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Stability Enhancement of DFIG Wind Farm Using SSSC With FOPID Controller

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ABSTRACT

Wind power generation is becoming increasingly important in order to meet rising energy demand. Doubly-fed induction generator (DFIG)-based wind power generation is recent and used in many countries due to its better power controllability. The controllers, like proportional integral (PI) controllers, are used for the stabilization of the waveforms of the supply system. The change in controllers has produced better oscillation damping in recent days. The effect of varying the wind input to generate power using the wind turbine results in instability in the power system because the control is done on a grid supply. This paper aims to propose an optimum First Order Proportional Integral Derivative (FOPID) controller for damping power system instability using a static synchronous series compensator (SSSC) system that takes into account the dynamics of wind energy conversion systems (WECS) connected to an infinite grid. The WECS model, which includes variations in wind supply to the wind turbine, has been developed to test the durability of the optimized controller that was developed to damp power system oscillations. The controller was used to take the power system dynamics into account. A new controller is being designed to include a corrective measure for damping the oscillations to adjust the instability caused by wind supply variations. The controller helps to tune the controller settings that lead to the achievement of the power oscillation damping objectives. These results are compared with those of a conventional Permanent Magnet Synchronous Machine (PMSM) based wind turbine system.

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1. INTRODUCTION

The power system is combination of many elements. If any part of the power system is under fault, then the entire system may be in trouble. Real and reactive power oscillate as a result of a fault in any part of the power system. This is due to the disturbance in the voltage and current. There are numerous Flexible AC Transmission System (FACTS) devices that can be used to reduce the impact of a fault. The SSSC is the series connected device which can inject the voltage for making the power flow in a correct direction. The series compensator (SSSC) shown in Figure 1 feeds voltage in series to the line to reduce voltage variation, and the injected voltage is regarded the line's inductive and capacitive equivalent.

The voltage injection in the line would replicate an impedance change that works as the series reactive compensating voltage, known as series compensation utilising SSSC. Several control devices based on FACTS technology have been conceived and installed in many applications over the past decade. In power systems, the use of FACTS devices improves the system's performance in a variety of ways. The FACTS devices are introduced and explained by researchers [1, 2, 3]. The thyristor-based facts are discussed in [4]. The value of facts is illustrated in [5], as can be seen. The utilisation of these devices and the right control of them can boost the damping, voltage stability, and regulation of the power system. Additionally, voltage stability can be increased. The FACTS devices are connected in series through the line, while other devices are connected in parallel or in a combination of series and parallel connections. FACTS devices can be purchased in a wide variety of different configurations. The FACTS technology is a collection of high-power controllers that can be used individually or in concert to manage one or more interrelated system parameters such as voltage, current, impedance, phase angle, and damping of oscillations at frequencies lower than the rated frequency. These parameters include voltage, current, impedance, and phase angle. In terms of reactive power compensation and voltage support, the SSSC plays a significantly larger role than any other FACTS device. This is due to the fact that its steady-state performance and operational characteristics are particularly appealing. Controllers such as the improved Proportional Derivative (PD) type controllers [6] and the modified differential evolution-pattern search [7] are utilised in this process.

