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Review Article

Enhancement of System Stability Using Series FACTS Device under LG-LLG Fault Condition : A Comparative Study of GCSC and TSSC

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Abstract - *The quick growth in Electric power demand led to a burden on the electrical network resulting in different types of problems in the network. Therefore, the enhancement of power system stability is the ultimate requirement. For improving stability, different types of FACTS devices have been used. Various studies have been done on power systems design, modeling, operation, control, and application of FACTS devices. Detailed studies of several FACTS devices are strongly needed. It is because a Flexible AC transmission system device's operation affects the multiple conditions in a power system. Furthermore, there is a need to assess how well these devices operate in a more intricate system. The modeling and use of GCSC and TSSC controllers in a multi-machine context are discussed in the paper. Numerous fault situations scenarios are considered to evaluate the controller's performance. PSS, or Power System Stabilizers, are probably present in large systems and are expected to work better when they operate simultaneously with the GCSC and TSSC. Results for the system if a compensating device is not present, with PSS alone, and with PSS augmented by a PI, FUZZY, and ANN controller Achieved are the GCSC and TSSC. The comparison demonstrates that the PSS-assisted with PI, Fuzzy, and ANN controller with TSSC FACTS reduces power system oscillations more quickly than in the past, improving the overall performance of the controller and effectively stabilizing the provided system.*

Keywords - *TSSC GCSC FACT.*

1. Introduction

As said previously, power utilities are emphasizing the current power system's stability limitations to expand the use of electrical energy, adopting novel strategies and viable countermeasures to enormously increase the system's stability for the electrical grid.PSS, the top-level power oscillation controller in the hierarchy, is one of the most common solutions for the stability issue. As a result, the FACTS controller opens up new possibilities for making the electricity system more stable in light of the recent and rapid power electronics advancement devices. These FACTS devices are essential for improving the energy flow of These FACTS devices are crucial in enhancing the power flow of transmission lines. It increases the stability and controllability of the power system. As mentioned previously, various FACTS devices are available to improve the functionality of the power system—the benefits of GCSC and TSSC controller installation in a multi-machine environment. GCSC and TSSC are series-connected devices with essentially identical properties. The only difference is that the former allows quick changes in transmission line impedance while the latter relies on converters for voltage sources (VSC) [10]. By reducing net loss, assisting with voltage, and removing, They could regulate the power by reducing sub-synchronous resonance and short circuits, dampening power system oscillations, and enhancing power system stability. In order to assess, many instances of fault situations are taken into account—the controller's performance.

2. Problem Statement

The stability of the power grid is a problem. Additional producing installations are needed because of the instability brought on by the numerous interconnections., etc. It happens because of withstanding and over-damped oscillations that occur after clearance of disturbances. Tremendous efforts have been made to increase the stability system of the electrical. The electricity system's placement of a stabilizer (PSS) on the generator's excitation system, which is the efficient solution for stability concerns, is a traditional approach to dampen out the oscillations that occur post-fault. It is considered the initial control in the hierarchy of power oscillation controls [9-11]. PSSs are systematic, even though they are primarily designed to dampen local modes. They fall short of reducing inter-area oscillations in large power networks [14]. Additionally, when severe disturbances produce a significant change, Poor power factor performance and system instability may result from changes in the voltage profile and PSSs.

3. System Description

The establishing and simulating of a power system stabilizer (PSS) By supplying the generator's exciter with additional external impulses, PSS stabilizes the voltage output. Power system stabilizers can be divided into two groups: the system of general power stabilizers and multiband power system stabilizers. Stabilizing the oscillations caused by the rotor is the primary objective of generic PSS. Power swings are the name for these oscillations. The synchronous machine receives feedback from the PSS signal known as VS, which is produced as output and captures its state or $\Delta\omega$, as input. The general PSS block diagram used in this work is shown in Figure 2

