STABILITY IMPROVEMENT OF WIND FARM USING STATCOM

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Abstract- *One of the most significant non-conventional power sources to replace fossil fuels in the energy period is wind power. For wind turbine mills, the stability of the distribution system for wind farms becomes more essential. In the near future, non-polluting energy can be generated by wind energy. An overall load & output of wind power facilities change during day. Reactive power improvement was necessary to keep the power system voltage at normal levels. Reactive power imbalances may be decreased by connecting the STATCOM, which may have a substantial effect on power system. FACTS have been utilized to give suitable answers for the different fixed issues of energy system. During the previous years of the WECS, mostly fixed-speed wind turbines were deployed. The best alternative for dynamic reactive power compensation is the SVC since it has a higher generation capacity than other FACTS devices and operates similarly to STATCOM at voltages lesser than typical voltage variation. A STATCOM is a synchronous voltage source with a shunt connection, whereas an SVC is a controlled reactive admittance with a shunt connection. The STATCOM's stronger function qualities, enhanced application flexibility and improved performance over an SVC are due to these differences. The target of this study is to survey past distributions and lead an exhaustive audit of WT and STATCOM. Then, at that point, the total displaying of FSIG WT associated with STATCOM is examined, increase the wind farm stability with the help of STATCOM.*

.**Keywords**- Wind Turbine (WT), Static Synchronous Compensator (STATCOM), Flexible Alternating Current Transmission System (FACTS), Squirrel Cage Induction Generator (SCIG), Wind Farm (WF), Wind Energy Conversion System (WECS), Fixed Speed Induction Generator (FSIG), Doubly Fed Induction Generator (DFIG), Static Var Compensator (SVC)

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1. Introduction

Renewable energy is becoming more popular around the world and unconventional energy sources like solar energy, bioenergy, tidal energy and wind energy might help in climate change issues. The use of fossil fuels accounts for more than 80% of all energy consumed by humanity. However, recent studies have showed that renewable energy is the most environment friendly option. It is among world's fastest-growing energy sources [1]. Renewable power has numerous merites as it is robust of dealing with concerns such as climate change since there are no direct releases or emissions of greenhouse gases. Moreover, sustainable power sources might support the decrease of waste material and subsequently, the decrease of threats to the climate. Human comfort and the renewable energy are viewed as a dependable source of energy subsequently the sources are limitless as they certainly not run out of force. But, these sustainable power sources are non-economical. Environmentally friendly power is a mutually beneficial arrangement. Not only the energy prices should be affordable, but they should also be reliable throughout time.

The generator produces various stages of power at a result of the variable wind speed, which results in power fluctuations. Therefore, a major area of research in the field of wind power is to enhance the technology to enhance voltage stability, frequency, and power quality stability [2]. Due to their affordability and durability, Induction Generators are one of the most often utilized types of wind turbine generators [3]. The variation in wind speed produces deviations in the real & reactive powers of Induction generators, which cause fluctuations in voltage & power since the induction generator's active power output and reactive power consumption are correlated [3]. Reactive power control is a significant technical challenge in large wind farms. When the wind speed fluctuates, a capacitor bank, which is designed to provide the required reactive power in steady state, is unable to keep output voltage constant. Devices based on voltage or current source inverters have been employed to address this issue and provide secure loading, flexible power flow management, and oscillation damping [4-5]. The ability of STATCOM to produce faster and smoother voltage as well as the fact that it is more affordable than alternative technologies are the main factors for STATCOM's preference in wind farms.

2. Problems with Renewable Energy

However, while wind energy installation provides various economic and environmental advantages, wind farm circulation can similarly impact the grid's stability and performance. Due to the discontinuous and non-dispatchable nature of wind energy, sudden changes in wind speed can cause a disturbance in voltage on the network. These voltage disruptions make it challenging to stable the supply and demand of energy. When the wind speed is small, the load is too great, and when it is high, the load is low. This situation leads to grid instability and problems with poor power quality, transmission line losses, voltage drop, voltage imbalance, and poor power factor. As a result, wind farms are disconnected. Grid instability and unscheduled outages can occur due to rapid voltage shifts [6]. Wind turbines can only produce electricity while the wind is blowing due to intermittent nature of wind energy. Batteries have capacity to store extra energy for later use, although they are typically expensive [11-12].