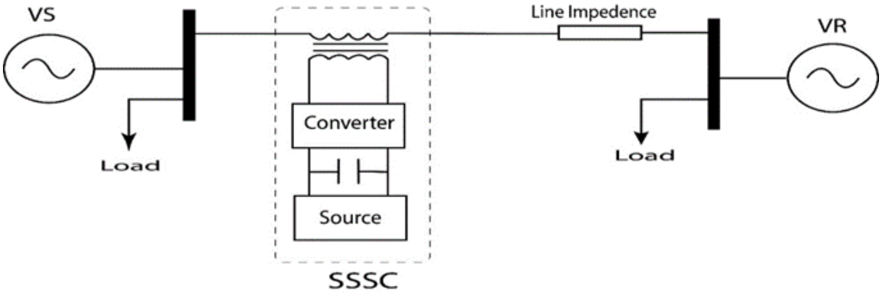

Figure 1. Static Synchronous Series Compensator Block Diagram

The power system is not always stable. It is variable in nature according to the frequency, voltage, and current in the system. Because of this, the power system is characterised by highly nonlinear behaviour. In [8], the fuzzy lead-lag optimization of the whale is explored. In [9], the fractional order controller is employed for the same whale optimization. Both the initial operating condition and nature of the disturbance play a role in determining whether or not a system will remain stable after being temporarily disrupted. The form of the disturbance plays a larger role in determining the stability of the system. The disturbance could be either modest or significantly more severe. The system is designed to adapt to its environment and respond appropriately whenever there is a shift in the status quo, including when there is a variation in the amount of load. Under these circumstances, the system needs to be capable of running smoothly while still being able to fulfil the load demand. In addition to this, it must be able to endure a number of severe disturbances, such as the loss of a main generator or a short circuit on a transmission line. Transmission system disturbances are often connected with oscillations of the generator angle or the line angle. These oscillations can be caused by a step increase in load, rapid changes in generator output, switching transmission lines, or short circuits. All of these factors can occur simultaneously. The multi-criteria optimization method is employed in [10, 11], where the dynamic model of the same phenomenon is described. The implementation of the binary bat to solve Multi-Input Single Output (MISO)-type PID SSSC can be found in [12]. In the aftermath of a significant problem, oscillations may continue for anywhere between three and twenty seconds at a time, depending on the properties of the power system. Extended oscillations that linger for a few seconds or longer are typically brought on by extremely weak damping in the system. These oscillations become most apparent when power transfers surpass the line's stability limit. During such angular oscillation periods, significant cycle variations in voltages, currents, and transmission line flows will occur [13–15]. These fluctuations need to be reduced as soon as it is practically possible because they are known to cause structural damage in power stations as well as a variety of problems related to the quality of the power. In the event that there are any further disturbances, the system will be susceptible. It is possible to implement the Supplementary Control Principles in already existing devices in order to provide greater voltage stability and reduce oscillations in power systems. These extra actions are referred to by their respective names, power oscillation damping (POD) and voltage stability control, respectively. A uniform interphase power controller (UIPC) model is constructed, and a control technique is proposed and implemented in order to control power flow and restrict the short-circuit contribution of WF. The construction of the model is based on the phase angles of the voltage that is injected into the SEC. The WF idea is predicated on the utilisation of a variable-speed double-fed induction generator that possesses an equivalent aggregated speed [16].

The Ferranti effect occurs when a transmission line is not carrying any loads, and it leads to an increase in voltage at the line's unloaded terminal. The magnitude of this voltage increase increases as the line's length increases. Injecting a voltage that is controllable in quadrature with the line current is something the SSSC is capable of doing. In the state where there is no load, the current in the transmission line has a quadratic relationship with the voltage along the line. By injecting a voltage that is in phase with the line voltage, the SSSC has the ability to use this to lessen the magnitude of the line voltage [17]. The findings of a microgrid system that combined an offshore wind farm (OWF), an offshore tidal farm (OTF), and a seashore wave farm (SWF) and fed to an onshore power grid via a high-voltage direct current (HVDC) link based on voltage-source converters were evaluated for their stability. The microgrid system was fed to the onshore power grid (VSC). For the purpose of approximating the properties of the investigated OWF, OTF, and SWF, an analogous aggregated wind doubly-fed induction generator (DFIG), an equivalent aggregated tidal DFIG, and a similar aggregated wave permanent-magnet synchronous generator (PMSG) [18] are utilized. The fault analysis is carried out, and the SSSC is put into practise in wind power generation by employing PMSM [19, 20].

This paper deals with the study of the real and reactive power oscillations generated by the fault in the system under study. The SSSC is controlled by a PI controller, and the same is used to reduce the oscillations in the proposed system.

2. METHODOLOGY

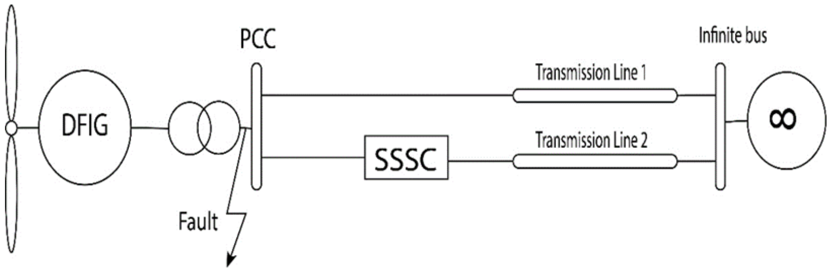

Figure 2. Proposed Block Diagram

The proposed block diagram is shown in Figure 2. The step-up transformer is linked to the DFIG wind generator and Point Of Common Coupling (PCC), which is subsequently linked to the PCC. After that, it is wired into the grid using a pair of transmission wires. Due to the fault developed on the transmission line system, DFIG creates more oscillations and then settles. These oscillations need to be dampened by the proposed SSSC control.