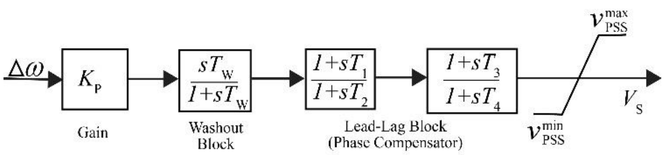

Fig. 1 Power system stabilizer

3.1. GCSC (GTO-controlled Series Capacitor)

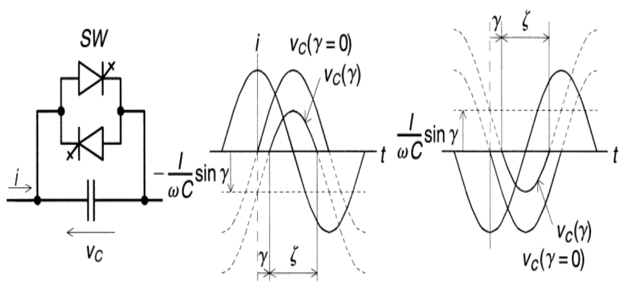

Fig. 2 GCSC Controller with ac voltage control of capacitor

Figure 2 depicts the GCSC scheme's goal; it regulates the ac voltage at a little line current, Vc, across the capacitor. Evidently, There is no voltage across the capacitor. While the GTO valve is closed, and it is highest when the valve is open. To manage the capacitor voltage, the valve's opening and closing are carried out once every synchronized with the half-cycle frequency of the ac system. When the voltage turns on, the capacitor falls below zero, and the GTO valve must automatically close. The valve's turnoff instant is nevertheless governed by a delay angle throughout each half cycleγ ($0 \leq \gamma \leq \pi/2$), with relation to the line current's peak. See Figure 2. b for information about the line current, I, and concerning the line current peak. Refer to Fig. 2.b, where the current of the line, I, and Vc(γ) are shown at $\gamma = 0$ and at With a positive and a half-capacitor voltage, respectively, arbitrary switch-off delay angle γa negative cycle The resultant capacitor voltage Vc when the current increases when the valve SW at the line's peak is opened. Obtained is the same as obtained with a permanently open switch in a steady state.

3.2. TSSC (Thyristor-Switched Series Capacitor)

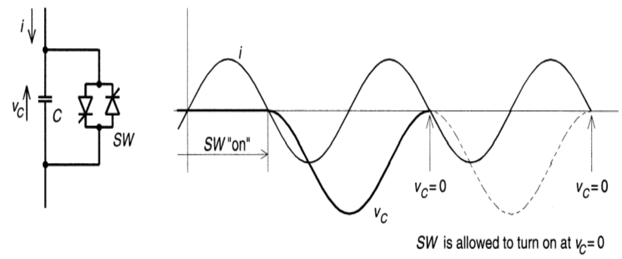

Fig. 3 Thyristor-Switched Series Capacitor

Thyristor-Switched Series Capacitor (TSSC) figure 3 depicts the basic circuit configuration of the series capacitor with a thyristor switch. It comprises several capacitors, each switched by a series of reverse parallel linked thyristors that form a suitably rated bypass valve. As can be observed, its circuit topology is identical to that of the sequentially operated GCSC in Figure 2, but it operates differently because of the typical thyristor valve's switching limitations. The TSSC's basic working principle is simple. The amount of series compensation is changed step-like by altering the number of series capacitors used. Changing the appropriate thyristor valve off, a capacitor is introduced and bypassed by turning the valve on. The commutation of a thyristor valve A thyristor valve either "naturally" commutates when the current reaches zero or shuts off. As a result, the thyristor valve can only add a capacitor to the line when the current in the line is zero. The capacitor will fully charge for half of the line current's duration because the insertion happens at zero line current—cycle, from minimum to maximum. In the following half-cycle of the line current with the opposite polarity, as shown in Figure 3, it will be discharged from this maximum to zero. As seen, the thyristor valve's switching limitation leads to a capacitor dc offset voltage generated at line current zero, equivalent to the AC capacitor voltage's amplitude. Only if there is no voltage on the capacitor, to reduce the first surge current in the valve and the related circuit transient, the thyristor valve should be turned on for bypassing. This requirement may delay up to one cycle because of the current dc offset. It would offer the TSSC's achievable reaction time theoretical top bound.

4. Methodology

The description of the system, as shown in figure 4, depicts the test system employed in this study. The system consists of two hydraulic generating units connected to buses 1 and 2, with a combined capacity of 1,000 MVA, 13,800 V, 50 Hz, and 5,000 MVA, 13,800 V, 50 Hz. These generating units are connected to the 1000 MW load by an 800 km transmission line. It is close to machine 2, where the load is connected, as shown in figure 4.