3. Wind Turbine

A rotating machine known as a WT, as shown in Fig. 1, converts the kinetic energy of the wind turbine into mechanical energy. kinetic energy may be changed to electricity and send to the grid. The wind turbine's rotor and generator are where most of this conversion takes place.

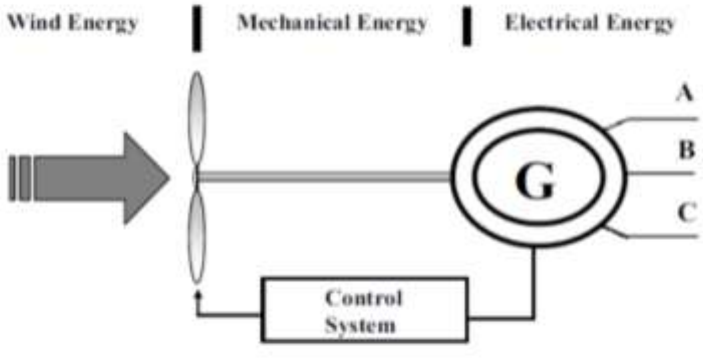

Fig. 1: WT and Energy Conversion [13]

The following formula can be used to determine wind power [14]

$$P_{\text{extracted}} = \frac{1}{2}\rho A C_{\text{Pmax}} u_1^3 \quad (1)$$

Where:

ρ = Air Pressure (kg/m^3)

A = Cleared Area of Rotor (m^2)

U1 =Wind Speed (m/s)

C_{Pmax} = Maximum Power Coefficient

From that point forward, the extracted energy is changed to electrical energy, which might be determined as follows:

$$P = VI \qquad (2)$$

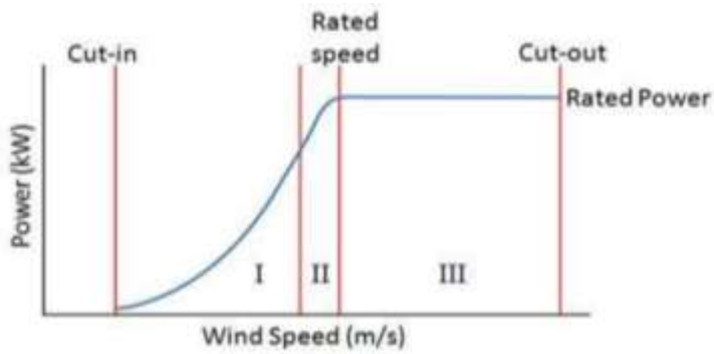

Fig. 2: Ideal WT Power Curve [15]

The highest and lowest speeds that a turbine can run safely are known as the cut-in and cut-out speeds. This range assurances that the amount of energy accessible is higher than the minimum. Cost and energy are taken into account by the manufacturer when determining the rated power.

4. Wind Turbine Technologies

There are four different varieties of WTs, which are classified as either variable speed or fixed speed WTs. During the previous years of the WECS, mostly fixed-speed wind turbines were deployed. Power electronics and generators are presently being used in variable speed WTs, which is a novel concept. The WT market is dominated by this power electronics-based technology. Many configurations of WECS [7] are depicted in Fig. 3.

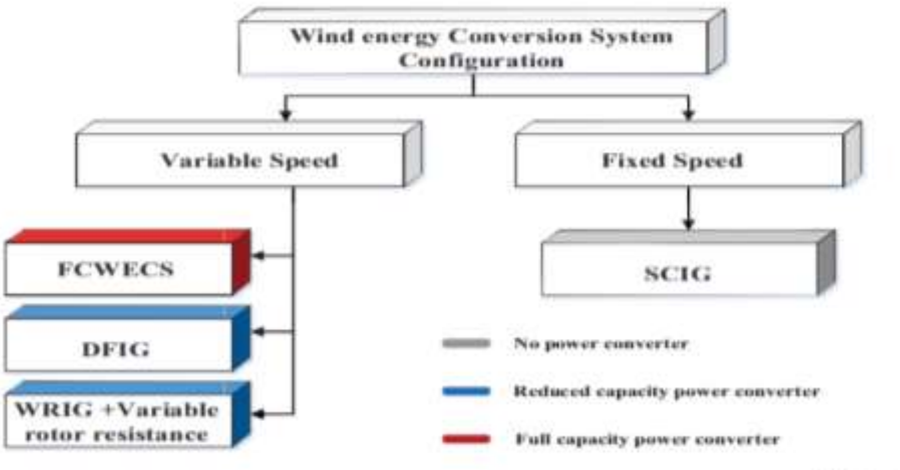

Fig. 3: WECS Types [7]