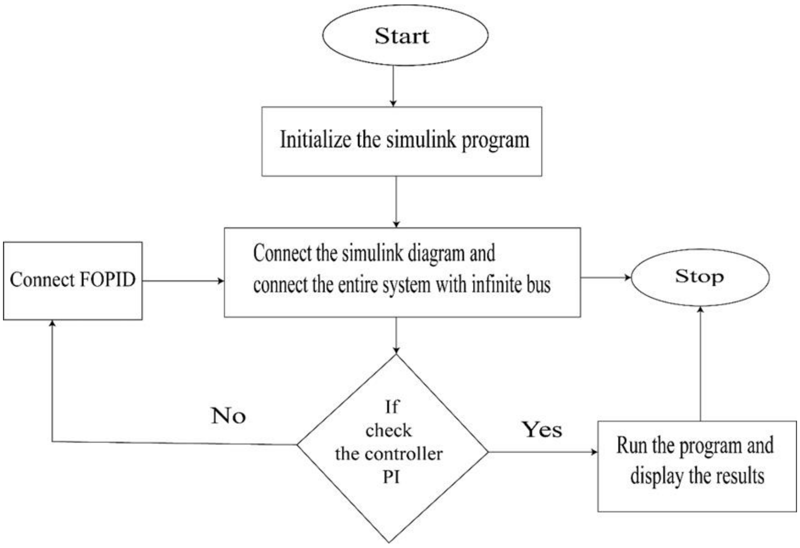

Figure 3. Operational flowchart of the proposed system

Figure 3 shows the operational flowchart of the proposed system. The simulation is started after initialising the variables. Set the simulation time and simulation types. Now the base system is connected to the infinite bus. Then it searches for the PI controller and, if found, turns it on for execution. If there are no requirements, then it checks for the FOPID, and it delivers the results after stopping the results. So all the time, the results are stored and compared.

3. SSSC MODELLING AND CONTROL

The basics model of the SSSC structure and modelling is presented as shown in Figure 4.

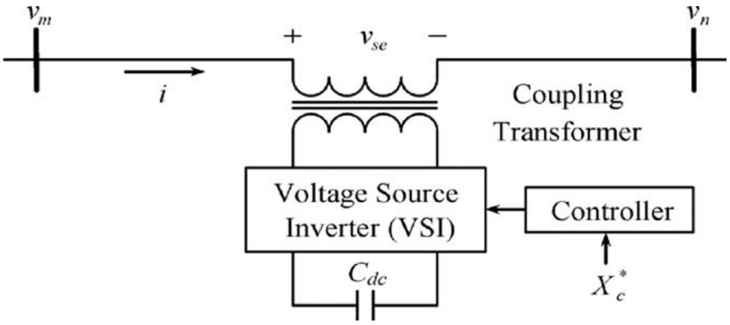

Figure 4. Configuration of an SSSC

It provides a visual representation of the fundamental elements that comprise an SSSC. The function of the inverter in the SSSC is to convert a voltage that is being supplied by direct current into a voltage that is being supplied by three-phase alternating current. Consequently, the components of an SSSC consist of a three-phase voltage source that has a natural frequency, a series-coupled transformer, a DC capacitor, and a DC link capacitor. In addition, an SSSC also has a DC capacitor. In order to model what is going on, we have used the synchronous reference frame that the SSSC provides. Both a d-axis and a q-axis may be found in this particular frame. The above parts are stated by the following equation, as are the parts of the series supplied voltage:

$$V_{dse} = n_c K_{inv} V_{dc_{sssc}} cos\alpha_{se} \tag{1}$$

$$V_{qse} = n_c K_{inv} V_{dc_{sssc}} sin\alpha_{se} \tag{2}$$

Where,
n_c transformer turns ratio,
$V_{dc_{sssc}}$ SSSC DC voltage,
α_{se} angle of injected voltage and
K_{inv} is constant of inverter

The real and reactive powers (P and Q) flows at the receiving end voltage source are given by

$$\mathrm{P} = \frac{V_s V_r}{X_L} \sin(\delta_s - \delta_r) = \frac{V^2}{X_L} \sin\delta \tag{3}$$

$$\mathrm{Q} = {}^{V_s V_r}/_{X_L}\,(1 - \cos(\delta_s - \delta_r)) = V^2/X_L \sin\delta \tag{4}$$

Where V_S and V_r are the magnitude of voltages, δ_s and δ_r are the phase angle of the voltage sources V_S and V_r respectively, X_{eff} is effective reactance. X_l/X_L is the line reactance. X_d and X_q are the direct and quadrature reactance. For simplicity the voltage magnitudes are chosen such those $V_s = V_r = V$ V and the difference between the phase angle is $\delta_s = \delta_r = \delta$.

