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Reduction of Oscillations in Generator Turbine due to Sub-Synchronous Resonance by using Fuzzy Controller

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Abstract: *Whenever a series compensated transmission line is connected across the transmission line there exists a problem known as Sub-Synchronous Resonance at particular impedance. This will lead to damage of the turbine shafts and other major parts of the generator. So, this can be avoided by the use of the FACTS devices[1,2] supplemented with the auxiliary control devices[3-7]. Many FACTS controllers have been proposed by using GCSC, TSSC,TCSC etc., But, the damping can be best obtained by the use of the Distributed Static Series Compensator along with controlled with the Fuzzy Logic based Damping Controller(FLDC). This paper mainly deals with the reduction of the oscillations that occur due to the SSR by using FLDC and also the comparison is made with the convention\al PI controller in order to get best view of the performance of FLDC.*
Key Terms: *D-FACTS, SSR, FLDC, PI Controller*

I. Introduction

In the present tremendous growing of the of the power system network, there is a requirement for the long transmission lines to send the power from the generating station to the consumer point with minimum losses and with great power transfer capability. When the long transmission lines are kept, there is a need to compensate the inductive reactive power with the capacitive reactive power in order to balance the voltage at the receiving end. Hence, series capacitors came into picture. In the previous days, Static Synchronous Series compensator (SSSC) has been used which faced many problems like located at only one point, high maintenance, high cost and also skilled operators are required. After the development of the D-FACTS devices, the usage of the SSSC has been reduced tremendously and the Distributed Static Series Compensators (DSSC) became popular.

Whenever these Distributed Static Series Compensators are employed in the System, the system exhibited with many more advantages but also it is facing with some drawbacks. One of them is Sub-Synchronous Resonance Effect (SSR). SSR is a phenomenon, when the natural impedance of the long transmission lines coincides with the generator impedance, at that point resonance occurs and the turbine experiences severe oscillations and hence the speed of the turbine will go into the uncontrolled manner and finally, the turbine shaft will get damage and also the other system components. Hence, this unfavorable phenomenon should be avoided by using suitable equipments and techniques to protect the turbine. So, many papers have been proposed for the reduction of the SSR by using GCSC, TSSC, TCSC[1] etc., but the performance of them is only satisfactory. But, the controller that designed should be capable of damping out the oscillations as quickly as possible and they have to reduce the speed of the generator to the controllable manner to avoid the system collapse.

For that a controller has been designed in order to damp out the oscillations quickly. In this paper, mainly the DSSC's are implemented for the compensation technique for the lines due to their inherent characteristics. A conventional PSO based damping controller has been proposed with PI controller and also another controller has been proposed based on the Fuzzy Logic to damp out the oscillations due to SSR. To capture the performance of the controllers, the power system network without controller has been considered. Output speed and torque characteristics for the system without controller, with the PI controller and the FLDC controller are compared. Finally the simulation results are presented.

II. Power system network Configuration for the Analysis

For the analysis of the reduction of the torque and the speed damping, the power system that considered is IEEE Second Benchmark Model (SBM)[13]. And the DSSC's are implemented for the series compensation of the network. The Fig.1 illustrates the single line diagram of the power system network. It consists of a generator of 600MVA, 22KV, 60Hz frequency with a low Pressure turbine and one High Pressure turbine. A fault has been created after a time period of 3sec and is cleared after a time period of 0.168sec. And the compensation given by the DSSC is set to 52%. And this total set up is connected to the infinite bus of the power system.

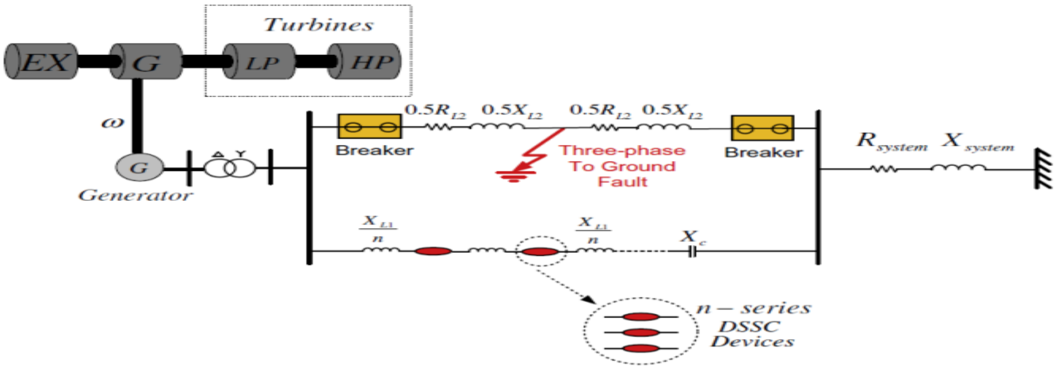


Fig.1: IEEE SBM model with DSSC modules

Now, there are two controllers that evaluate the performance of the damping under the fault condition and they are, one is PI controller and the other is FLDC.