4.1 Fixed-Speed Wind-Turbine Technology

The proper speed WT is displayed in Fig. 4. It directly connected to grid utilizes the SCIG in the bureau throu a grip transformer [16]. The capacitor battery is require on the ground that the issues related to the acceptance generator are the utilization of reactive power, reduced power quality & mechanical pressure [17]. The changes FSIG turbine are communicated in mechanical force as vacillations and effect electric power variances. The changes in power be able to prompt solid voltage changes in weak network [18].

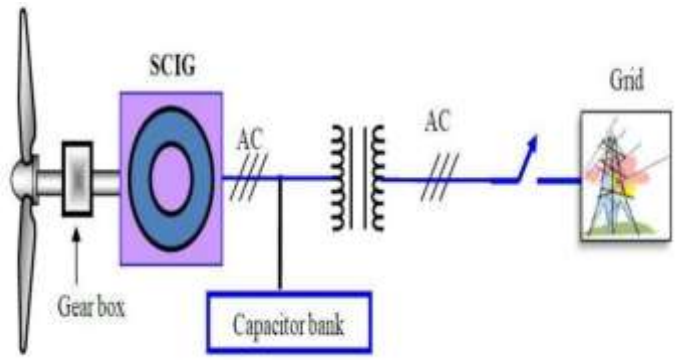

Fig. 4: Fixed Speed with Induction Generator [16]

4.2 Doubly Fed Induction Generator

In a DFIG model, the stator connected to the rotor speed, control network and its frequency, however, the rotor is connected to the network through voltage converter. Depending on the size of the drive, DFIG invention can operate at a wide variety of speeds. Financially appealing, variable rates often have a range of roughly 30% around the simultaneous speed [19]. Generated power is sent to the grid, as the generator rotates concurrently with the grid rotor after it reaches supersonic speed. As depicted in Figs. 4 and 5, respectively, coordinated rotor generator and self-excited with acceptance generator are powered by variable speed WT [20].

This wind turbine has routine maintenance because a gearbox, Additionally, wind turbine size is growing [21]. Voltage loss is the DFIG wind energy plant's second flaw because the stator is connected to the network & impedance is extremely difficult to set up. Additionally, voltage drops can produce overvoltage and cause access current under the rotor winding, both of which result, harm the rotor side converter [22].

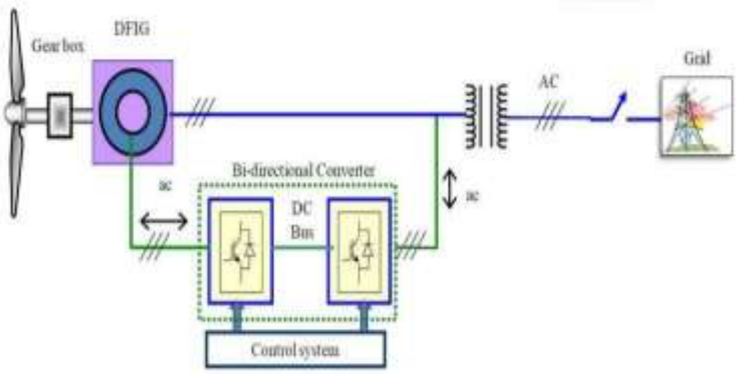

Fig. 5: Double Fed Induction Generator [20]

4.3 PMSG Variable Speed Wind turbine

In PMSG, generator output is connected to grid and the turbine is directly connected to the rotor of the generator without a transmission line using an AC-DC-AC converter, as like shown in Fig. 6. For complete control of power, this setup is generally proper, since it is associated with the network assistance of power converter [23].