$$P_{q=} \frac{V^2}{X_{eff}} \sin\delta = \frac{V^2}{X_l\left(1 - {}^{X_q}/_{X_l}\right)} \sin\delta \tag{5}$$

$$\mathrm{Q} = {}^{V^2}/_{X_{eff}}\,(1 - \cos(\delta)) = \left\{ V^2 / X_l \left(1 - {}^{X_q}/_{X_l} \right) \right\} \sin\delta \tag{6}$$

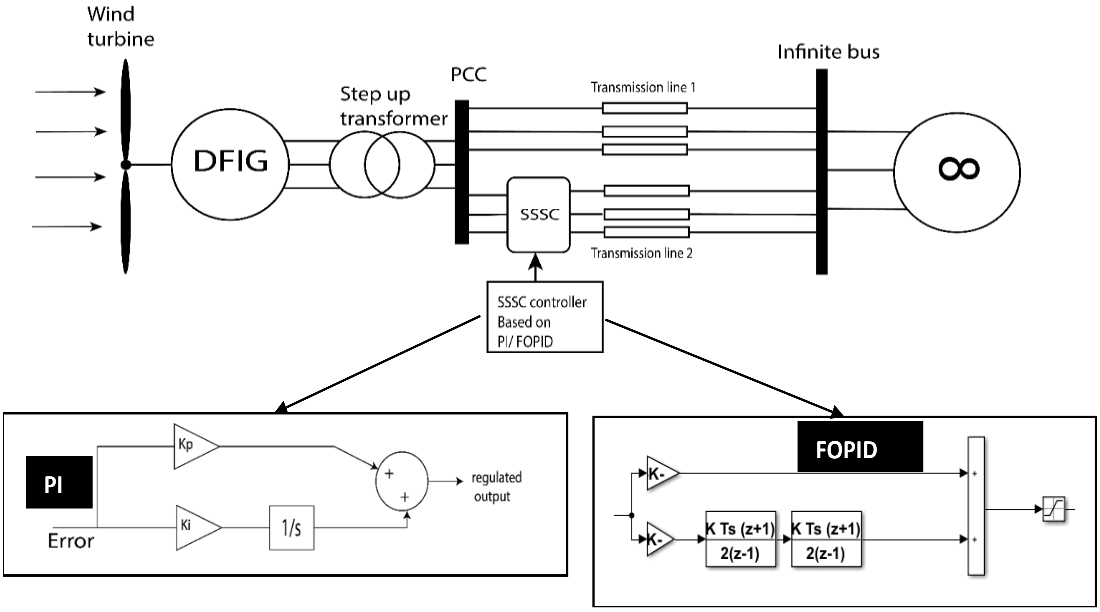

Figure 5. Schematic diagram of an SSSC including the designed PI damping Controller and FOPID controller.

The appropriate formulation of the parameter relationship with the optimised changeable coefficient is used to suggest a simpler fractional order PID (FOPID) controller. All of the proportional, integral, and derivative components are retained, despite the reduction in the number of pending controller parameters. The best FOPID controller settings can be found analytically using the estimate model for the optimal relation coefficient between the controller parameters.

The SSSC may be operated in capacitive or inductive mode to increase or decrease the power flow through the transmission line, respectively. Only the capacitive mode of the SSSC is presented in this paper. The injection of voltage is performed for stabilization. Figure 5 shows the SSSC with a PI controller and a FOPID controller for oscillation damping.

The reference voltage is compared with the measured DC, and the resultant error is connected to the PI controller. This error is added to the measured AC voltage from the grid. Then this voltage is subtracted from the measured one. This error is given to the PI controller, and the corresponding alpha angle is generated. According to the angle, the voltage magnitude and phase are injected by the series-connected inverter. The PI controller is replaced with FOPID, and the results are compared.

In general, PI or PID controllers are used for the current regulation of electrical systems. The output of the conventional current regulator is expressed in equation 7. The out(s) is the steady state error.

$$Out(s) = K_p({V_{dc}}^* - V_{dc}) + \frac{K_i}{s}(V_{dc}^* - V_{dc}) \tag{7}$$

Where, ${V_{dc}}^*$ is reference voltage and V_{dc} is the measured voltage; and the disparity between them is what results in the inaccuracy, which the PI controller should work to reduce as much as possible. The proposed signal with the least amount of error is found at the output, denoted by out(t). The proportional constant is denoted by Kp, while the integral constant is denoted by Ki. Manual tuning is used to adjust the values for the parameters Kp and Ki.

$$Out(s) = K_p({V_{dc}}^* - V_{dc}) + \frac{K_i}{s^2}(V_{dc}^* - V_{dc}) \tag{8}$$

In FOPID the integration is done twice. It can also be represented as discrete equation (8) shows the FOPID.