III. Design of the DSSC Modules

DSSC[12] is a single-phase model of the SSSC. But, the DSSC can be implemented for three-phases in order to get the proper power flow in the transmission lines and to maintain the symmetry of the transmission lines. Each module is suspended from the line and also it will replace the insulating clamp and hence there is a reduction in the extra insulation.

Fig.2 represents the DSSC module schematic diagram in which all the components of DSSC are present. It mainly consists of current transformer (CT) to give back the feedback signal, one processing unit serves as controller, a single turn transformer to inject the voltage into the transmission line, a single phase inverter to generate the sinusoidal voltage. The capacitor placed will maintain constant DC voltage of the DC bus of the inverter. Harmonics are eliminated through the LC filter circuit and the power losses in the inverter circuit are compensated by absorbing the active power from the transmission line.The power line communication system sends corresponding signals to the gradual changes in the transmission line when subjected to fault. The CT is of single turn and hence the current handled by the inverter is very less. So, power loss in the inverter is significantly low. And also the cost incurred for the inverters is low, they are also smaller in size.

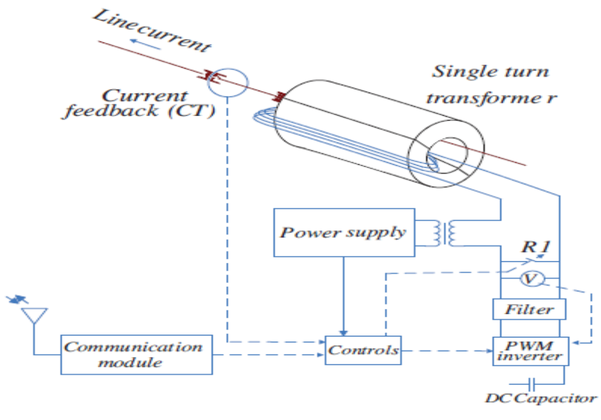


Fig.2: Schematic of the DSSC module

IV. Controller Design

4.1 Design of the Conventional PI controller

A conventional PI controller has been designed in order to damp out the torsional oscillations in the turbine. And the PI controller is shown in the Fig.3

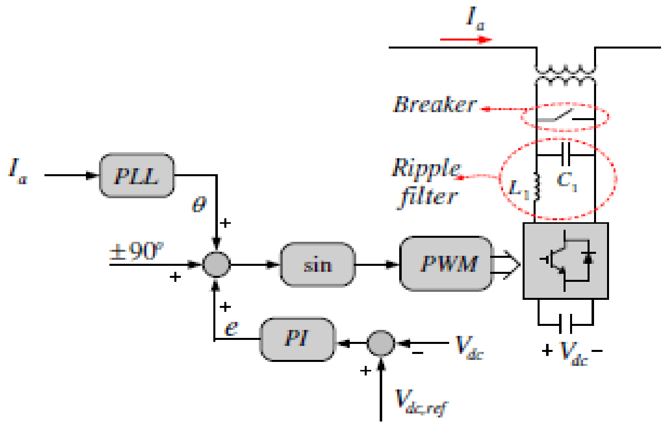


Fig.3: Schematic control circuit for DSSC

The DSSC modules are linked to the series compensated transmission line to reduce the oscillations. DSSC will inject the voltage in quadrature with the line current in order to control the power in the transmission line. These DSSC modules will perform in extreme manner if they supplied with the controllers. Many algorithms have been proposed for the controllers [8]. For the controlling, here we are using PI controller using Particle Swarm Optimization[9,10].

In the PSO algorithm, the trajectory of the velocity of each particle s altered in the search space. The best objective function is derived from all over the particles and is considered as Pb. And the overall best value of the objective function is obtained by the particle at time is represented as Gb and these can be calculated by using the below formula.

