https://doi.org/10.5194/wes-2024-75
Preprint. Discussion started: 16 August 2024

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Mitigation of Power System Oscillations in Wind Farm Integrated Multi-Machine System using PSS and TCSC

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Abstract. Nowadays, the rapid growth of wind power is utilized by integrating wind farm with electrical network. The induction generator used in the wind farms, on the appearance of fault create the sub synchronous resonance as well as power oscillations. This paper reports the mitigation of power system oscillations by using power system stabilizer aided TCSC. For analyzing the performance of the wind-farm integrated test system, various parameters (line power, bus voltages, rotor angle deviation, active & re-active power) of the test system are observed under random speed variation with different types of faults. The PSS and TCSC are used to stabilize the resulting over damped oscillations system parameters. The settling time of the oscillations of one parameter is reduced by 45.14% when coordinated PSS and TCSC is used in place of PSS alone. After rigorous comparison, it is found that the presented TCSC exhibits excellent performance in fast damping of power system oscillation and thereby enhances the stability of the existing system.

Keywords: PSS; FACTS; power system stability; TCSC; wind power system

1. Introduction

Environmental pollution and depletion of fossil fuels are the two most important issues discussed nowadays (Mohammadpour et al. 2015, Varma et al. 2008) which shifted the interest of power engineers and utilities towards more sustainable green energy sources like hydro, tidal, solar, wind, etc. (Shanthi et al. 2017, Rini & Razzak, 2015, Fatnani & Mitra, 2019, Tamura et al. 2020). Among all, wind energy offers promising performances due to the vast abundance of wind and state-of-the-art technologies available to gather it. Moreover, this system is potentially environmentally friendly and thus has an advantage over conventional systems. Several researchers carried out extensive studies on the integration of the wind energy conversion system in numerous network (Jaoued et al, 2013, Tianqi et al. 2020).

Now a day there are several wind farms integrated with the grid. So, it is required to transfer power without congestion. Also, for improving the transmission network stability, power system stabilizer is an effective solution (Ghosh et al 2018, Eslami et al. 2010). But when a three-phase fault is present in the system, Power System Stabilizer (PSS) is not sufficient to maintain the stability of the power system. So, for that cases system require a compensation device to enhance the system stability.

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Flexible AC Transmission System (FACTS) devices provide new opportunities for power network. There are different FACTS devices for improving the power transfer capability of network which are explained in literature. In this work, TCSC is used for enhancing the stability of a test system (Anyanor et al. 2022, Patil et al. 2023, Mirsaeidi et al. 2023, Marouani et al. 2023. TCSC is one of the effective FACTS devices which mitigate the sub-synchronous resonance and also mitigates continuous oscillations occurred in the power system. It also improves the voltage dip that occurs in the fault cases (Jamil et al. 2017).

A few works also reported use of SVCs and STATCOMs for mitigating the SSR damping (Fan et al. 2012, Okedu et al. 2011). Hossein et al integrate the wind turbine generator with the SMIB system for increasing the electric power generation and simultaneously TCSC is used for further enhancement of the power flow of the system (Mohammadpour et al. 2015, Okedu et al. 2011). Similarly, Varma et al. (2008) report the occurrence and damping of sub-synchronous oscillations due to generator present in a wind farm with the help of TCSC (Varma et al. 2008, Hua et al. 2011). Jaoued et al. (2013) improves the stability of IEEE 5-Bus system using TCSC. Similarly, Joshi et al presented the use of TCSC in a grid-connected wind energy system. This concluded that the TCSC improves the flow of power, and control the power swing damping of the system (Joshi & Mohan, 2006). In India there are number of FACTS devices are installed, like TCSC is installed at Kanpur and Ballabhgarh transmission line and which was the first FACTS device installed in India. Also, one device is installed at Raipur-Rorkela line and in Andhra Pradesh also (Paliwal 2022).

The motivation behind this work is to integrate the wind energy system into the multi-machine system and to enhance the system stability for two scenarios that is with and without fault, with the help of PSS and TCSC. PSS mitigates the oscillations of the line power, bus voltages as well as rotor angle speed when there is a random change in the speed of the wind. And PSS damps out the oscillations slowly under faulty condition. So, integrating the TCSC with PSS for fast mitigation of the power oscillations of the different parameters in the network and improves the power flow, overall stability of the system, etc.