4. RESULTS AND DICUSSION

The prosed system is modelled using Simulink model and the studies has been carried out. Change the operation mode to "SSSC (Voltage injection)" in the GUI block menu. Make sure of the initial settings as per Table 1. Table 1 parameter is the random test of sudden change in injection voltage The initial voltage is set at 0 pu, and then increased to 0.8 pu at t=0.3 sec.

Table 1. Simulation parameters

Parameters	**Values**
Injection Voltage (Vinj) in V	0
Initial Vinj in V	0.08
Step time in sec	0.3

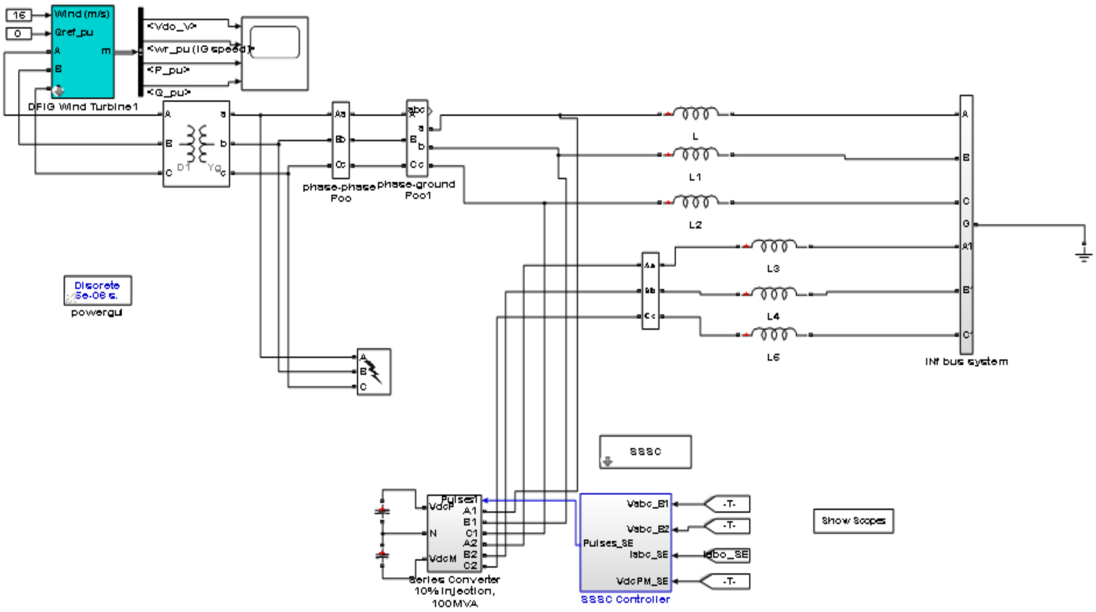

Figure 6. Proposed Simulated Diagram

Once the initialization process is completed then turn on the simulation and analyze the impact of injected voltage on the P and Q components flowing through the three transmission lines SSSC using scope each line, Unlike in UPFC mode, the series inverter in SSSC mode has a constant conduction angle (Sigma= 172.5 degrees). The Variation of the dc voltage, which is proportional to V_{inj}, which in turn controls the magnitude of the injected voltage (3rd trace). Examine the waveforms of the injected voltages (1st trace) and the currents flowing through the SSSC as well (2nd trace). The SSSC functions as either a variable inductance or capacitance because the voltages and currents remain in quadrature. The obtained simulation results are presented below.