$V_{id}(t)= w \times V_{id}(t-1) + C_1r_1 \times (P_{id}(t-1)-X_{id}(t-1)) + C_2r_2 \times (P_{gt}(t-1) - X_{id}(t-1))$ (1)

$X_{id}(t)= X_{id}(t-1) + C\, V_{id}(t)$ (2)

Where, X_{id} is the i^{th} particle position at time ‘t’ and v_{id} is the i^{th} particle velocity at time ‘t’. The positive constants C_1 and C_2 are responsible for alteration of velocity of the particle towards their respective best values. Random constants r1 and r2 are the two random constants between ‘0’ and ‘1’ and ‘c’ is a factor which can modify the velocity of the particle to next position in the next iteration. In the above schematic circuit, Phase Locked loop is used for generating the synchronization signal ‘Θ’. The signal coming from the PI controller adds up with the ‘Θ’ and the resulting signal will be given to the inverter circuit through PWM component. This is how we can design the PI controller.

4.2 Design of the Fuzzy Logic Controller

Now, another controller is FLDC. Generally, the power system network faults are non-linear in nature. So, the conventional PI damping controllers are not sufficient to meet the best performance. As the Fuzzy controllers[17] are non-linear in nature and hence they are best suitable to design the controllers for the power system network. Fig.4 depicts the schematic diagram of the DSSC controller based on the fuzzy logic[16]. In this figure, the FLDC is added to conventional power flow controller of the DSSC.

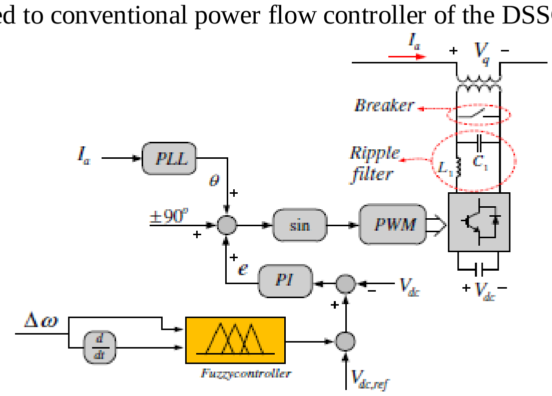


Fig.4: Schematic FLDC for DSSC

Because of the variable reactance induced by the DSSC, it can compensate the reactive power as well as it will damp out the oscillations. And it can be realized by the equation

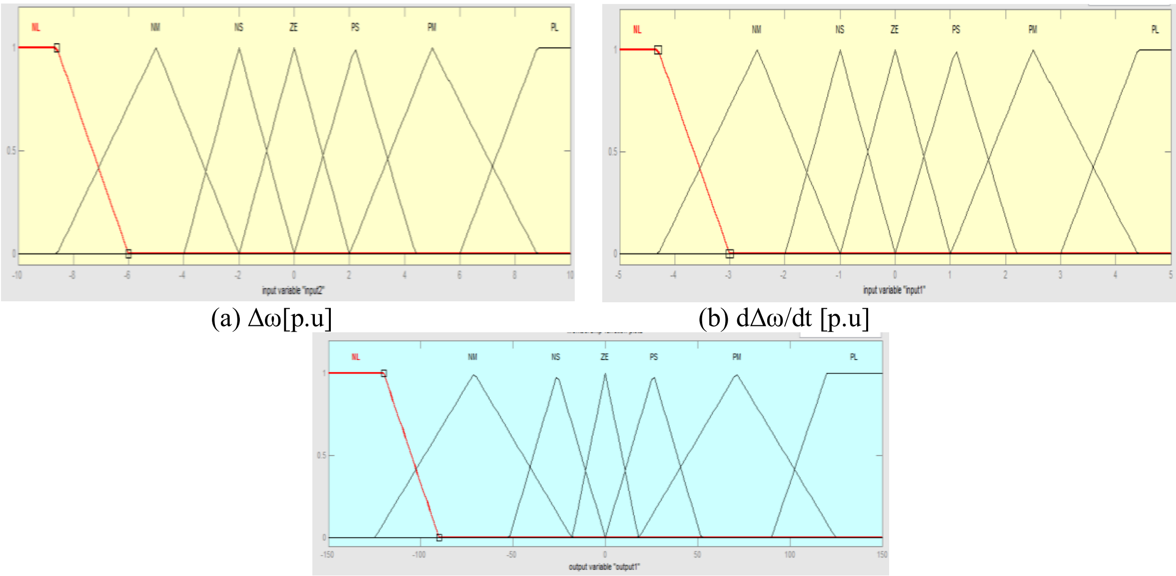
$$X_q = \frac{V_q}{I_L}$$

Where, V_q is the quadrature voltage induced in the network and I_L is the line current. The output of the FLDC is used to adjust the value of the $V_{dc\ ref}$ of each DSSC module to provide the best damping performance of the SSR attenuation. The controller that proposed works on the basis of the Mamdani inference engine. In this, triangular membership function is used and centroid method is used for the defuzzification.