2. **Power systems under study**

The circuit diagram of a 500 kV two-machine transmission system adopted for the study is shown in Fig. 1. It consists of two salient-pole type alternators of 1000 and 5000 MVA rating. To control the rotor speed and the output voltage, turbine and regulator set are provided with each alternator. A generic power system stabilizer is also provided with each alternator to improve small disturbances occurring in the system. The two alternators feed power into an 800 km long transmission network by employing step-up transformers of rating 13,800V (Δ) /500 kV (Y) 1000 MVA and 13,800V (Δ) /500 kV (Y), 5000 MVA, connected at buses B1 and B2 respectively. Bus 1 and 2 are connected through 400 km line L1 and Bus 2 and 3 are connected with 400 km line L2, each modelled on distributed parameters. The variable load is connected at Bus 3 with a fixed load of 1000 MW. A TCSC is introduced between bus B1 and B2 to suppress oscillations and provide stability to the system in case of faults and contingencies. To assure the continuity and reliability of the supply, a wind turbine farm is connected at bus B1. It consists of 4x3 MW wind turbines, each coupled with IG. The output of each IG is connected to the transmission network at B1 using a 33 kV (Y)/ 500 kV (Y) step-up coupling transformer and an 8 km feeder line modelled as a π-network.

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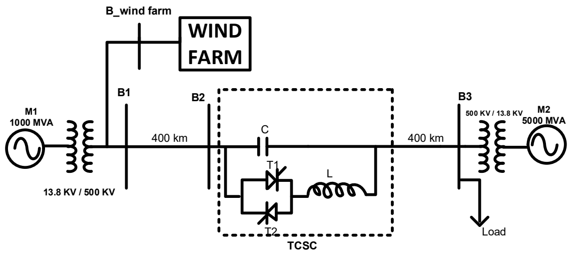

Figure.1. Test System

3. Modelling of PSS and TCSC

3.1 Power System Stabilizer (PSS)

It stabilizes the system's voltage by adding external signals to the generator's exciter (Hughes et al. 2006, Lal& Kalappan, 2021). Basically, there are two types of PSS (namely, generic and multiband PSS). This work presents the generic type of PSS (as shown in fig. 2). The given PSS stabilizes power swings of the machine. The input of PSS is speed deviation (dω) of the machine / Pa (accelerating power) and the output is V_{stab}.

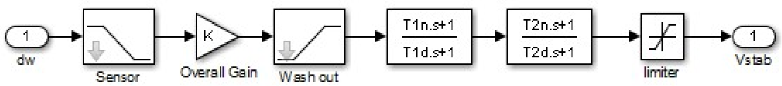

Figure.2. Generic PSS

3.2 Thyristor Controlled Series Compensator/Capacitor

It is series connected compensated devices in the FACTS family. The concept of TCSC was found in mid of the 1980s and was installed in 1992 in the USA. In India, a TCSC controller was installed at the Kanpur-Ballabhgarh 400KV transmission line located in Northern India. It can reduce power network losses, mitigate the sub-synchronous damping, provide voltage support and prevent voltage collapse, etc. It can enhance the power flow, loadability of the transmission line, voltage and transient stability of the system by controlling transmission line impedance by adjusting the impedance of TCSC, which can vary according to the firing angle, $\boldsymbol{\alpha}$ of a thyristor. Figure 3 shows the basic diagram of TCSC, consists of a capacitor, C, shunted with one TCR, which is variable inductive reactance. It is obtained by connecting back-to-back thyristor in series with a fixed inductor, Ls. The overall transmission line impedance can decrease by using series compensation and then power flow of the line is increased (Kumar & Nagaraju, 2007, Piyasinghe et al. 2015, Chatterjee & Ghosh , 2007, Ganthia et al. 2018, Ain et al. 2020).

The impedance of TCSC can be controlled according to firing angle α variation, and therefore the reactance of compensator X_{TCSC} is varied according to the following relation given in equation 1.