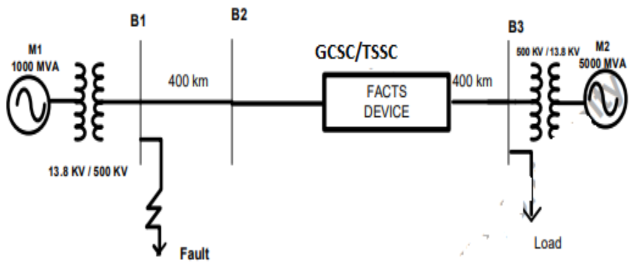

Fig. 4 System configuration multimachine system

Figure 4 System under study using GCSC and TSSC controller. The generators represent the hydraulic turbine, governor, and excitation system. Buses 1 and 2 are connected through line 1 (400 km long), and buses 2 and 3 are connected through line 2 (400 km long), each modeled on distributed parameters. The L-G fault and LLL-G faults are applied to the system in that order. The system is built so that when the machines are entirely out of synchronism, the simulation will end promptly. FACTS devices, i.e. GCSC and TSSC, are introduced one by one between buses B1 and B2 to suppress the unwanted oscillations and to provide stability in the system in case of faults and contingencies. The values of the different parameters of synchronous machines, transformers, and feeder lines adopted to carry out the modeling of a given system are similar to those in the earlier chapter. And the value of parameters involved in the FACTS device and different contingencies are given in tables 1

5. Results and Discussion

A model, the MATLAB/Simulink environment, is used to develop a model of the multi-machine power system and related components. Two fault types, On the system, L-G and LLL-G faults, are enforced to measure and test their efficiency. FACTS devices in reducing unwanted power oscillations. The effectiveness of the system is examined both with and without compensating mechanisms. The system's performance when problems occur at 2 seconds and precise at 2.4 seconds is depicted in figures 5 to 10. The system has been evaluated for various situations, including an uncompensated system, a system using PSS alone, and a system using PSS in conjunction with a GCSC or TSSC compensating device, respectively. In contrast, in the chosen situations, system parameters such as Measurements are made of rotor angle deviation, bus voltages, and line power.

Figures 5 and 6 show, for the system without compensation, the system with PSS alone, and the system with PSS assisted with PI, Fuzzy, and ANN controllers, respectively, the temporal response of Rotor angle deviation and machine terminal voltage for three different controllers: PID, Fuzzy, and ANN. The results of Figures 5 and 6 make it abundantly evident how poorly damped the system is in the absence of compensation. Figures 7, 8, 9, 10, 11, and 12 show the temporal response of the rotor angle deviation, the terminal voltage, and the line power with the compensating device, the GCSC and TSSC. It gives a better result, and The damping out of oscillations has been noticed.

