capacitive or inductive current may be regulated in this device regardless of the AC bus voltage. If the system's voltage is unexpectedly dropped, STATCOM can compensate for the drop in voltage by injecting capacitive reactive power. The voltage supply converter (VSC) and coupling transformer are the two primary parts of STATCOM, as shown in Figure 5. In order for the STATCOM DC voltage to function properly, it is normally set to a fixed value. The STATCOM has two modes of operation: inductive and capacitive. The STATCOM is regarded a capacitive reactance and operates in capacitive mode when the converter voltage is equal to the transmission line voltage. Similarly, when the system voltage is equal to the converter voltage, the system observes an inductive reactance between its terminals, and STATCOM runs in inductive mode. Current flows from STATCOM toward system in inductive mode and from STATCOM toward system in capacitive mode. STATCOM can prepare inductive and capacitive compensation for a single system using these two performance modes.

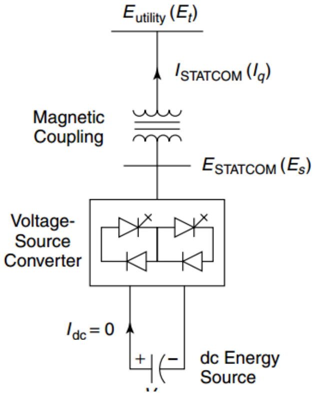

Fig. 5. STATCOM

SVC devices are another type of FACTS device that connects to the system in parallel. A series of fixed capacitors or reactors, thyristor switched capacitors (TSC), and thyristor controlled reactors (TCR) are linked in parallel with the electrical system to form an SVC. Using anti-parallel linked thyristors as switching components, the TSC divides a capacitor bank into suitably tiny capacitance steps and turns each step on and off independently. TCR regulates the fundamental-frequency current component in the reactor by delaying the closure of the thyristor switches in relation to the current's natural zero crossing. Figure 6 depicts the equivalent circuit of an SVC coupled to an HV bus. SVC can also be thought of as an adjustable susceptance, with a maximum reactive current proportional to the network voltage.

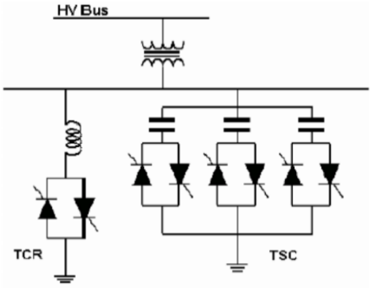

Fig. 6. Static Var Compensator (SVC)

IV. SIMULATION ENVIRONMENT

The SVC and STATCOM wind farm was simulated using the MATLAB/SIMULINK toolkit. The system depicted in Figure 7 consists of a 9-megawatt wind farm with six 1.5-megawatt wind turbines. The generators are squirrel cage induction generators with pitch angle control and fixed speeds. A 25-kilometer transmission cable connects the farm to a 132 kV network. The table 2 shows the system parameters. A 400 KVar PFC capacitor is attached to the generator terminal for each wind turbine to compensate for some of the absorbed reactive power by the squirrel cage induction generator.

The balance of the reactive power is supplied by SVC and STATCOM, which are coupled to the 33 kV bus. Each SVC and STATCOM has a capacity of three MVar. Figures 8 and 9 depict the systems furnished by STATCOM and SVC, respectively. A 132 kV generator with a 50 Hz frequency is part of the power network. The generator has an X1/R1 =10 ratio and a short circuit ratio of 2500 MVA, and it links to the transformer through a 132/33 kV Y/ 50 MVA transformer. A 25-kilometer transmission cable connects it to a 33-kV bus.