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$$X_{TCSC}=\frac{V_{CF}}{\pi}=X_c-\frac{X_c^2(2\beta+\sin 2\beta)}{(X_c-X_L)\pi}+\frac{4X_c^2}{X_c-X_L}\frac{\cos^2\beta}{k^2-1}\frac{(k.\tan k\beta-\tan\beta)}{\pi} \quad (1)$$

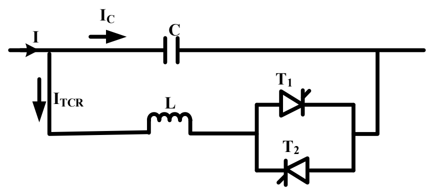

Figure 3. A basic TCSC module

4. Modelling of Wind Farm

Wind energy is considered one of the fastest growing sources of renewable energy in the world. A wind turbine is a device in which, kinetic energy is changed into mechanical energy with the help of torque which is produced by an IG (Salehi et al. 2006, Choudhury 2021, Thoker & Lone, 2020). Finally, the converted mechanical energy is further converted into electrical energy. The power, P_w produced by the wind turbine is given in equation 2.

$$Pw = 0.5\rho\pi R^2 V_w^3 C_p(\lambda,\beta) \quad (2)$$

The wind turbine characteristics and variation of wind speed with time are reported in this present paper are given in Fig. 4(a) and 4(b) respectively. Wind turbine characteristics is reported here for different pitch angles of the blade. The different wind speed used here is 6, 8, 5, 7, 8 and 4 m/s respectively.

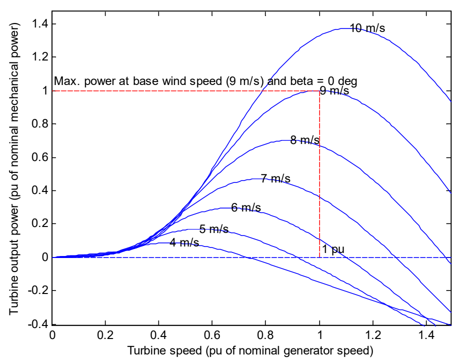

Figure.4. Characteristics of Wind Turbine

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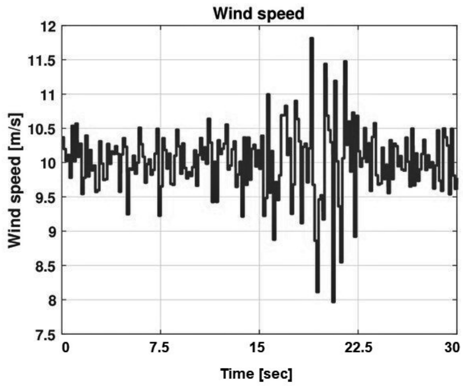

Figure.4(b). Variation of wind speed with time

5. Results and discussion

The effectiveness of PSS and TCSC in the mitigation of unwanted oscillations due to random change of wind speed and occurrence of a fault is verified. The parameters employed to examine the performance of PSS and TCSC are line power, voltages of different buses, rotor angle deviation between two machines, and powers of the wind energy system. These parameters are depicted from Fig. 6 to 15 for the cases with and without fault.

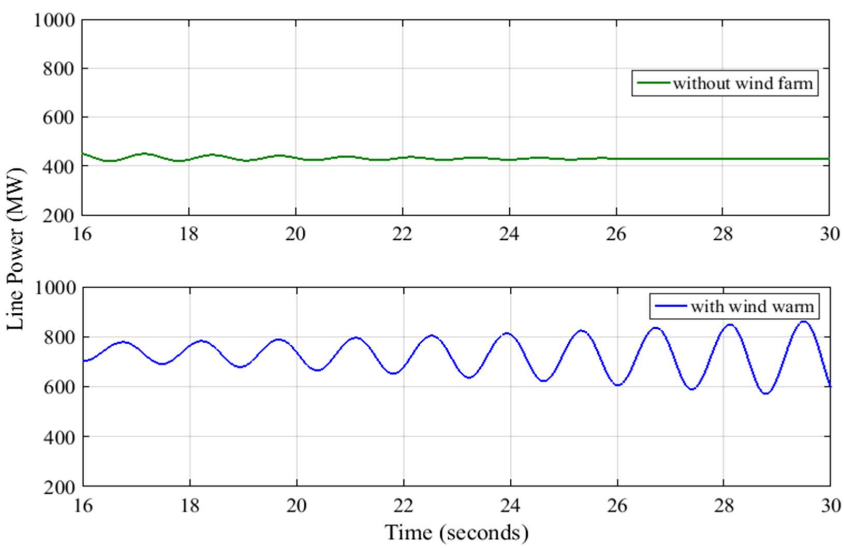

Figure.5 Line Power Vs Time (with and without wind farm)

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5.1 Without Fault

Fig. 6 to 10 shows the line power, voltages of different buses, rotor angle deviation and powers of the wind energy system for two scenarios i.e., with and without PSS. It can be observed from (i) part of the Fig. 6 to 10 that the oscillations are not damped out but when PSS is added to the system, the oscillations of all the parameters were mitigated which is shown by (ii) parts of above figures. From these observations, it can be said that PSS can stabilize the system when fault is not present in the system.