In the fuzzification, fuzzy logic controller involves mapping the fuzzy variables to crisp numbers used by fuzzy controller. Fuzzification implements a membership grade to translate the numeric values of error into linguistic values. In this paper, the fuzzy input includes two input signals namely speed deviation Δω[p.u] and its derivative dΔω/dt . By studying the behavior of these two input signals in different situations before and after the fault, fuzzy sets for fuzzy controller is designed. The membership functions for inputs and output of the FLDC are depicted in Fig.5. For each input and output, seven membership functions are introduced and tuned based on simulation and knowledge of the power system. By testing various functions, it has been found that a triangular membership function is preferred for both input and output which results in a better damping effect for small angle deviations.

In the fuzzy membership function, the below notations are used.

ZE: Zero NL: Negative Large NM: Negative Medium NS: Negative Small
PS: Positive Small PM: Positive Medium PL: Positive Large



(a) Δω[p.u] (b) dΔω/dt [p.u]

(c)Δu [p.u]

Fig3.6: Triangular membership functions for (a, b) inputs and (c) output fuzzy sets of the FLDC

The next one is the implementation of the rule base[14] in the system. The inference engine makes all the possible combinations of the inputs and gives the proper outputs. The rules are chosen based on human reasoning and performance.

The set of rules that are followed are given below.

	Δω						
dΔω/dt	**PL**	PM	PS	ZE	NS	NM	NL
PL	PL	PL	PL	PL	PM	PS	ZE
PM	PL	PL	PM	PM	PS	ZE	NS
PS	PL	PM	PS	PS	ZE	NS	NM
ZE	PL	PM	PS	ZE	NS	NM	NL
NS	PM	PS	ZE	NS	NS	NM	NL
NM	PS	ZE	NS	NM	NM	NL	NL
NL	ZE	NS	NM	NL	NL	NL	NL

Table1: Fuzzy Rule System

Final stage in it is the de-fuzzification. Each output that got from the inference engine is then de-fuzzified and given to the further process that to be carried out.

V. Analysis and Simulation Results

The simulations are carried out in the MATLAB. The simulation circuit for the network without any damping controller is shown in the Fig.5

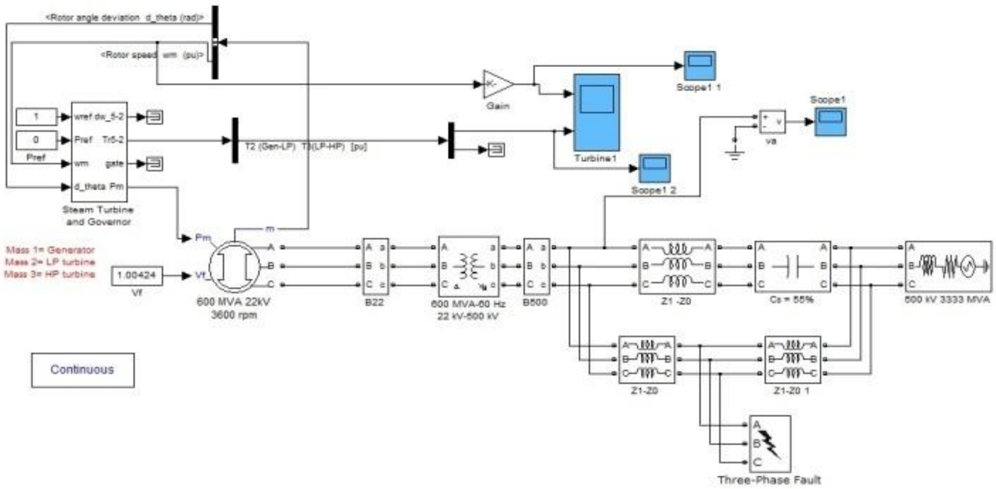
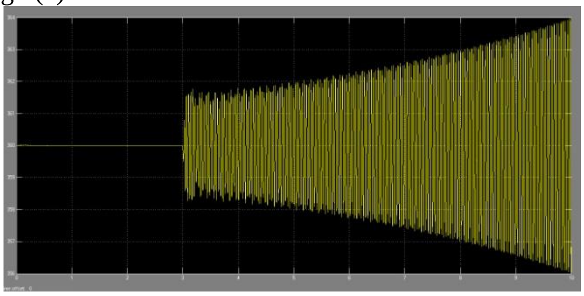