TABLE 2: System Parameters

Base Voltage	132 kV
Base Power	9 MW
Stator Resistance of Wind Turbine	0.004843 pu
Rotor Resistance of Wind Turbine	0.004377 pu
Magnetizing Inductance	6.77 pu
Reactive power of SVC and STATCOM	3 MVAr

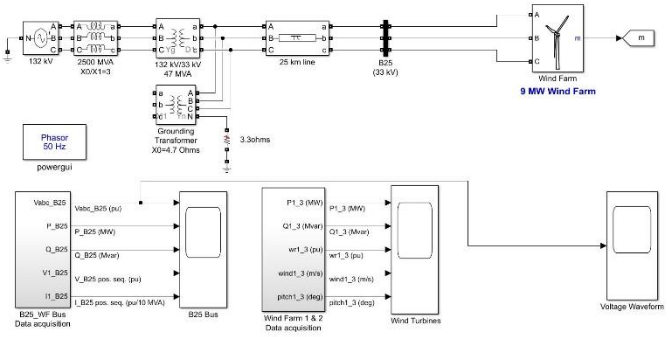

Fig. 7. Simulated System

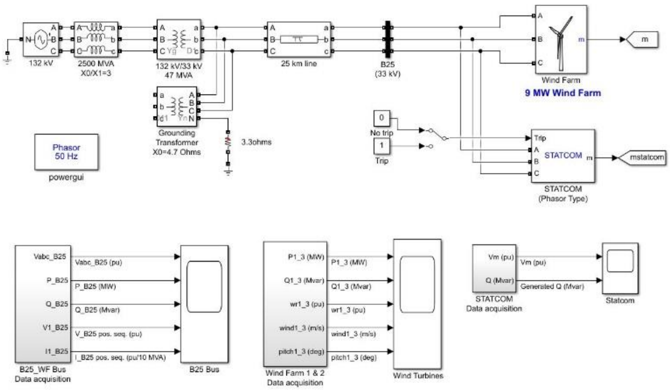

Fig. 8. System Equipped by STATCOM

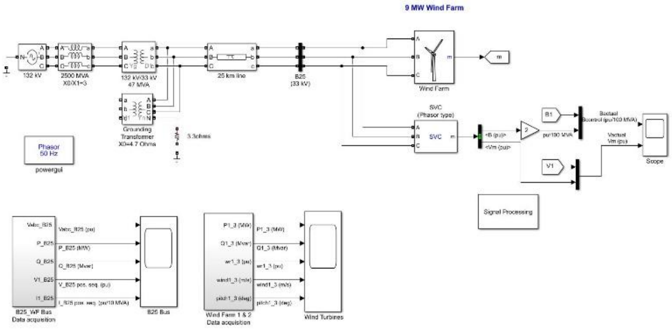

Fig. 9. System Equipped by SVC

V. SIMULATION AND RESULTS

Primarily, system was simulated with only power factor correction device and without fault. The results are shown in figure 10. The system was simulated for 20 seconds.

Figure 10 shows that the first wind turbine, due to a 7% voltage drop at 33 kV bus at t = 13.43sec., as shown in Fig. (10c), was unable to absorb enough reactive power, and as a result of the reduced electrical torque, the turbine lost its stability, resulting in an increase in rotor speed as seen in Fig (10f). The first wind turbine is then disconnected from the network by the protection system, and its active and reactive power drop to zero, as shown in Fig. 10d) (10e).