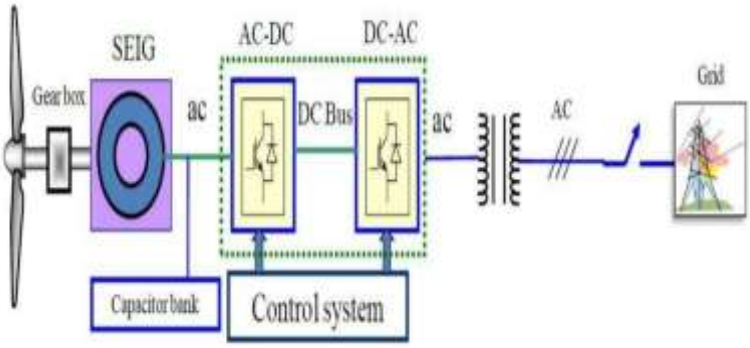

Fig. 6: Self-Excited Induction Generator [22]

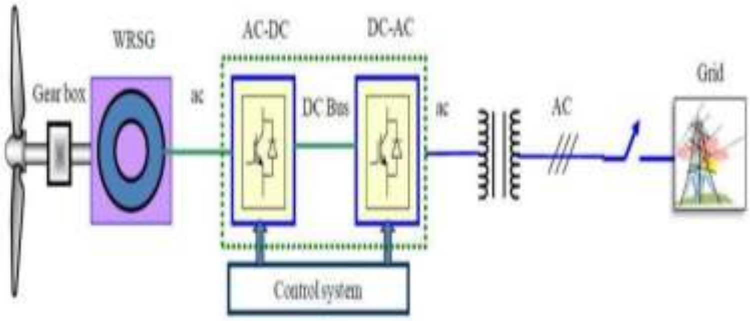

Fig. 7: Variable Speed Gear-Driven WT [21]

The two Primary destinations of the power converters are:

1. It goes about as power reserve (DC-connect) for power changes.
2. On the network side, make sure to control both reactive & active system ability. Primary elements of wind turbine PMSG are:

- Operation with no gears & more prominent unwavering quality.
- Smaller size, less complex design and lower cost PMSG.
- Good proficiency & most extreme PF.
- No solicitation to help reactive power.
- In converters, greater expenses & power losses.
- There is no outside excitation necessity.

The PMSG system is more capable of dealing with faults than the DFIG system because it is less complex and more effective.

5. FACTS Controller

According to FACTS, an alternating current transmission system is one that "utilizes static and other power electronic-based controllers to improve controllability and expand power transfer capabilities" [8]. The following are the most common uses of FACTS equipment reactive power compensation: -

- Increases in stability
- Enhancement the quality of power
- Controlling the flow of electricity
- Controlling the voltage
- Enhancement of transmission capacity
- Conditioning of power
- Mitigation of flicker
- Renewable and distributed generation and storage are interconnected.

6. Shunt Compensator Operation

Figure 8(a) depicts double machine power system with transmission line shunt correction. The transmission line (X) in fig. 8(b) is considered to be lossless, with Vs = Vr = Vm = V. The transmission cable (X) in the centre, a shunt compensator is connected [9].

Each terminal's active powers are equivalent and may be determined using the equation.

$$P = \frac{V^2}{X}\sin\frac{\delta}{2} \qquad (2)$$

The shunt compensator's reactive power is calculated as follows:

$$Q = VI\sin\frac{\delta}{4} = \frac{4V^2}{X}\left(1-\cos\frac{\delta}{2}\right) \qquad (3)$$

Figure 8(c) depicts the link between angle, reactive power (Q), and actual power (P).It may be established that shunt adjustment at the transmission's midpoint can significantly enhance power.

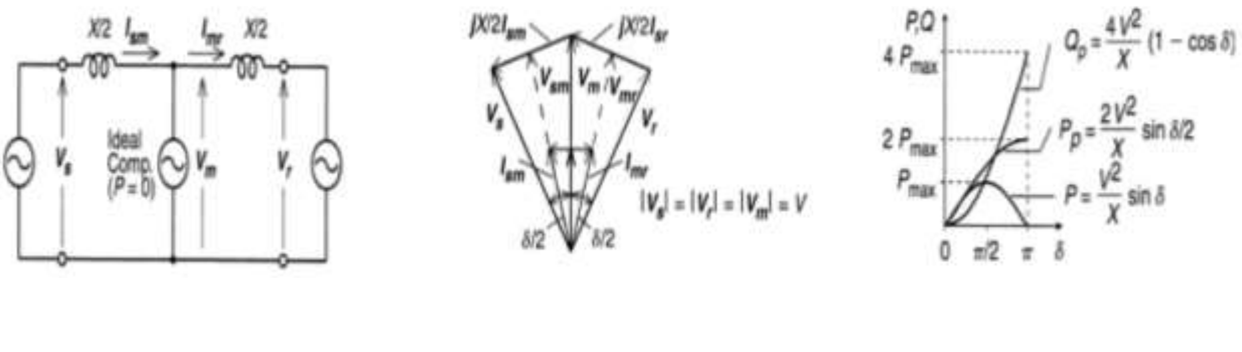

Fig. 8 (a) Reactive Compensator in a Power System (b) **Phasor Diag. (c) Power Angle Characteristics [24]**

