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Damping of Sub Synchronous Resonance in Negative and Zero Sequence Using Neural Network Controlled UPFC

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***Abstract*— The increase in power demand has compelled the power system utilities to use series capacitive compensation in long transmission lines. A problem called sub synchronous resonance (SSR) occurs in long lines because of series compensation. In this paper a flexible a.c. transmission system (FACTS) device is used along with a proposed controller to damp out the sub synchronous oscillations from the system. An IEEE second bench mark model is used for investigating the SSR problem, where a three phase short circuit fault is applied on the compensated transmission line for analysis. A Matlab/Simulink model is used to study the time domain analysis of the system. An improvement in damping is seen with the use of FACTS device i.e. unified power flow controller (UPFC) which is controlled by a Neural network (NN) based proportional integral (PI) controller.**

***Index Terms*— flexible AC Transmission system(FACTS)Neural Network(NN) Sub Synchronous Resonance(SSR) Unified Power Flow Controller(UPFC).**

I. INTRODUCTION

The power consumption by the utility is subsequently increasing day by day. The increase in power demand had compelled the power engineers to use long transmission line which enables bulk power transfer. In order to satisfy the load demand in long transmission lines, series capacitive compensation is being used which increases the power delivering capability of the transmission line effectively. Further, it also improves the transient stability of the system Because of series capacitive compensation the problem of sub synchronous resonance (SSR) may occur in long transmission lines.

categories namely, torque amplification (TA) also known as transient torque and steady state SSR. The steady state SSR is further divided to torque interaction (TI) and induction generator effect (IEG) [4]. In this paper TI problem is taken into consideration which bears a threat to power system.

A flexible a.c. transmission system (FACTS) is used in power system to improve power quality, power security and its integration. The FACTS devices have several uses in the power system but mainly they are used for reactive and real power compensation, to improve power system stability (both transient and steady state), to control the line impedance, to suppress the harmonics, to improve the power factor of the system and even to mitigate the SSR problem. To suppress the sub harmonic oscillations there are many FACTS devices like static synchronous compensator (STATCOM), static voltage compensator (SVC), static series synchronous compensator (SSSC), unified power flow controller (UPFC) and thyristor controlled series compensator (TCSC) that can be used in the system [5]. This paper uses UPFC as a FACTS device for eliminating the SSR problem from the system due to the several advantages of UPFC over other FACTS devices. For achieving robust control over the UPFC a neural network (NN) based proportional integral (PI) controller has been used. The use of UPFC device along with NN based PI enhances the dynamic controllability in the power system. The NN based PI scheme is preferred over other controlling devices for its various advantages like robustness, less computational time and decreased space requirement. Moreover, it eliminates the need of mathematical model requirement of the system and also works for non linear system which makes it unique as compared to other controllers.In this paper an IEEE second bench mark simulink model is used to analyze the SSR problem. The UPFC is connected to the system along with NN based PI controller inorder to mitigate the SSR problem from the system.

II. SYSTEM UNDER STUDY

block. The two masses of turbine system are low pressure (LP) turbine and high pressure (HP) turbine. The SSR problem occurs in this system as it is series compensated. A three phase fault is applied and cleared to excite the torsional oscillation in the two mass shaft system. It can be observed that these induced oscillations produce the torque amplification in the system and thus causing SSR problem.

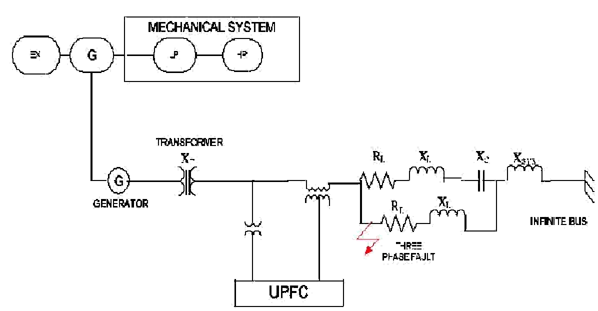

Fig. 1. System under study

The use of fuzzy logic scheme eliminated the requirement of mathematical modeling of the system and linearization of power system. So the system parameters are modeled by using non linear equations

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III. SUB SYNCHRONOUS RESONANCE

The sub synchronous resonance phenomenon is mostly observed in series capacitive compensated power system network. The series compensation of long transmission line results in excitation of SSR current in the system at electrical frequency f_e is given by equation (1):
Where,
f_e= Electrical resonant frequency f_s=
Fundamental system frequency x_c=
Series capacitor reactance

x_t = Total reactance of the line (including transformer leakage reactance and generator reactance)

The SSR phenomenon deals with the sustained oscillation caused below the system frequency. The danger of SSR is found when the long transmission lines are series compensated. In this phenomenon the electromagnetic forces in the generator caused by the SSR current produces a torque oscillations which interacts with the mechanical shafts of turbine section [7]. The interaction between these two systems results in mechanical shaft failure.