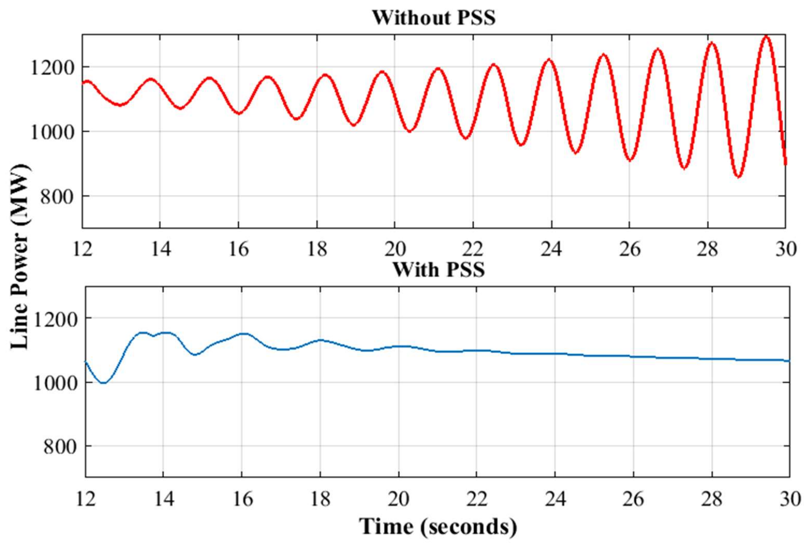

Figure.6. Line Power Vs Time

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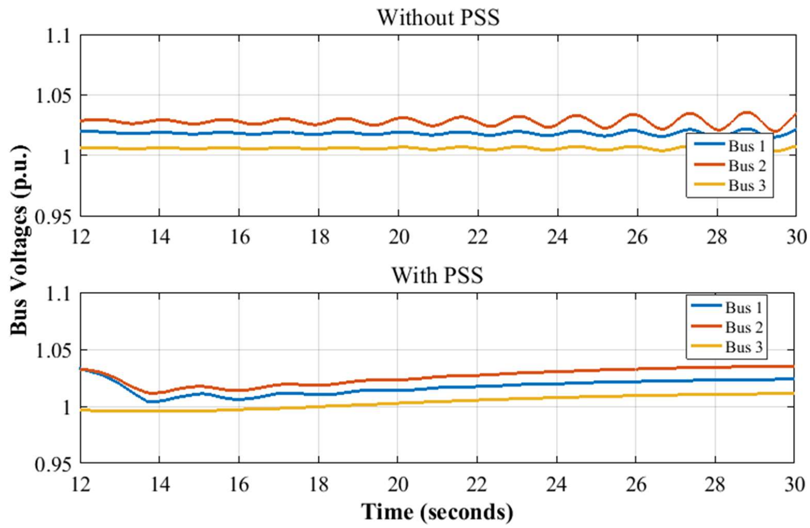