7. STATCOM

The IEEE definition of a STATCOM is "a static synchronous generator operated as a shunt connected Static Var Compensator whose capacitive or inductive output current can be adjusted independent of the AC system voltage." [10].

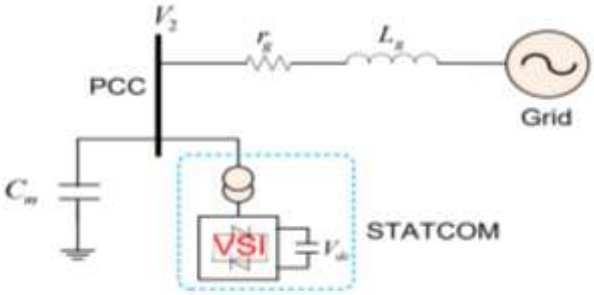

Fig. 9: STATCOM with Grid [25]

In the AC power system frequency, VSC generates a series of programmable 3-phase output voltages. The charged capacitor provides the VSC with a DC voltage. By varying converter output voltage's amplitude in proportion to the line bus voltage, it may continuously produce or consume reactive power while enabling a regulated current to pass between STATCOM and power grid through the tie reactance (jXs).

Whenever the output voltage amplitude exceeds the line bus voltage, the STATCOM generates a leading current, also known as reactive power. A lagging current develops when the output voltage is reduced under the bus line voltage, and STATCOM absorbs reactive power. There is no power exchange if the two voltages' amplitudes match. As a result, voltage may be regulated and voltage variations such sags, swells, and transient disturbances can be minimized.

8. Wind Farm Model

A 9MW wind farm consist of three (2*1.5) MW WT is too connected with 25kv distribution network. The typical turbine systems used in the 9MW wind farm include SCIG and unstable pitch WT. The pitch angle is changed to maintain generatored power at it feasible level in winds that are faster than the generator's nominal wind speed of 9 m/s. Voltage, current, and machine speed in each wind turbine are all monitored by a safety system. MATLAB/Simulink is used to model the system in below figure.

Table 1: System Model Values

Parameters	Values
V_{base}	120kv
P_{base}	9MW
F_{base}	50HZ

Table 2: WT Model Parameters

Parameters	Values
Stator Resistance	0.00484
Rotor Resistance	0.00437
Magnetizing Inductance	6.77