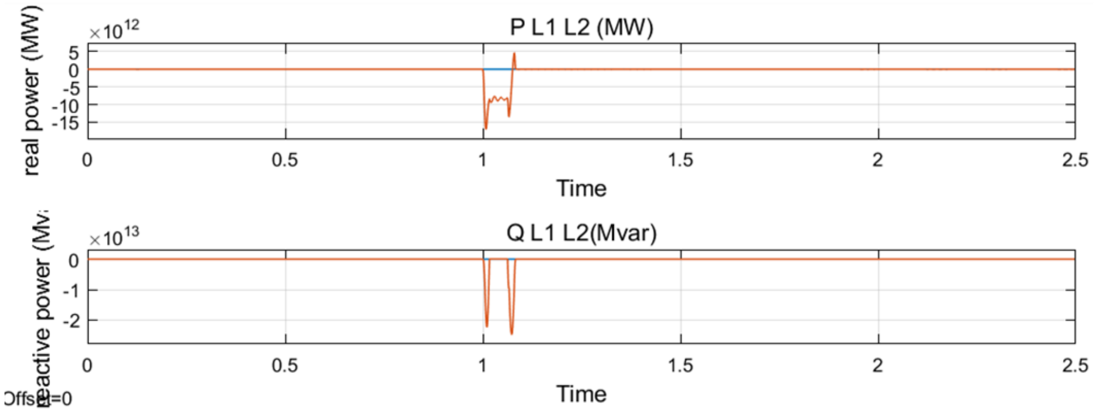

Figure 7. Real and Reactive Power through Line 1 and Line 2

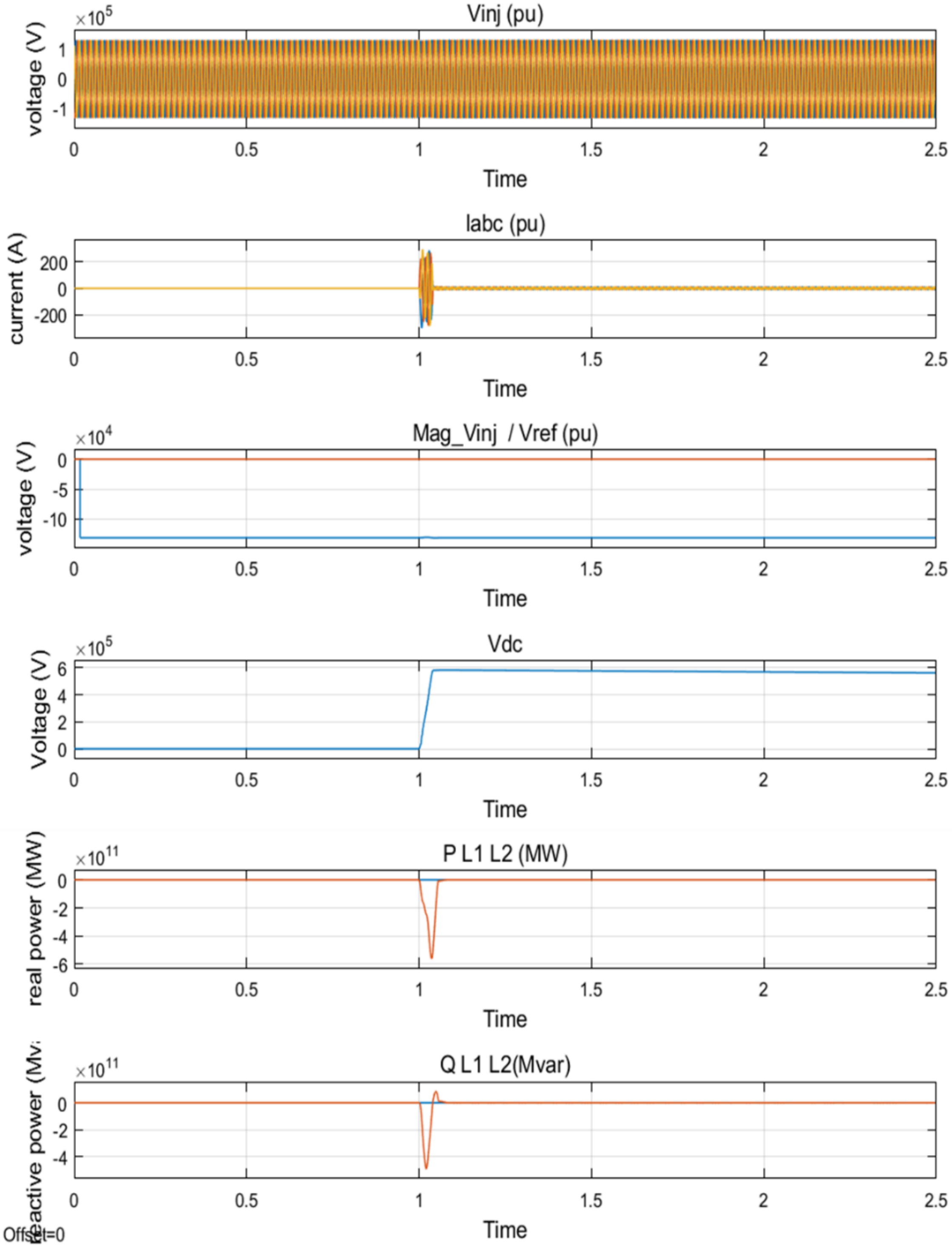

Figure 8. Injected Voltage, Current, Reference Voltage, DC Voltage of SSSC, Real and Reactive Power of Line 1 and Line 2 after connecting SSSC

The schematic representation of the simulation is shown in Figure 6. This is similar to the block diagram that was suggested earlier. Figure 7 depicts the real and reactive power that is flowing through lines 1 and 2 while SSSC is not connected. Because of the flaw, both the real and reactive powers oscillate more frequently. After connecting SSSC, the injected voltage, current, reference voltage, and DC voltage are all displayed in Figure 8, along with the real and reactive powers of lines 1 and 2, respectively. This demonstrates that the SSSC is able to inject the desired voltage, and as a result, the impacts of the failure on the power flow in lines 1 and 2 are mitigated.