There exists a sub harmonic frequency in the system caused by the SSR phenomenon denoted by f_r and is given by equation (2)
Where f_{sub}= Sub synchronous frequency component

The value of electrical resonant frequency is always less as compared with the fundamental system frequency. The electrical circuit parameters start oscillating when the system under study is subjected to fault. The series compensated long transmission line having sub harmonic current generates a field at sub harmonic frequency. The sub harmonic field rotates backward as compared to main field and a torque is produced at frequency f_{sub}. If the sub synchronous frequency component f_{sub} matches with any one of the torsional frequencies of the mechanical mass system then a resonance condition occurs and energy is transferred between the two systems. This exchange of energy excites the torsional oscillations between the systems and it damages the shaft of the turbine generator set.

IV. NN BASED PI CONTROLLER

NN based PI controller is a hybrid controller having many advantages over the conventional ones. This controller has combined advantages of both neural network controller (NNC) and proportional integral controller. The basic block diagram of NN based PI controller is shown in Fig. 2 [8].

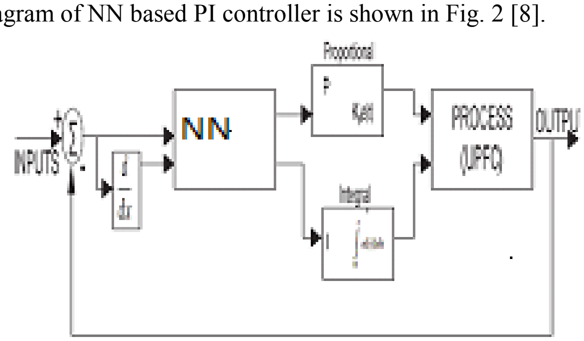


Fig 2. Block diagram of FL based PI controller

The parameter to be controlled becomes input to the FLC. The logical block diagram of FLC is shown in Fig. 3 [9].

NNC is that it can work on non linear system. The linearized output obtained from the

NNc set as input for the PI controller. This type of hybrid controller is used when both the operating conditions and system dynamics are know and where a single linear time invariant model is insufficient. In case of conventional PI controller the gain constants k_p and k_i are constant but in case of NN based PI the gain constants vary dynamically. This type of controller increases the robustness in the controlling system. The PI controller indeed becomes self tuned [10]. There are two inputs for the neural system and one output from it. The output is directly given to proportional block and the same is fed to integral block too.

In this paper the two inputs to the NNC are speed deviation ( ) and its derivative (d). The input membership functions are designed using triangular shaped member functions (tri). The single output of the NNC is denoted by U and the output member function is designed by triangular shaped member function (tri). The corresponding membership functions are shown in Fig. 4. The neural set used is defined in Table 1 and Table 2. The surface plot of the NNC is shown in Fig. 5.

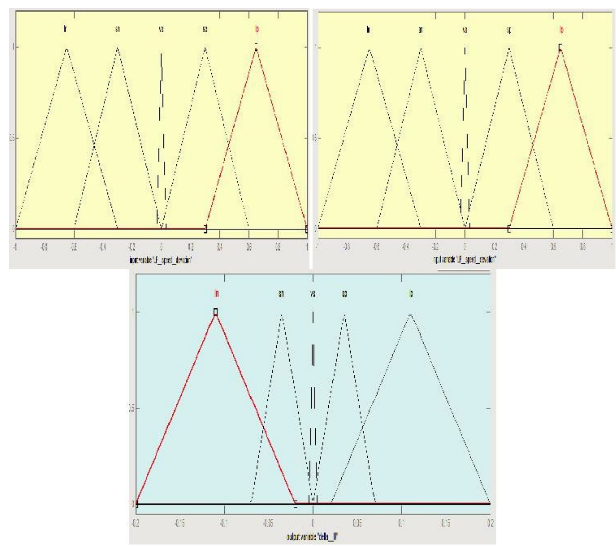


Fig. 3. Input and output membership functions

TABLE I. NEURALSET

	h				
i	***LN***	***SN***	***VS***	***SP***	***LP***
LN	SN	SN	LN	LN	LN
SN	SN	SN	SN	LN	SN
VS	SP	SP	VS	SN	SN
SP	LP	SP	SP	SP	SP
LP	LP	LP	LP	SP	SP

TABLE II. ABBREVIATION OF LINGUISTIC VARIABLES USED IN NEURAL KNOWLEDGE BASE.