Fig.5: IEEE SBM under fault without controller

The simulation results for the turbine speed for above network is shown in the Fig.6(a) and torque is shown in Fig.6(b)



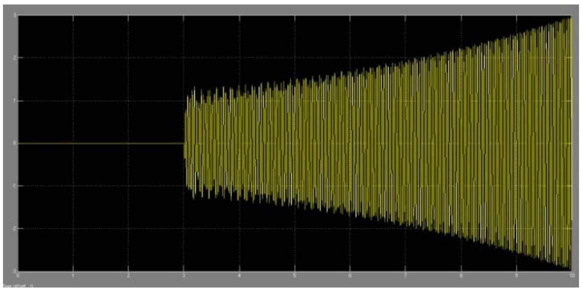


Fig.6(a): Turbine speed without controller **Fig.6(b)** Turbine torque without any controller

From the above simulation results, we can clearly see that, in the event of fault, the speed of the turbine as well as torque are going to the uncontrolled manner and they are highly dangerous which even damage the turbine shaft and other mechanical components. So, there is a need to fix up this problem by using controller. So, conventional controller came into picture to damp out these oscillations.

The Fig.7 shows conventional damping controller using PSO algorithm.

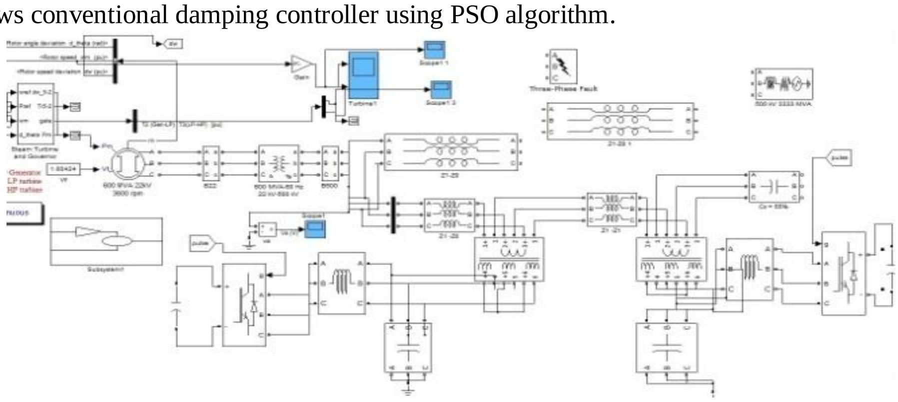


Fig.7: DSSC with conventional PI controller

The output speed and the generator torque characteristics for the turbine are shown in the Fig.8(a) and Fig.8(b) respectively.

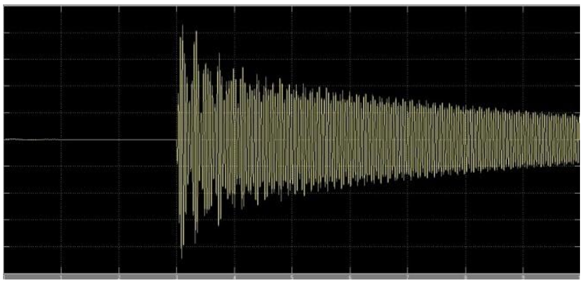


Fig.8 (a): Speed characteristics of generator under under fault with PI controller

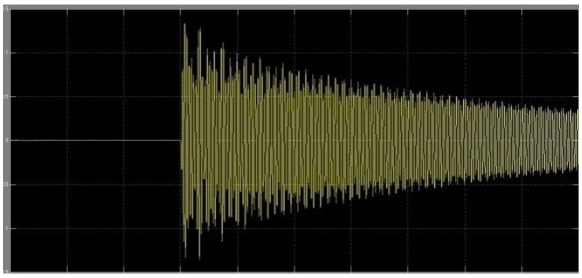


Fig.8(b): Torque characteristics of generator fault with PI controller

From the above results, and by comparing the simulation results of the network without and with damping controllers, the system oscillations are reduced tremendously. But, these oscillations are to be reduced even in a faster manner to avoid the damage to the turbine shaft. So, FLBD is used in doing this operation. Fig.10 depicts a clear circuit diagram of the Fuzzy based damping controller. Turbine speed and the generator torque behaviors are depicted in the Fig.9(a) and Fig.9(b) respectively.