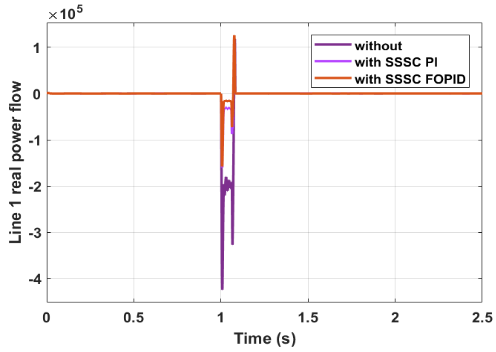

Figure 9 (a) Real power at line 1 for all the cases

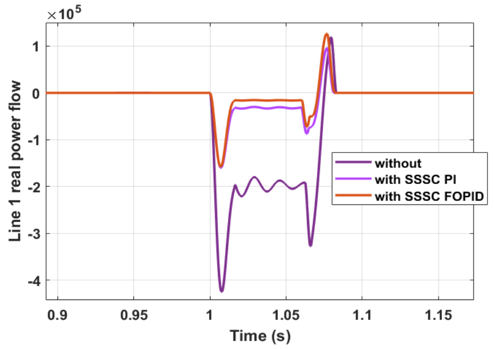

Figure 9 (b) Zoomed View 0f Figure 9a

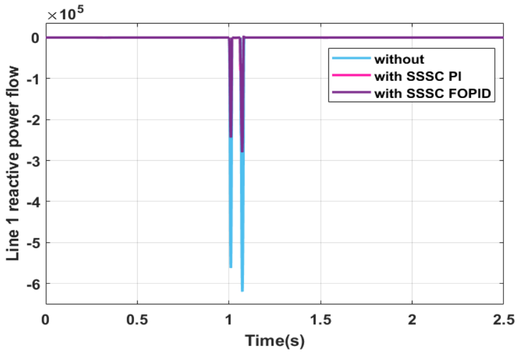

Figure 9 (c) Reactive power at line 1 for all the cases

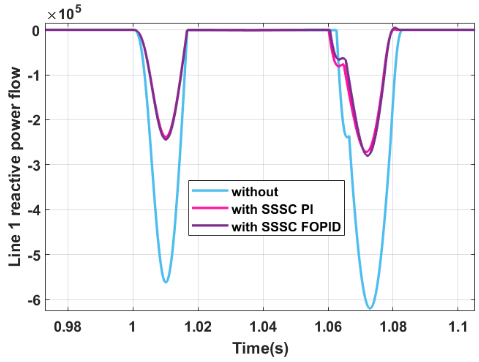

Figure 9 (d) Zoomed View of Figure 9c

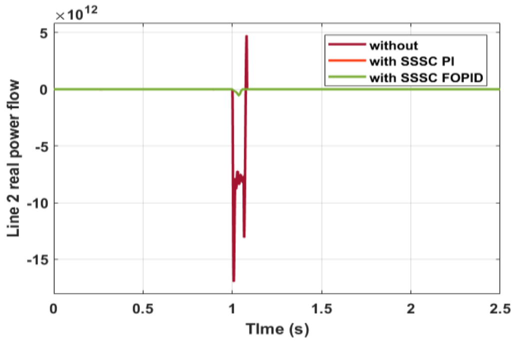

Figure 9 (e) real power of line 2 for all the cases

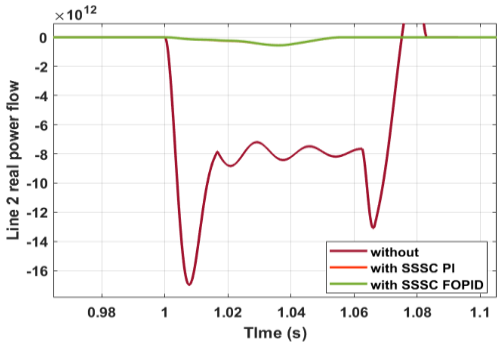

Figure 9 (f) Zoomed View of Figure 8e

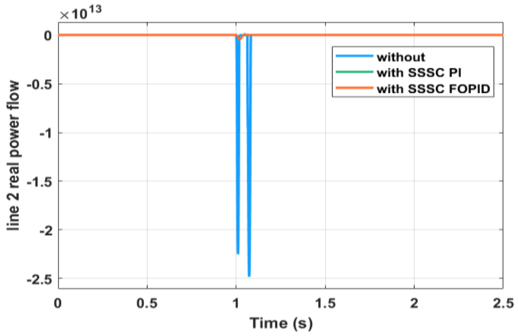

Figure 9 (g) reactive power of line 2 for all the cases

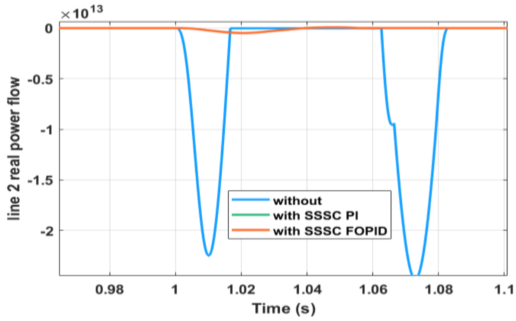

Figure 9 (h) Zoomed View of Figure 9g

The line 1 actual power is illustrated in Figure 9 (a), both with and without the SSSC. The zoomed-in perspective can be seen in Figure 9 (b), which follows. The reactive power for line 1 is depicted in Figure 9 (c), both with and without the SSSC. Figure 9(d) is a magnified version of Figure 9(c). The line 2 actual power is depicted in Figure 9 (e), both with and without the SSSC. Figure 9f is a magnified version of Figure 9(e). Figure 9(f) illustrates the line 2 reactive power both with and without SSSC, and Figure 9(g) provides a zoomed-in view of the same data. According to these figures, these is an improvement can be seen in both the real and reactive powers as a result of the existence of SSSC, which is regulated by FOPID controller, and as a result, oscillations are brought down to a level that is acceptable. Which confirms the utility of the controller.

Table 2. Parameters used in the simulation

SSSC	
Power rating (MVA)	1
Percentage of compensation (%)	10
Transmission line inductances per phase	75.5uH
GRID	
Voltage (kV)	161
Frequency (Hz)	60
Transformer	
Type	D/Y
Primary Voltage(V)	575
Secondary Voltage (V)	161000
Frequency (Hz)	50

Table 3. Comparison of the peak value during the fault

Comparison Parameter	**Conventional System [20]**	**Without SSSC (Peak value)**	**With SSSC PI (Peak value)**	**With SSSC FOPID (Peak value)**