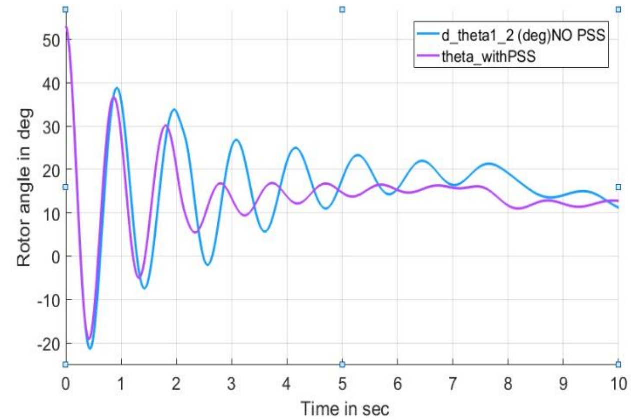

Fig. 5 Rotor angle deviation without compensating the device

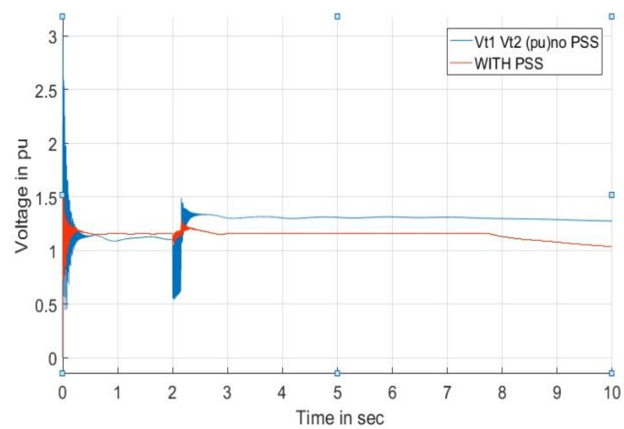

Fig. 6 The terminal voltage of the machine without compensating the device

5.1. CASE 01 Results with L-G fault

5.1.1. The settling time (seconds) of oscillations occurred after the clearance of the L-G fault

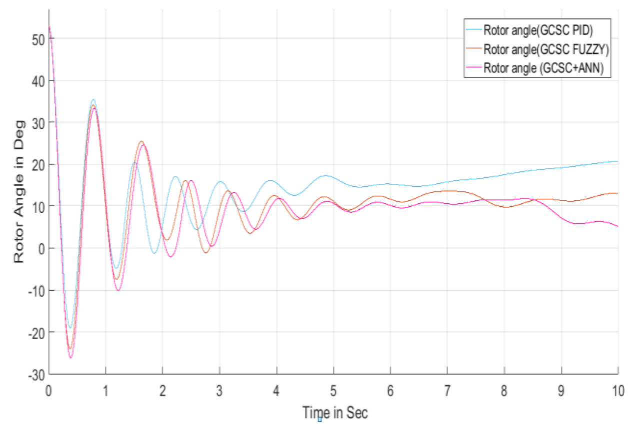

Fig. 7 Rotor angle concerning time for GCSC

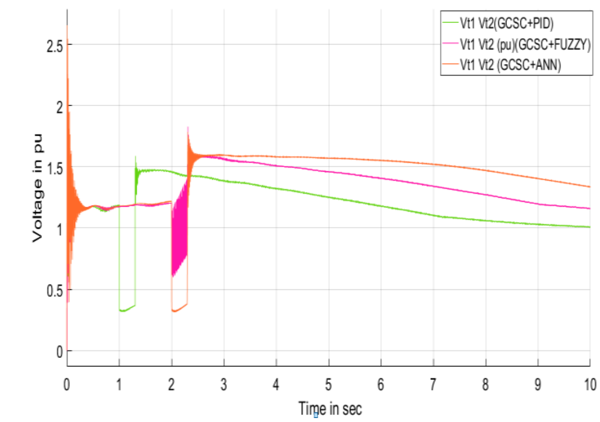

Fig. 8 Terminal voltage concerning the time

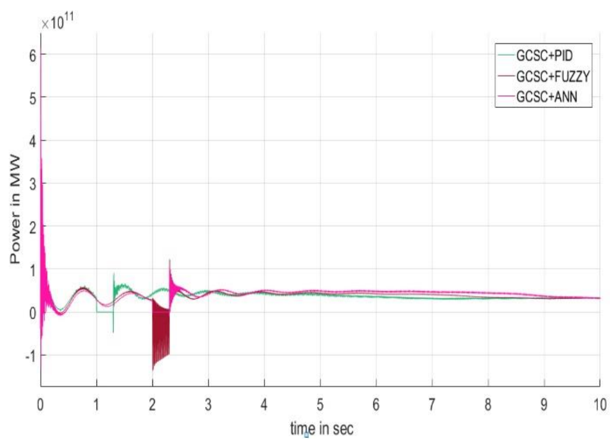

Fig. 9 Power w.r.t. time

5.2. Single line to Ground Fault for TSSC

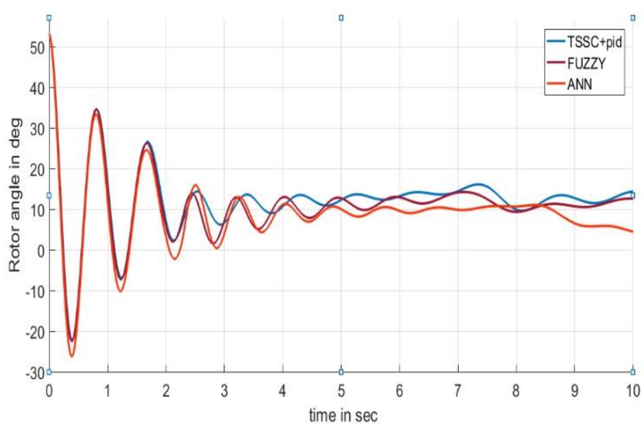

Fig. 10 Rotor angle deviation w.r.t. time

For rotor angle 7.80 seec and 7.25 sec, for terminal voltage for GCSC and TSSC Will be 6.60sec and 5.20sec ,when only PSS is used and damped out at 9.65 sec Compensating device with PSS plus PID, Fuzzy and ANN controller is used for both compensating device 9.50sec for GCSC and for 9.49 sec deviation of rotor angle for TSSS ,for terminal voltage PSS with PID for GCSC it will take 7.40