Figure.7. Voltages of Bus 1, 2, and 3 with respect of time

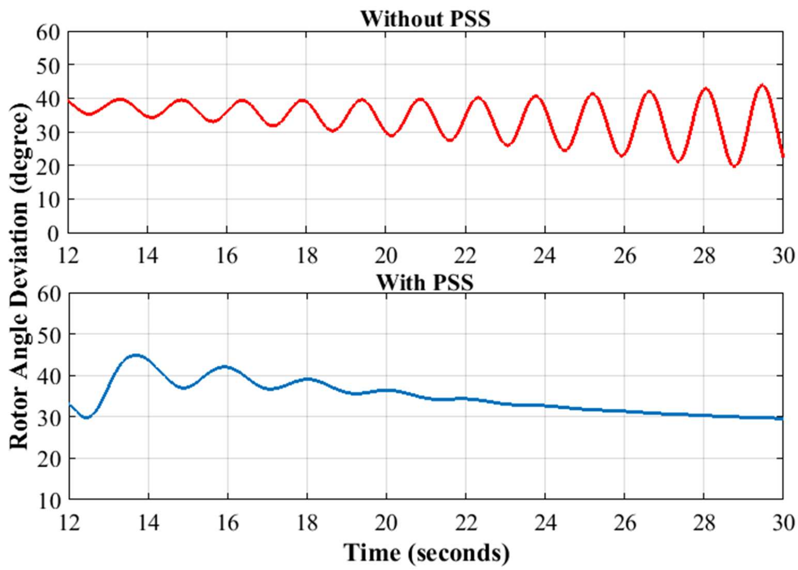

Figure.8. Rotor Angle Deviation

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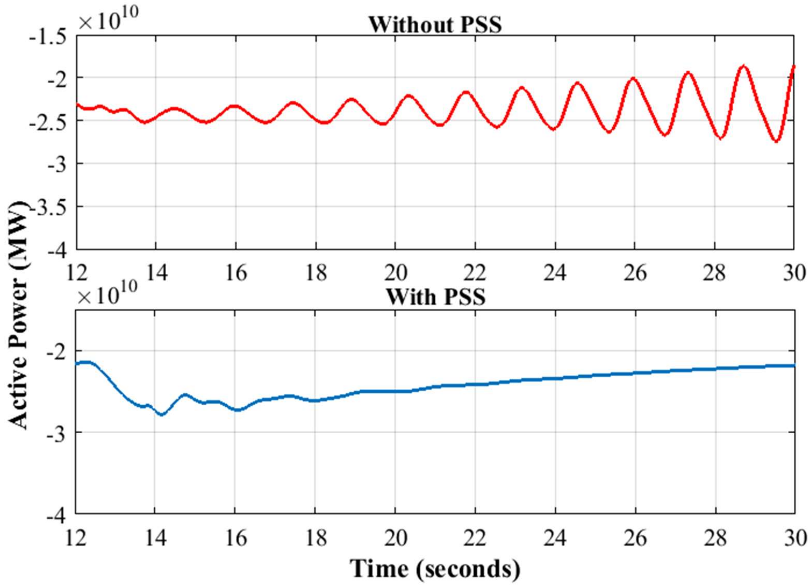

Figure.9. Active power of wind energy system

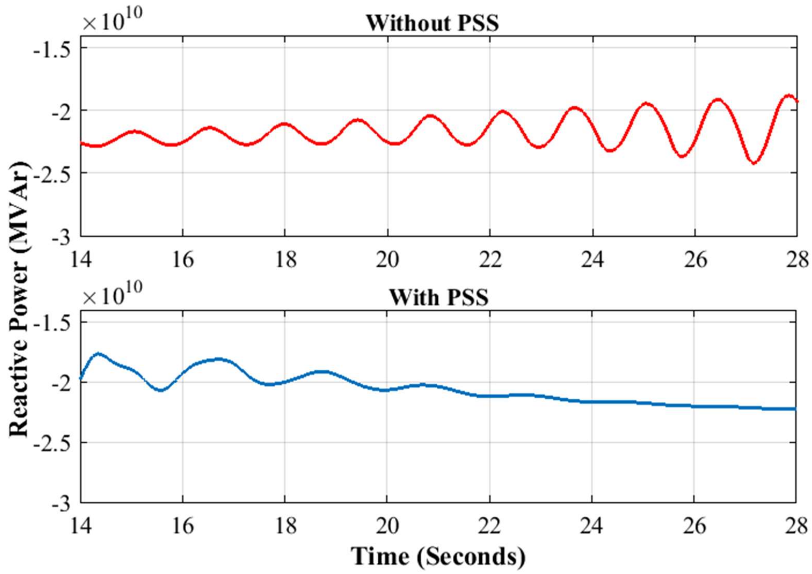

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Figure.10. Reactive power of wind energy system