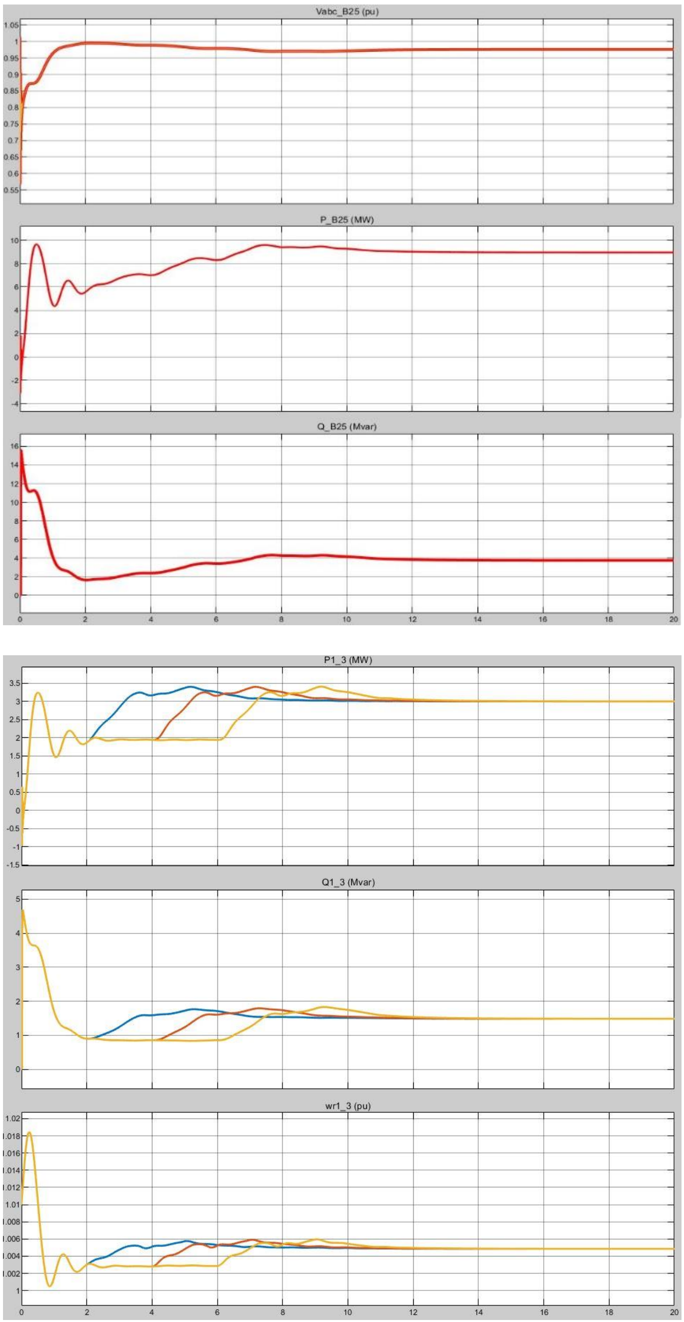

Fig. 10. simulation results with only PFC and without fault: a) voltage magnitude at 33 kV bus, b) active power flow at 33 kV bus, c) reactive power at 33 kV bus, d) active power of wind farm, e) reactive power of wind farm, f) angular velocity of turbines

The following simulation is run using only PFC and a fault that is cleared after 0.1 seconds. The outcomes are depicted in Fig. 11. At t = 15 seconds, a line to line to ground fault develops at the second wind turbine's terminal, and the fault is cleared after 0.1 seconds (t = 15.1).