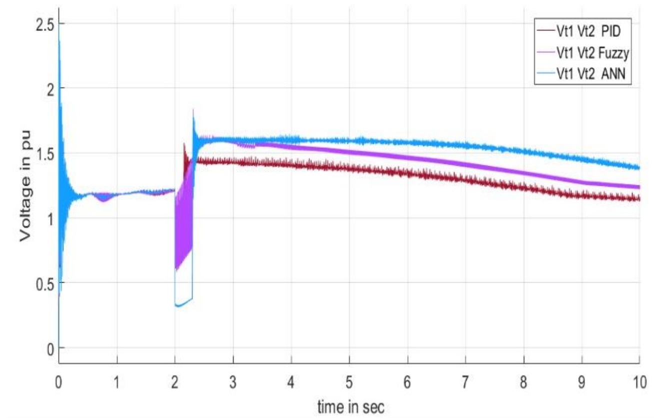

Fig. 11 Terminal voltage w.r.t. time

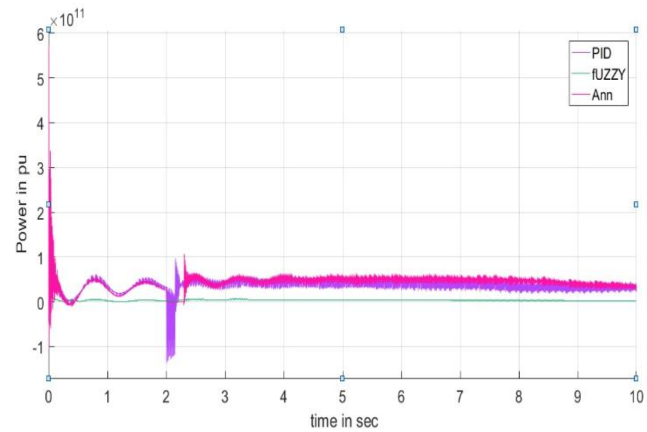

Fig. 12 Line power w.r.t. time

seconds for TSSC it will take 7.012second similarly line power it takes 3.50sec for GCSC and 3.95 sec for TSSC using other controller like Fuzzy and ANN for GCSC and TSSC with the system parameter of rotor angle deviation it takes 8.75 and 8.80seconds respectively and for terminal voltage and line power for both controller oscillation will damped out 7.08 sec and 5.95 sec and 4.0sec and 3.520 sec for ANN with GCSC and TSSC rotor angle deviation occurs at 7.75sec and 7.20sec and terminal voltage 6.25sec and 5.10sec and for line power variation will be 4.150sec and 3.45sec respectively which is shown in figure 11 and figure 12 ANN controller with TSSC facts device take less time to damped out oscillation , from the figure, it is clear that the In comparison to PSS alone and With TSSC controller, oscillations are dampened down in a noticeably shorter amount of time due to the synchronised functioning of PSS and TSSC. Figures 8, 9, 10, 11, and 12 show how different buses respond to positive sequence voltages. Figure 11 illustrates how the system becomes unstable when using the compensation device is not present. The system becomes stable at 7.644 seconds when PSS is added to the system, but the system was found to be stable (at 7.254 seconds) when the system was connected in series with the TSSC compensating device.

Similarly, for the line power, bus voltage oscillations are damped out faster when TSSC is installed in place of GCSC. Figure 7 and figure 10 demonstrate how three different situations' responses to rotor angle deviations. Figure 7 to figure 12 clearly shows that the unwanted system oscillations after the clearance of the fault are continuously increasing in magnitude. So, it can be easily said that the system is unstable without any compensation device. Moreover, for the system with PSS only, with GCSC and TSSC, At 8.4, 6.9, and 6.1 seconds, the oscillations are reduced accordingly. The graph shows that the TSSC stabilizes the system more quickly than the PSS and GCSC do as a result.

Table 1. The value of parameters involved in the FACTS device and different contingencies

Types of compensated device						
Parameters	**Without compensation devices**	**With PSS only**	**With PSS+GCSC (PID Controller)**	**With PSS+GCSC (Fuzzy Logic Controller)**	**With PSS+GCSC (ANN Controller)**
Rotor angle	Sustained oscillations	7.80	9.65	8.75	7.75
	Unstable	2.670	6.90	7.20	6.25
Terminal voltage	Sustained oscillations	6.60	7.40	7.08	6.25
	Unstable	3.544	6.10	4.25	3.25
Bus Power	Sustained oscillations	4.250	3.50	4.0	4.150
	Unstable	4.250	3.95	4.10	3.850
Parameters	**Without compensation devices**	**With PSS only**	**With PSS+TSSC (PID Controller)**	**With PSS+TSSC (Fuzzy Logic Controller)**	**With PSS+TSSC (ANN Controller)**
Rotor angle	Sustained oscillations	7.25	9.50	8.50	7.20
	Unstable	6.958	8.85	8.40	6.90
Terminal voltage	Sustained oscillations	5.20	7.0	5.95	5.10
	Unstable	5.25	6.10	6.80	5.20
Bus Power	Sustained oscillations	4.250	3.950	3.520	3.45
	Unstable	4.250	4.10	5.120	4.10