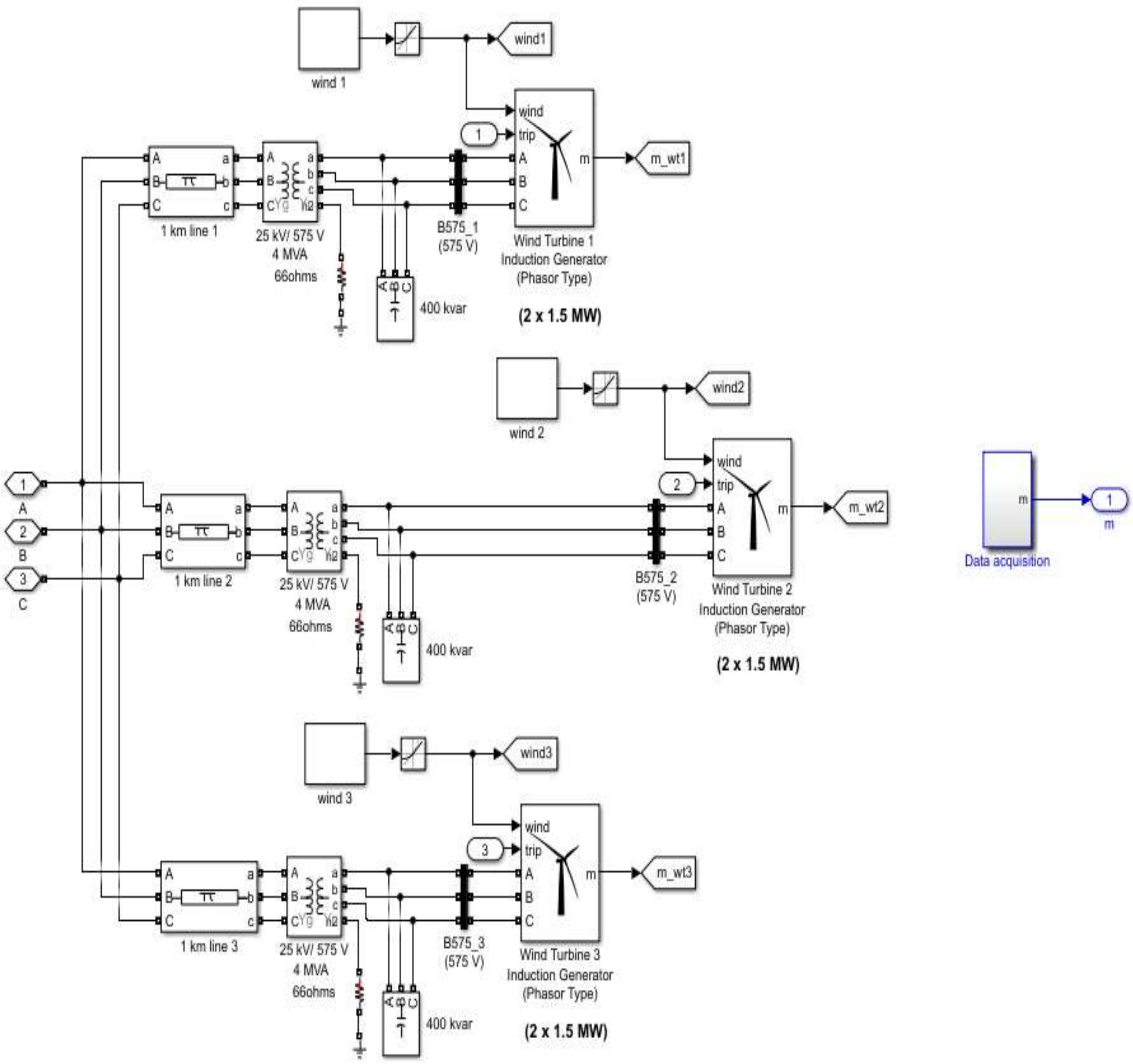

Fig. 10: MATLAB Simulink of Wind Farm

9. Simulink Model

The simulation results of a 25km wind farm connected to the distribution system and 120 KV grid. The model uses Simulink MATLAB software to examine the influence of the fixed-speed wind turbine on the system during three phase-faults. The simulation results show that the presence of STATCOM enhances outcomes and performance. The wind turbine speed, voltage, active power, reactive power and rotor speed have analysed. The system model includes a source, transformer, STATCOM, measurement block, and wind turbines. Additional features include a bus line data acquisition circuit and data acquisition description circuit. A warning indicator is given out to show system failure behaviour, such as voltage dips or AC over current.