5.2 With Faults

Fig. 11 to 15 display all the above parameters of the system when there is an occurrence of three-phase fault for two sec. A line is tripped at t = 20 sec for 2 seconds. Three different cases are considered for checking the effectiveness of TCSC. After the clearance of fault power system is not successfully maintain the stability and thereby large fluctuation is experienced in all the parameters which are demonstrated in the first part of Fig. 11, 12, 13, 14 and 15. Then PSS is added to the system and undamped oscillations present in the line power were damped out at t = 26.52 sec, employs that after approx. 4.5 sec, the system will stable. To improve the performance of the given system TCSC is added with the proposed system. The TCSC can mitigate the oscillations after a few cycles or faster than the system with PSS alone. From the third part of Fig. 10, it can be observed that TCSC maintains the stability 2.1 sec faster than PSS. Table-1 shows the exact settling time of power oscillations of described parameters. It can also see that the peak of the parameters at the fault duration is reduced when TCSC is connected in the system. Similarly, from Fig. 11, 12, 13, 14 and 15, and Table-1, it is seen, performance of the TCSC is superior in damping of power system oscillation than the system with PSS only.

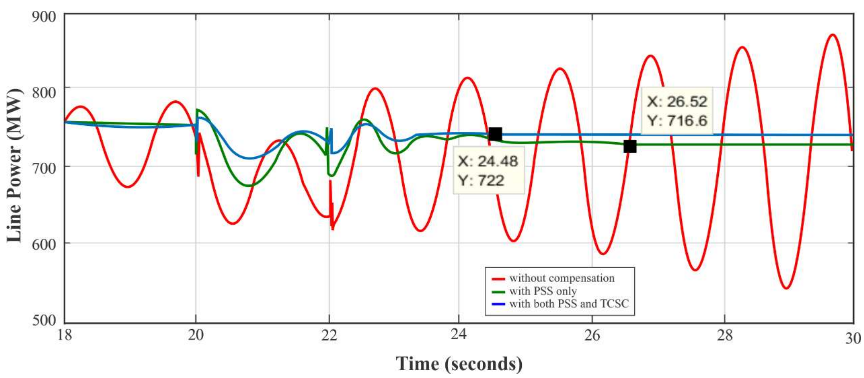

Figure.11. Line Power Vs Time

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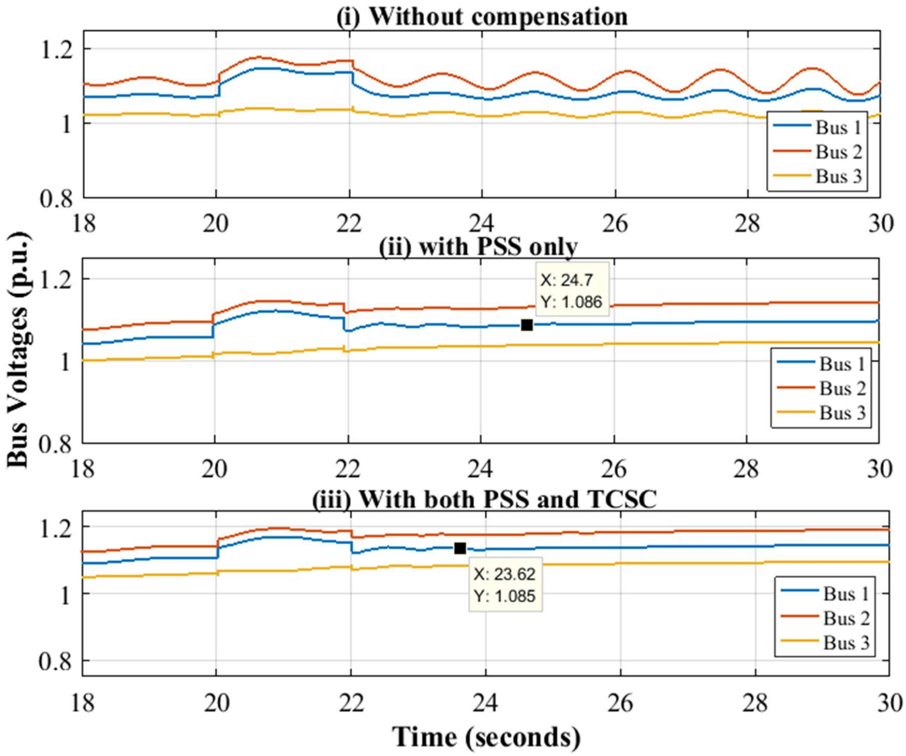