Figure 5 demonstrates the temporal behavior is Considering three distinct controllers—PI, Fuzzy, and ANN—of the Rotor angle deviation for the systems without compensating, the systems with PSS alone, and the systems with PSS supported. by PI, Fuzzy, and ANN in conjunction with GCSC and TSSC controllers, respectively. The outcomes unequivocally demonstrate how inadequately damped the system without compensation is. According to the figures, oscillations are damped out at rotor angles of 2.67 and 6.95 sec for the terminal voltage for the GCSC and TSSC. It will be 3.545 seconds and 5.25 seconds, respectively, when only PSS is employed and damped out at 6.90 with PSS+PID for GCSC and 8.85 seconds deviation of rotor angle for TSSS. Figure 5 shows the time response of Rotor angle deviation for three differing 6.10 seconds for TSSC; it will take 6.150 seconds.

Similarly, line power will take 3.950 for GCSC and 4.102 sec for TSSC using other controllers like Fuzzy and ANN for GCSC and TSSC with the system parameter of rotor angle deviation. It will take 7.20 and 8.40 seconds, respectively. For terminal voltage and line power for both controller oscillation will damp out 4.250 sec and 6.805 sec and 4.0sec and 5.125 sec for ANN with GCSC and TSSC rotor angle deviation occurs at 6.255sec and 6.90sec and terminal voltage 3.250 and 5.20sec and for line power variation will be 3.851 and 4.100 respectively which is shown in the figure. The figure shows that the ANN controller with TSSC facts device takes less time to dampen oscillation. It is evident that PSS and TSSC working together effectively dampens out oscillations in less time than PSS working alone and with a TSSC controller. So, it can be said that after 6.6 seconds, the system loses its synchronism under the LLL-G fault. However, this system can maintain its synchronism even after LLLG faults when GCSC and TSSSC devices are installed in the given test system. From figure 5.5, it is also found that the SSC stabilizes the time response of line power about 2 seconds earlier than the GCC controller. Figures 5.6 and 5.7 show the rotor angle deviation between two machines of the sample test system and the time response of the voltages at various buses with and without FACTS devices. From figure 5.6, it is clearly shown that the system's unwanted oscillations after clearance of fault were damped out in 3.742 seconds, whereas this system becomes stable in 3.492 seconds when TSSC is used in place of GCSC.