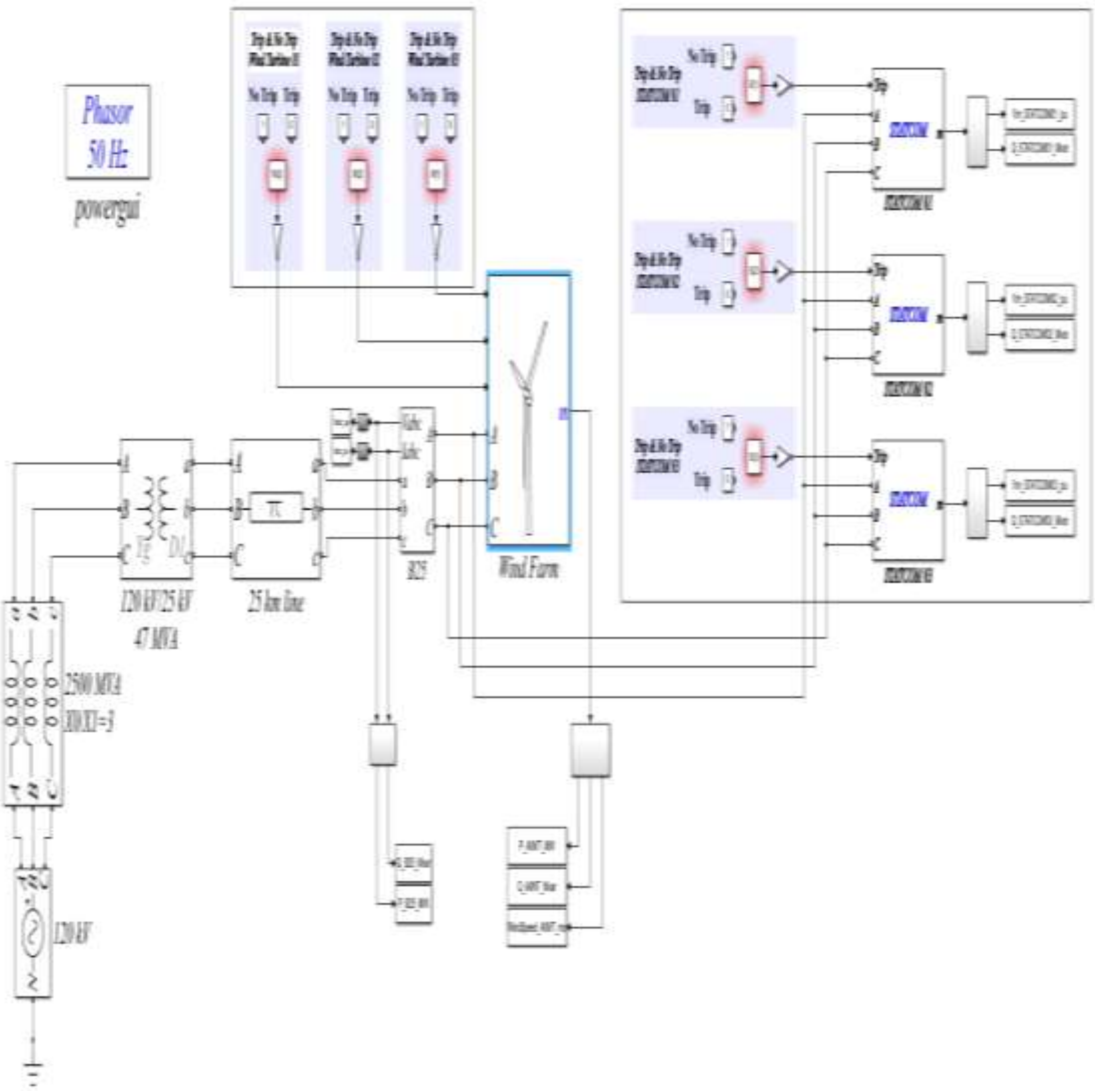

Fig. 11: Simulink Model of Wind Farm with STATCOM

10. Results

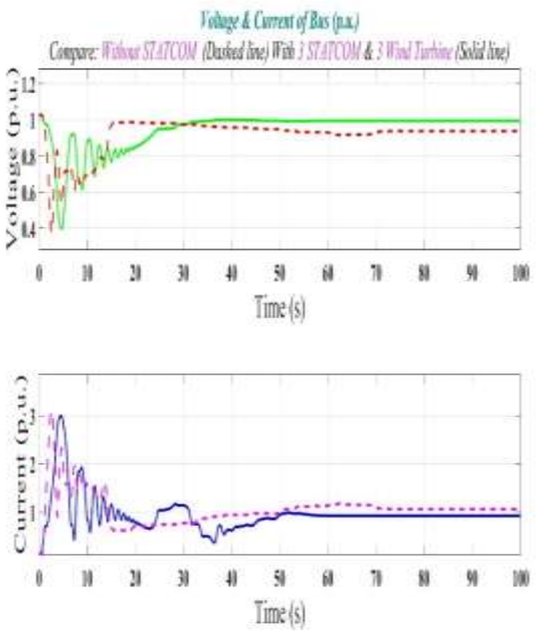

Fig. 12: Voltage & Current of Bus

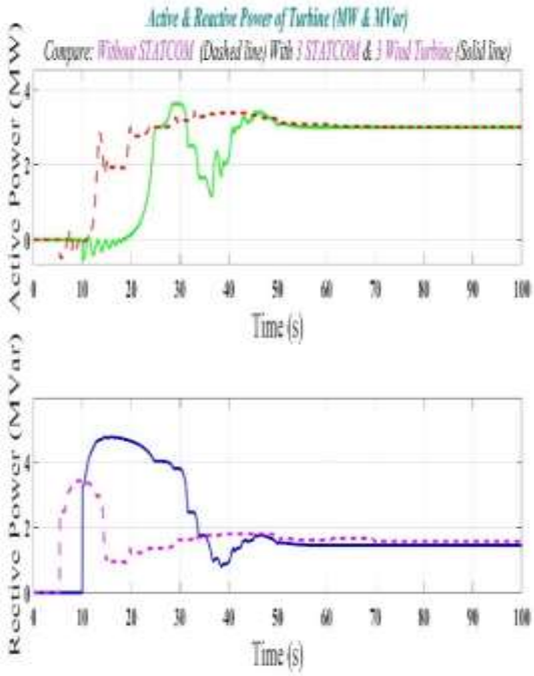

Fig. 13: Power of Turbine

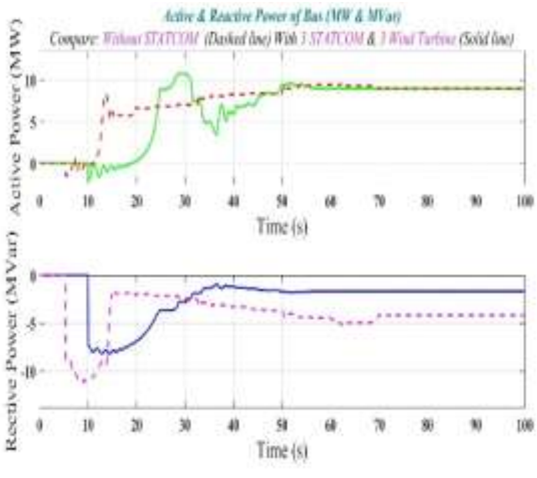

Fig. 14: Power of Bus

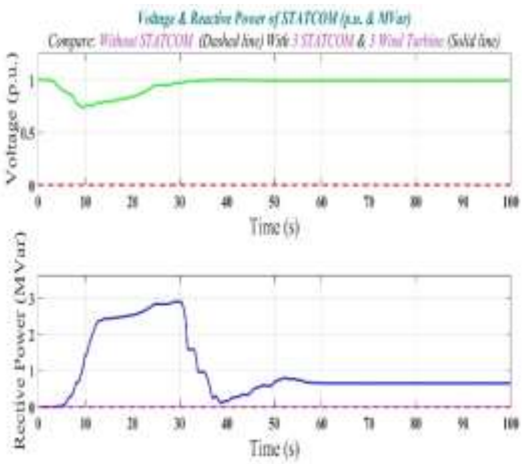

Fig. 15: Voltage & Reactive Power of STATCOM

11. Conclusion

This paper investigates the concept of STATCOM that are connected to wind turbines in order to offer reactive power control. Wind farm models used here consist DFIG & FSIG, which need reactive power correction during network interruptions. STATCOM can therefore offer the requisite reactive power while linked to a weak network. Additionally, an advanced degree of STATCOM can employed to effectively control stress & improve wind farm dependability, but economic considerations limit its classification. The simulation results demonstrate that by speedily restoring voltage characteristics, an external device like STATCOM can considerably improve wind turbine recovery. Depending on the rating, STATCOM may or may not be able to support this. With a higher grade, more help is available. The safety of wind turbine connections with poor networks is also impacted powered by the wind turbine. When wind turbines are linked to a faulty grid, the quantity & frequency of failures, grid deviations, voltage & frequency all occur in abundance. Wind turbines can be affected by a variety of factors. Wind turbine's dynamic power has been measured. STATCOM has enhanced the electrical grid. STATCOM is used to enhance the wind turbine's indicate to quick load variations.

12. Future Work

The simulation tests indicate that STATCOM improves the dynamic performance of wind farms. Future studies might involve analysing the system's harmonics and evaluating approaches for minimizing harmonics. Lower order harmonics can be reduced using a multilevel STATCOM. The system's reaction to high-impedance three-phase short-circuit faults was explored in this study, which may be expanded to other types of failures. The hybrid wind farm, which includes DFIG and FSIG WTs is modelled here. The research is limited to DFIG and FSIG presentation, but it can expanded to include WT types and larger systems that examine STATCOM's assistance.

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