Line 1 real power in MW	0.42	0.42	0.16	0.15
Line 1 reactive power in MW	0.6	0.6	0.2	0.19
Line 2 real power in MW	1.7×10^7	1.7×10^7	5.6×10^5	5.5×10^5
Line 2 reactive power in MW	2.5×10^7	2.5×10^7	4×10^5	3.9×10^5

Table 2 shows the parameters used in the simulation process for the comparison purpose. Table 3 shows the values of reactive and real power with and without SSSC. In comparison to when there is no SSSC, the presence of SSSC controls the peak power during the fault. Table 4 shows the percentage reduction in PI and FOPID peak values. The improvement is seen using FOPID controller as compared to PI controller.

Table 4. Percentage reduction of peak value after placing SSSC with PI and FOPID controller

Comparison Parameter	**With SSSC PI % reduction of peak value**	**With SSSC FOPID % reduction of peak value**
Line 1 real power in MW	61.9047619	64.28571429
Line 1 reactive power in MW	66.6666667	68.33333333
Line 2 real power in MW	96.7058824	96.76470588
Line 2 reactive power in MW	98.4	98.44

5. CONCLUSION

The DFIG wind farm's penetration into a SMIB has been investigated. The structure of the system is that of DFIG machines and transformers, all of which are connected to one another over an infinite bus. The three-phase fault method is used to test the reliability of the DFIG wind farm. The SSSC has been modelled and simulated in order to expose the oscillations caused by the disturbances. The SSSC works quite satisfactorily and has also shown a tendency to decrease the oscillations. The various results derived are presented in the form of graphs to prove that the real and reactive power flow oscillations are very low while using the SSSC. The implemented scheme was compared to the conventional technique, and it was demonstrated that the proposed SSSC controller reduces the peak amplitude of the power during fault conditions. The FOPID is found to be better than the PI controller based on the results derived.

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