5.3. CASE 02 Results with LLL-G fault

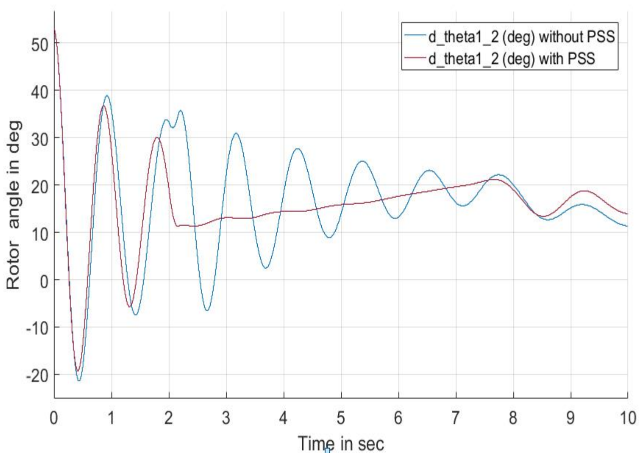

Fig. 13 rotor angle deviations without compensating device LLL-G Fault

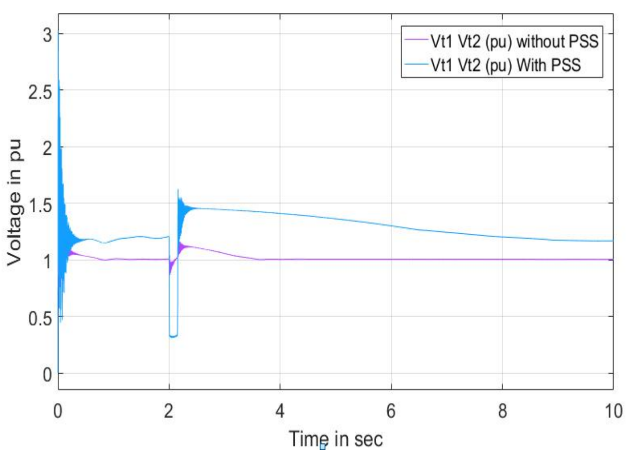

Fig. 14 Terminal voltage of machine without compensating device for LLL-G Fault

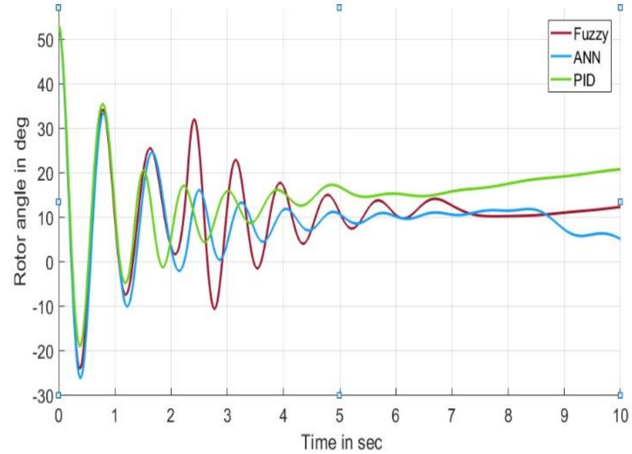

Fig. 15 Rotor angle deviation w.r.t. time

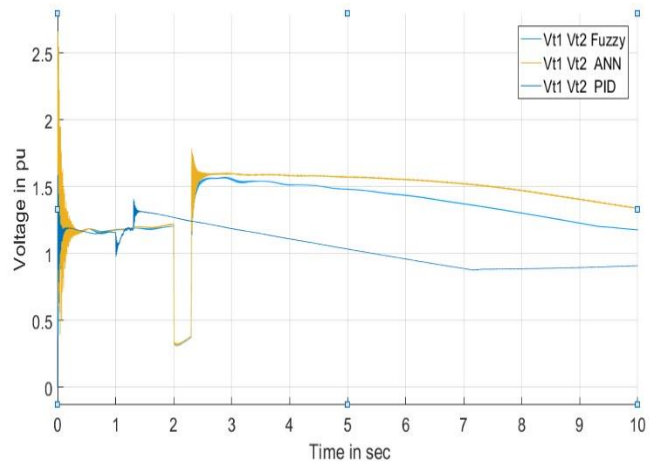

Fig. 16 Terminal voltage w.r.t. time

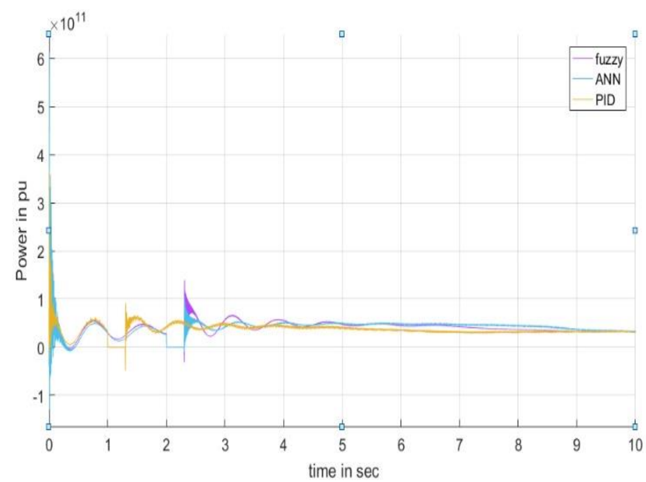

Fig. 17 Power w.r.t.time

5.3.1. After the LLL-G fault was cleared, the oscillations settled (within seconds)
The TSSC facts device's three-phase problem