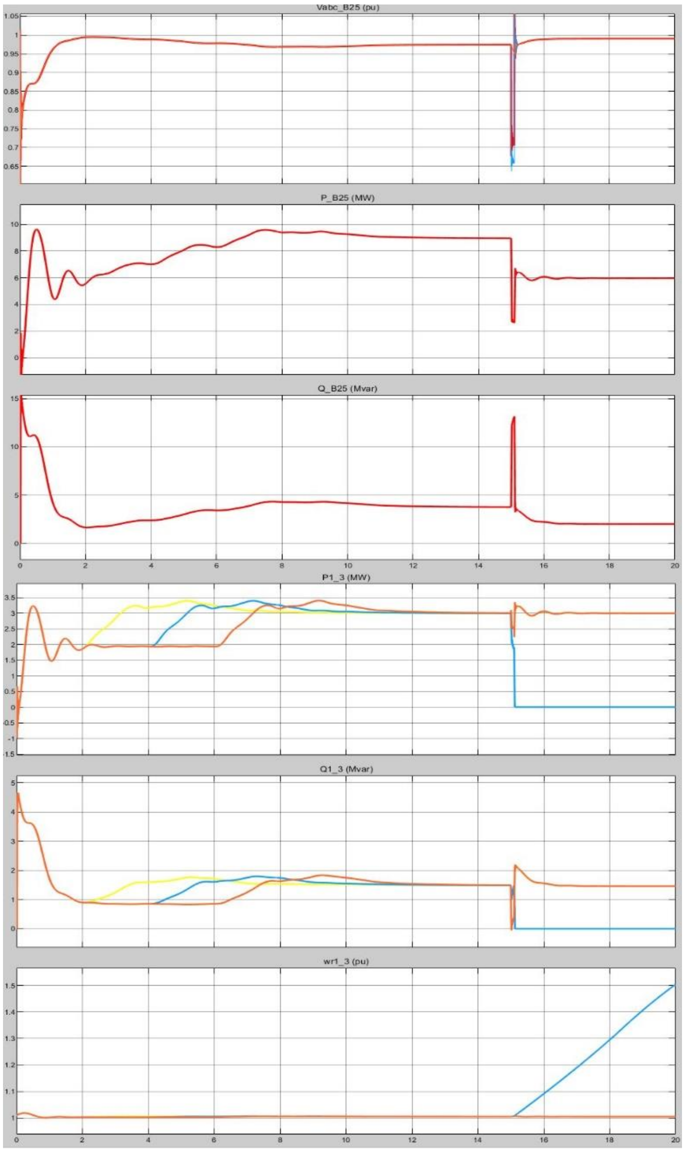

Fig. 11. simulation results with only PFC and with a fault at t = 15sec: a) voltage magnitude at 33 kV bus, b) active power flow at 33 kV bus, c) reactive power at 33 kV bus, d) active power of wind farm, e) reactive power of wind farm, f) angular velocity of turbines

The first wind turbine is blocked due to electrical torque weakness at t = 13.43 seconds, followed by the occurrence of a line to line to ground fault at t = 15 seconds, which is cleared at t = 15.1 seconds, and the second wind turbine will proceed to accelerate as shown in Fig. (11f). Because of a lack of reactive power and electrical torque in the FSIG, the second turbine is tripped by the protective system, as shown in Figures 11d and 11e. As a result, the third wind turbine is in charge of supplying active and reactive power to the 33 kV bus, as shown in Fig (11b). Figure 11c shows what happens after a failure occurs at t = 15 seconds. Reactive power is pumped into the 33 kv bus through a 400 kvar PFC capacitor linked to the wind turbines' terminals. Reactive power injection diminishes when the fault is cleared at t = 15.1 sec.

Figures 12 and 13 show the simulation results of the same network architecture with an extra 3 MVar SVC and STATCOM. Because of the presence of SVC and STATCOM, as shown in Figure (12d), the first wind turbine, which was removed by the protective system at t=13.43 sec in the previous simulation, can maintain its stability and create active and reactive electricity (13d). Because the capability of SVC and STATCOM to generate requisite reactive power is insufficient, the second wind turbine is tripped as shown in Figure (12f) (13f).