Figure.12. Bus Voltages

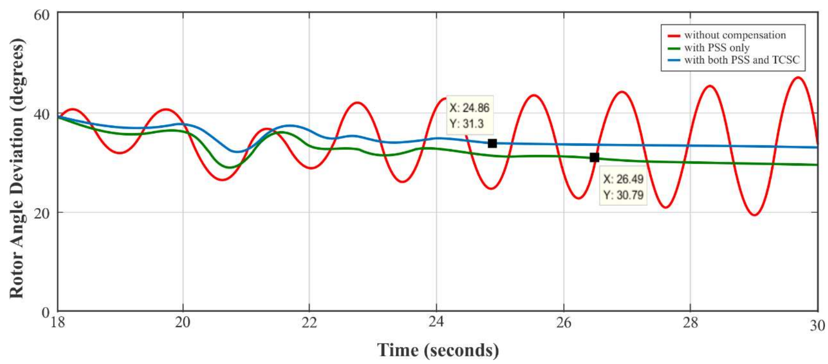

Figure.13. Rotor Angle Deviation vs time

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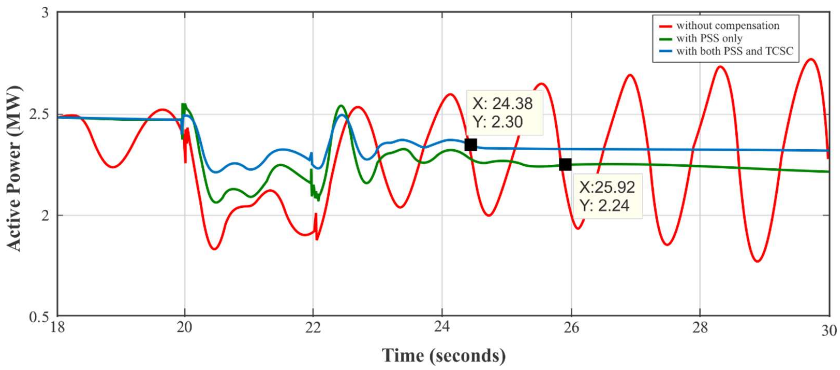

Figure.14. Active Power of wind energy system

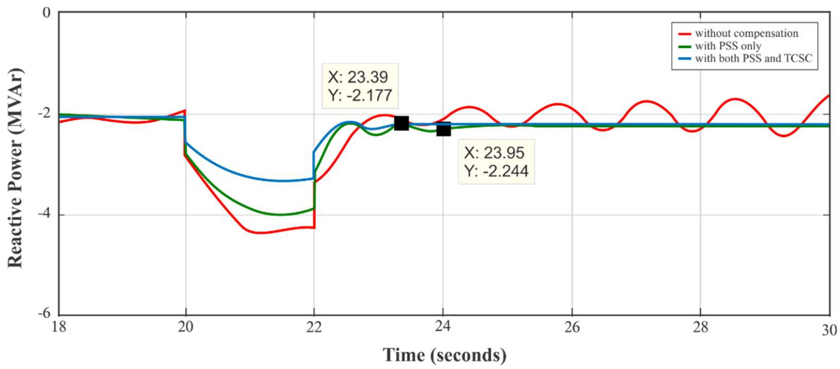

Figure.15. Reactive power of wind energy system

Table.1. Settling time (seconds) of the oscillations

Parameters	PSS alone	PSS +TCSC
Line Power	4.52	2.48
Bus Voltage	2.77	1.62
Rotor angle deviation	4.49	2.87
Active power of wind farm	3.92	2.38
Reactive power of wind farm	1.95	0.6

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6. Conclusion

In this paper, wind farm is integrated with the multimachine power system and its performance is observed under two conditions i.e., with and without the occurrence of a fault. It can be observed that the large oscillations are present in the line power, rotor angle deviation and bus voltages. These oscillations are present due to the intermittent change in the wind speeds. These oscillations are damped out with the help of the PSS which is present in the test system. Then the performance of the system with the 3-phase fault in the wind farm was analyzed. It is observed that the oscillations were present even after the clearance of the fault and the system becomes unstable. Although PSS is capable of damping out these oscillations, it requires more time to do so. Therefore, TCSC is added to the test system for fast mitigation of unwanted power system oscillations. It is observed that the settling time of oscillation is less when TCSC is connected with the test system. Hence, it can be concluded that TCSC enhances the stability of wind farm integrated multi-machine power system.

Competing interests

The contact author has declared that none of the authors has any competing interests.

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