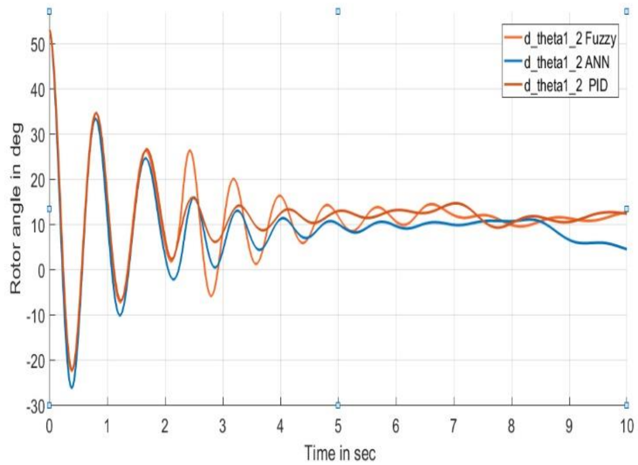

Fig. 18 Rotor angle deviation w.r.t.time

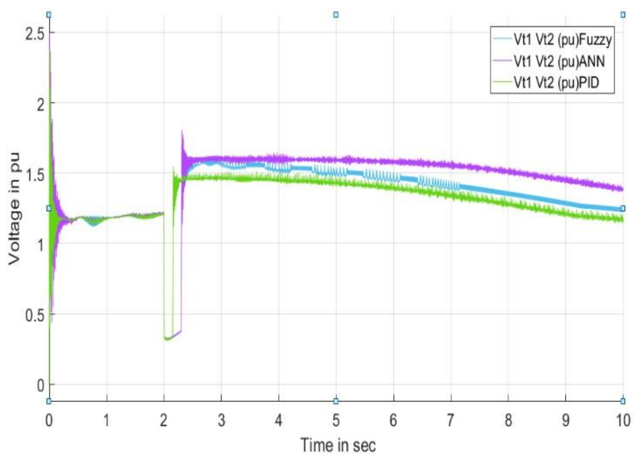

Fig. 19 Terminal voltage w.r.t.time

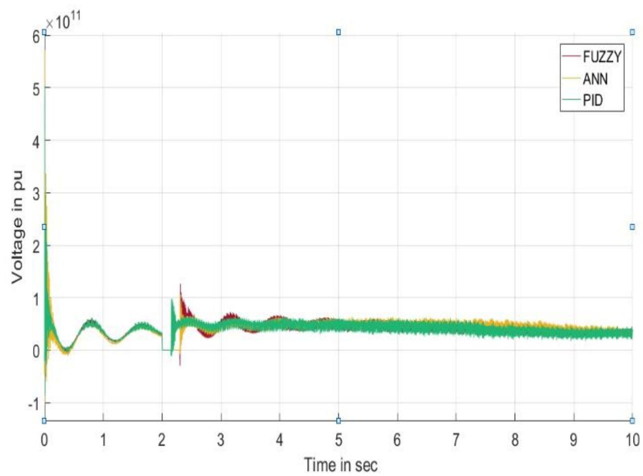

Fig. 20 Bus power w.r.t. time

6. Conclusion

In this paper, The controllers of the GCSC and TSSC are studied. The multimachine system is modeled, and To assess the efficiency of the suggested controller, faults for L-G and LLL-G were tested both with and without these compensating devices. It can be observed that when both faults were applied to the system, sustained oscillations were present in the system's parameter, which means that the system performance degraded significantly or the system, even after the problem had been fixed, was unstable. It is evident that oscillations have a longer settling time in the case of the LLL-G fault. Therefore, the LLL-G fault is more severe than the L-G fault. It can also be seen from the results that unwanted power system oscillations after the clearance of faults were mitigated when GCSC and TSSC were connected to the test system. The oscillations sustain for a lesser duration when TSSC is used in the system, thereby improving the system's performance. It demonstrates the viability and superiority of the TSSC over a conventional variable, a FACTS device with an impedance-based device such as the TSSC, for providing quick power oscillation damping.

Consequently, the GCSC controller may be preferred over the To mitigate system oscillation better and more quickly, transmission networks use TSSC as a compensating mechanism. This study investigates the impact of PSS on the GCSC and TSSC controller. The suggested multi-machine system is simulated and evaluated for two different types of disturbances, including and excluding the compensating devices, during L-G and LLL-G failures. The LLL-G fault is more severe than the L-G fault, and the system's effectiveness has been seen to diminish significantly in the absence of devices. Additionally, the results demonstrate that the system performs better in both circumstances when TSSC and PSS are synchronized since the system needs more time to stabilize and experiences fewer oscillations. It demonstrates the usefulness and superiority of the TSSC, an impedance-based FACTS device, compared to more traditional variable devices like the GCSC for quick-dampening power oscillations. The GCSC controller may be preferred over the TSSC as the compensation device to provide better and faster system oscillation mitigation in transmission networks.

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