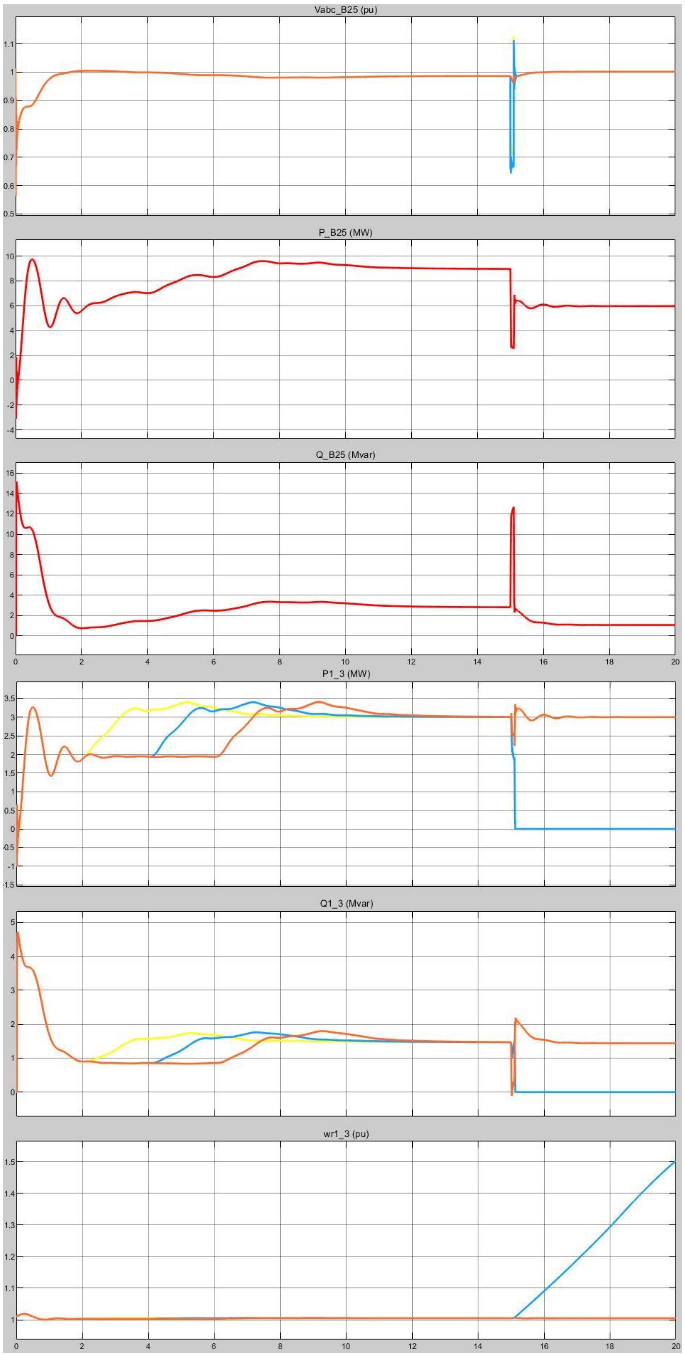

Fig. 12. simulation results with only PFC and 3 MVAr SVC with a fault at t = 15sec: a) voltage magnitude at 33 kV bus, b) active power flow at 33 kV bus, c) reactive power at 33 kV bus, d) active power of wind farm, e) reactive power of wind farm, f) angular velocity of turbines

Figures (12b) and (13b) show that once a fault occurs on t = 15, the active power of a 33 kv bus power decreases, and this decline continues until the fault is removed on t = 15.1. However, when SVC is present, active power reduction is greater than when STATCOM is present. The reactive power provided by SVC is lowered when the voltage profile is reduced. The highest reactive current of STATCOM, on the other hand, is solely limited by the capabilities of thyristors and is unaffected by network voltage. Furthermore, at t = 15.1 sec., the active power of the bus increases until it reaches its steady value (6MW) after numerous swings.

The outage of the second wind turbine may be avoided by increasing SVC capacity from 3MVar to 4MVar and STATCOM capacity from 3MVar to 3.5 Mvar.

The effects of network strength employing the SVC and STATCON on stability have been investigated in figure 10. For different network strengths, this graph demonstrates the fluctuation in critical clearance time for systems with PFC alone, SVC, and STATCOM. Both the SVC and the STATCOM received a 3 MVar rating in this investigation. In comparison to the SVC, it is obvious that the STATCOM has a greater influence on the crucial clearing time in the same short circuit ratio.