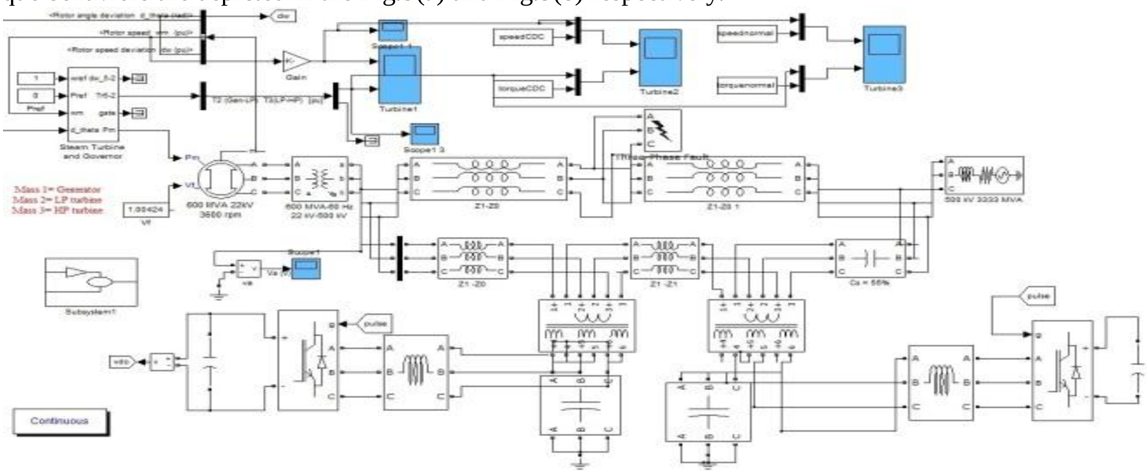


Fig.9: Fuzzy Damping controller for the system under fault

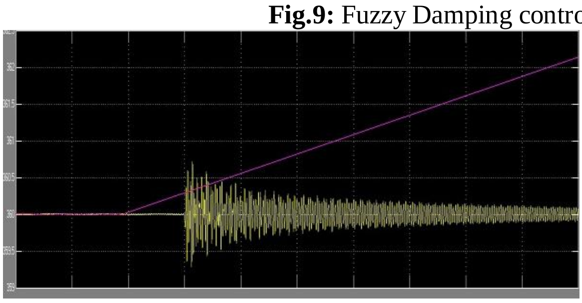


Fig.9(a): Generator speed characteristics with fuzzy controller under fault

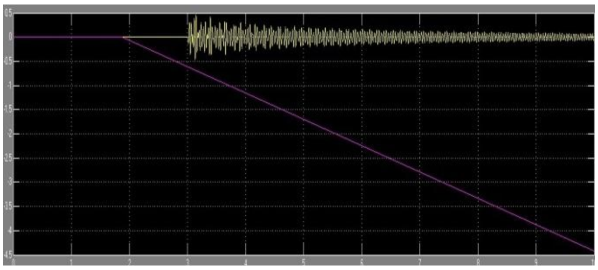


Fig.9(b): Generator torque characteristics with fuzzy controller under fault

From the above simulation results, we can clearly say that there is a good performance with the conventional PI controller. But, the oscillations in the system are too high and these are not to be negotiated. So, by implementing the Fuzzy based controller in the system, the oscillations of the system are damped out fastly, low frequency oscillations[15] are eliminated and at the same time, low frequency harmonics are eliminated.

VI. Conclusion

FACTS device namely the DSSC in SSR suppression is interrogated. Due to the fact that the conventional controller of the DSSC is not capable of mitigating the SSR, a Fuzzy logic based damping controller is designed and granted to the conventional controller of the DSSC. It has been shown that, the designed controller not only is capable of mitigating the SSR, but also it can alleviate the low frequency oscillations. In order to better assess the capability of the proposed FLBDC, a PSO based CDC is also designed and granted to the conventional controller of the DSSC in order to suppress the SSR. From the simulation results, it can be concluded that the speed and torque of the system can be brought to a controlled value by using conventional PI controller. But with the use of Fuzzy controller, the system oscillations can be damped out even more fastly and also the lower harmonics are mitigated. Hence, we can say that by the use of the fuzzy controller, the system is speeded up as well as the oscillations are damped out.

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