LN	Large negative
SN	Small negative
VS	Very small
SP	Small positive
LP	Large positive

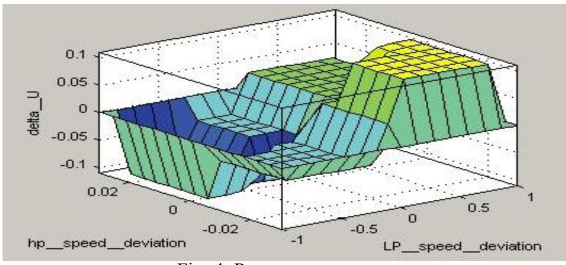


Fig. 4. Pressures parameters

V. UNIFIED POWER FLOW CONTROLLER (UPFC)

The unified power flow controller is a unique and versatile flexible a.c. transmission system device which uses power electronics device to control the flow of power. The UPFC deals with both active power and reactive power. It consists of both series compensator like static synchronous series compensator (SSSC) and shunt compensator like static synchronous compensator (STATCOM) along with a d.c. link. Here the d.c. link is a capacitor [11]. It also consists of two voltage source converters (VSC) connected along the secondary side of both series transformer and shunt transformer respectively [12]. The d.c. capacitor is connected between the two voltage sorce converters. The block diagram of UPFC is shown in the Fig. 6.

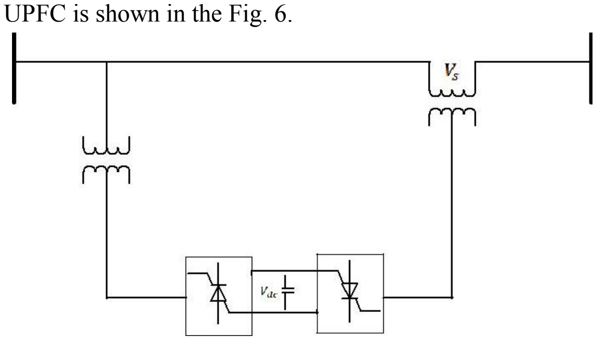


Fig. 5. Circuit diagram of UPFC

The UPFC has combined advantages of both series converter (SSSC) and shunt converter (STATCOM). The active power can be transferred via d.c. link from shunt converter to series converter. In case of SSSC the injected voltage is always in quadrature with the line current but in case of UPFC the phase angle of the injected voltage is independent of the line current. By changing the phase angle and magnitude of the injected voltage one can control both active power and reactive power. Inorder to have additional control over the active and reactive power the shunt converter operates to control the voltage V_1 by generating or absorbing the reactive power [13]. The common capacitor connected in between two VSCs acts like a d.c. voltage source. The VSC uses forced commutation power electronics devices to obtain a desired voltage from the d.c. voltage source.

VI. SIMULATION RESULTS

The results obtained after using UPFC along with NN based PI controller has shown improved performance as compared with system having un controlled UPFC. The analysis for the suppression of sub harmonic frequency is carried out by observing the waveforms of generator speed deviation, LP-HP speed deviation, rotor speed deviation and LP-HP torque deviation. The use of NN based PI has shown better results in case of speed deviation in generator, LP turbine and HP turbine by damping the oscillations and decreasing the settling time and is shown in Fig. 7 to Fig. 9. The improvement in rotor speed is also prominent as the value tends to 1 p.u. and is shown in Fig. 10. In case of torque deviation in LP turbine and HP turbine the damping and settling time has decreased considerably and is shown in Fig. 11 and Fig. 12 respectively.