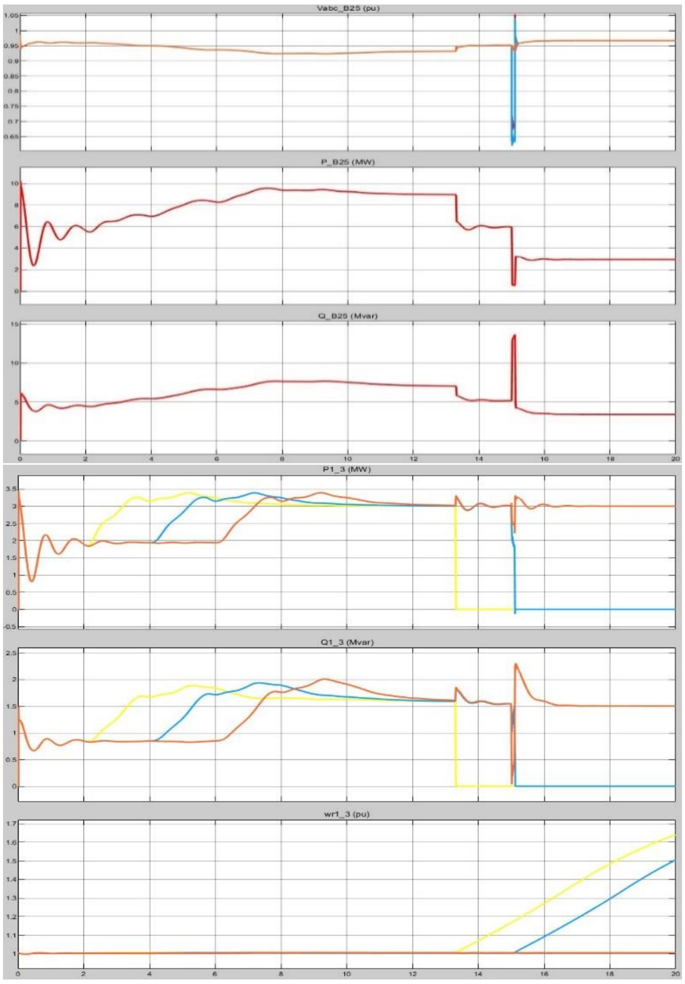

Fig. 13. Simulation results with only PFC and 3 MVAr STATCOM with a fault at t = 15sec: a) voltage magnitude at 33 kV bus, b) active power flow at 33 kV bus, c) reactive power at 33 kV bus, d) active power of wind farm, e) reactive power of wind farm, f) angular velocity of turbines

The influence of SVC and STSTCOM ratings on essential clearance time is seen in Figure 15. It shows that when compensator capacity increases, the critical clearing time increases and stability improves.

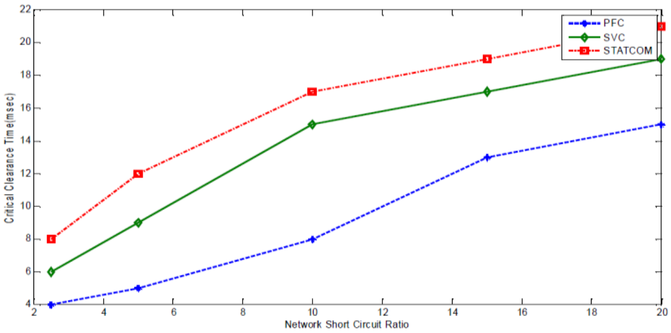

Fig. 14. Variation of Critical clearing time with network short circuit ratio

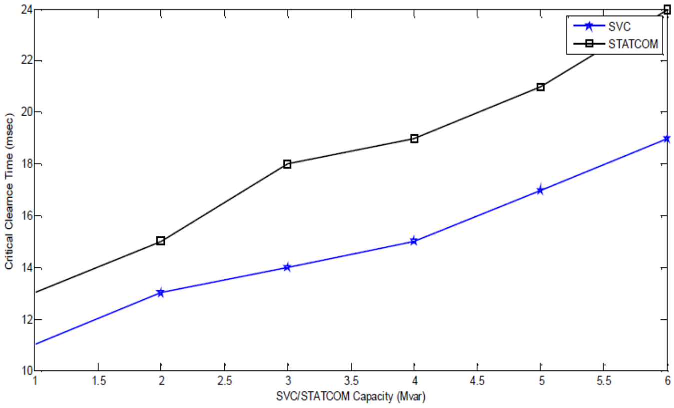

Fig. 15. Variation of Critical clearing time with compensating device rating

VI. CONCLUSIONS

The function of FACTS devices like SVC and STATCOM in improving system performance is defined. Improvement aspects include improved stability, power swing damping, voltage regulation, increased power transfer, and, most importantly, as a provider of regulated reactive power to hasten voltage recovery once a fault occurs. During fault occurrence, the simulation results reveal that STSTCOM compensation performs better than SVC compensation in terms of wind farm stability.

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