Fig 6. Reactive power values

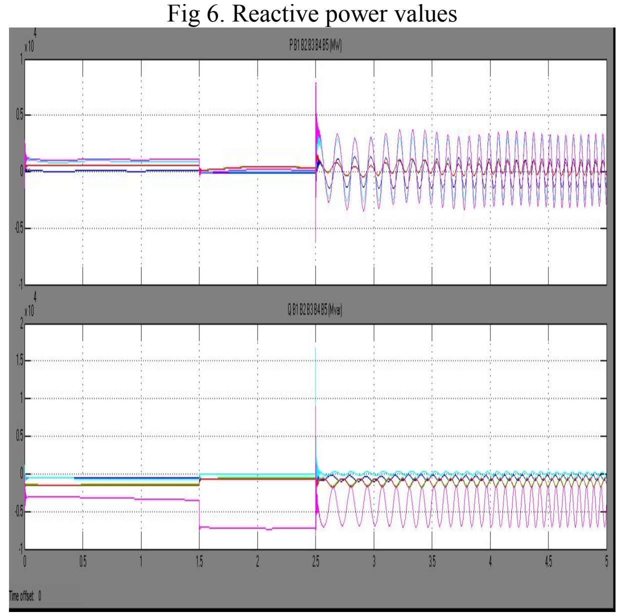
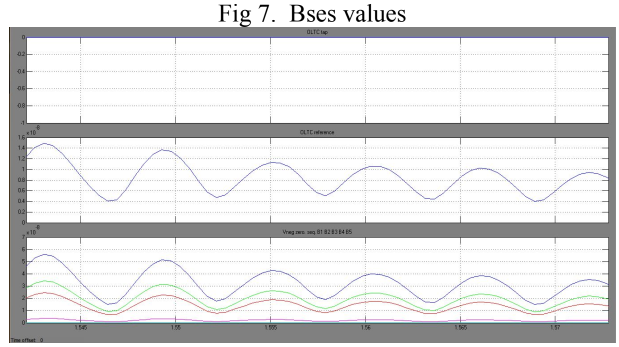


Fig 7. Bses values



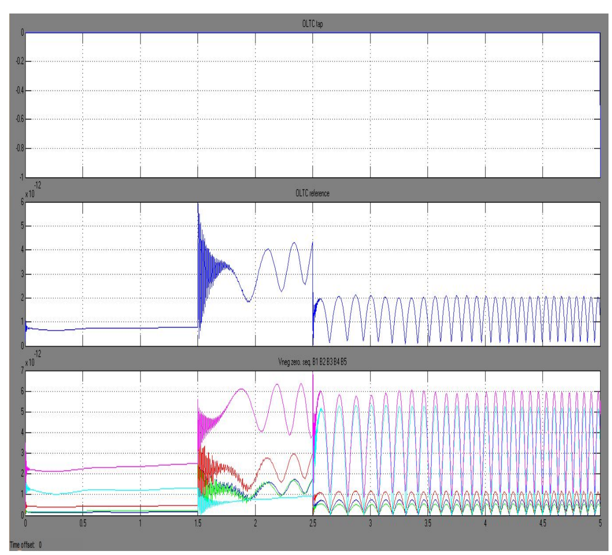
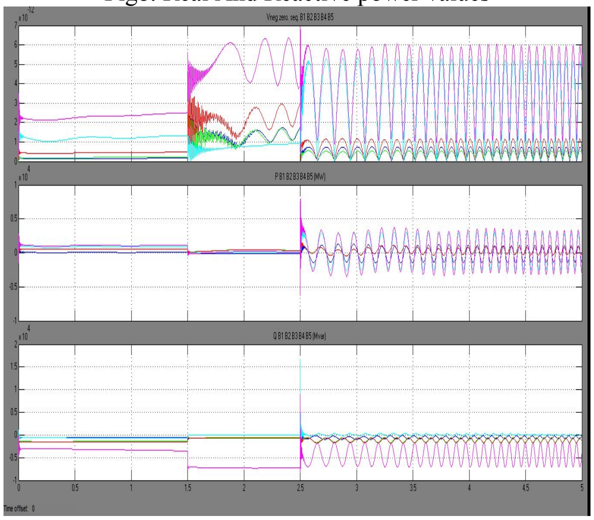


Fig8. Real And Reactive power values



CONCLUSION

The UPFC controlled by NN based PI controller is used for mitigation of SSR problem from the single machine infinite bus system after the application of three phase fault. The use of UPFC along with NN based PI, provides better results in minimizing torque deviation and speed deviation by increasing the damping and decreasing the steady state error both in case of generator and LP-HP turbines. Further, it is observed that generator speed reaches the rated speed i.e. 1 p.u. in less time with the use NN based PI controller. With the proposed FL based PI supplementary control signal for UPFC it has been analyzed that the SSR problem is mitigated from the power system.

ACKNOWLEDEMENT

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