Performance comparison of PI and Fuzzy Logic Controller in a SSSC based wind power integrated power system

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ABSTRACT

Background: For Renewable Energy Power Generation system Wind power has become the most widely used technique. Therefore the need for large wind turbine generators has become vital in electrical power grids. The power generated from this source has to be transmitted to maintain large power flow. To enhance power transfer capability and to maintain system stability series compensation are widely used, but this leads to the creation of Sub Synchronous Resonance (SSR). In order to overcome this problem flexible AC transmission systems (FACTS) devices with suitable controllers are used to reduce the effect of SSR. Objective: This paper investigates a modified IEEE second benchmark system for analysing damping of SSR. This system consists of DFIG wind power generation unit and steam turbine with SSSC (Static Synchronous Series Compensator). Results: In this Paper Performance analysis of PI and Fuzzy Controller is compared and their effectiveness is shown in MATLAB/ Simulink software. Conclusion: This paper proves that Fuzzy Logic Controller can damp ssr oscillation faster than a pi controller.

INTRODUCTION

SSR phenomenon might take place in FACTS device incorporated transmission system whenever transient operation happens in the power system. Due to the synchronization of the series compensated electrical network and the turbine generator mechanical arrangement, torsional torques are produced in the turbine generator unit. This torsional torque may be led to the shaft fatigue when the system has transient mode operations. Therefore, SSR mitigation has got more attention, so significant case study has to be done to avoid the problems associated with SSR, thereby making it a continuous subject for research and development. Referring to that, many studied are done in SSR mitigation, especially when the DFIG was employed as the generator in wind energy. The basic study of the SSR quantities calculation and tests is presented in (N.G.Hingorani et al., 2011). This work (Javad Khazaei et al.,2013) discusses clearly the DFIG control strategy by using voltage as the source of command in the grid side converter (GSC) to damp SSR. Moreover, the SSR definition, classification and mitigation have attained great interest in today’s scenario. The SSR mitigation using FACTS device in a series-compensated wind energy generation system has been demonstrated in various literature(Seyed Mohammad Hassan et al., 2013 & Dipendra Rai et al., 2011). These FACTS devices include the static synchronous series compensator (SSSC), thyristor-controlled series capacitor (TCSC), static var compensator (SVC) and STATCOM. In a modern paper (Seyed Mohammad Hassan et al., 2013) the SSR study in a modified IEEE benchmark model is mitigated by using SSSC. The more recent research was oriented to SSR damping using the sub synchronous current suppressor with the SSSC. Many other FACTS devices such as TCSC is applied in many modes of SSR suppression study either in the frequency scanning or impedance method. Moreover, the TCSC has useful application in the damping of SSR study exactly in the scanning frequency method. Both (B.Singh et al., 2009) and (R.K.Varma et al.,2013) explained a novel control for mitigating SSR in the wind farm and wind park with series compensated by using SSSC controller. Most efforts that have been focused on auxiliary damping controllers designed for SSSC are based on a liberalized system model. During the instant of the matter of large disturbances, the system conditions exhibit extremely nonlinear behaviors in the sense
that normal controllers have no chance to dampen the oscillations. In this condition, the controller may play the role of a destabilizing factor for the disturbances, for example by imposing negative damping. The control design technique hence needs to utilize the available nonlinear dynamics nature of the power system in order to overcome such undesirable problems. For this purpose, many control methods for stabilizing the power system have been suggested. The latest fuzzy control algorithm developed illustrates a procedural approach for controlling the nonlinear nature of the system. The performance of the system depends on the selection of number of variable parameter destabilizing the system. It has been proved that a fuzzy controller in a SSSC provides a better stabilization than a PI controller in a wide range of operation for mitigation of SSR effect (Ghafori et al., 2007 & S. Limyingcharone et al., 1998). Consequently, the main target of this work is to design a supplementary fuzzy logic damping controller (FLDC) for SSSC to mitigate the effect of SSR. The FLDC is varied considerably by proper selection of membership functions and parameters.

II Sub Synchronous Resonance:

The SSR is defined as “an condition exhibited in power system network due to the interaction between electrical network and turbine generator unit at frequencies below synchronous frequency of the system”. SSR effect results in the creation of SSR induction generator effect (IGE), torsional interaction effect (TI) and torque amplification (TA).

Induction generator effect (IGE):

Induction generator effect is a pure electrical phenomenon taking place at frequencies very close to the rated network frequency and in power systems having high degree of series compensation. In particular, IGE is a self excitation phenomenon occurring due to the self excitation of the electrical system.

Torsional interaction effect (TI):

TI is an instability state occurring due to the energy exchange between generator shaft and electrical power network. This state results in generation oscillation thereby inducing voltage components at both frequencies- sub synchronous frequency (f0-fm) and super synchronous (f0+fm) frequencies, where fm and f0 are the natural frequency and the system frequency of the generator shaft respectively.

Torque amplification (TA):

TA is the phenomenon that results from system disturbances. In case of power system network without series-compensation, this will contribute to dc offset that will decay with the sub transient and transient time constants of the generator. In the case of a series-compensated line, oscillations at frequency corresponding to the resonance frequency of the network will be experienced. If this frequency of these oscillations coincides with any of the natural frequencies of the generator shaft, large torques will be experienced. SSR due to TA can cause severe mechanical torsional oscillations connecting the generator and the turbines shaft in thermal power plants.

III Mathematical Modelling of Dfig:

The general scheme of electrical energy’s generation from the wind power on the basis of using doubly-fed induction generator is shown in figure 1. The stator of the DFIG is directly connected to the grid directly whereas the rotor is via a back-to-back converter. Rotor side converter is a current regulate-voltage source inverter and grid side converter is a PWM inverter.

![Fig. 1: Model Of wind Power Plant](#)

Amount of power that wind turbines can produce from wind can be expressed as:

\[ P_m = C_p \times P_w - - - - - - - - (1) \]

\[ P_w = 0.5 \times \pi p R^2 \omega^3 - - - - (2) \]
Where \( P_m \) is the mechanical power generated from the wind, \( P_w \) being the actual wind power, \( \rho \) is the density of air, \( R \) is the wind turbine blades radius, \( V_w \) is the wind speed and \( C_p \) is the efficiency index. The efficiency index \( (C_p) \) represents the part of the actual wind energy that is extractable by wind turbine and is depended to the blade’s aerodynamic formula, as described by:

\[
P_c = f(\lambda, \beta) = \frac{K_{\lambda, \beta}}{V_w} \quad (3)
\]

\[
\lambda = \frac{R_{\omega}}{V_w} \quad (4)
\]

\[
P_c = (0.44-0.0167\beta)\sin(\frac{\Pi(\lambda - 2)}{(13-0.3\beta)}) - 0.00184(\lambda-2)\beta \quad (5)
\]

**Fig. 2:** Nonlinear curve in terms of \( \lambda \) in place of different \( \beta \)

**IV System Model Study:**

The IEEE second bench mark model aggregated with the SSSC as shown in figure 3, illustrates the single-line diagram of the power system. A single generator of 600 MVA (22 kV) connected to an infinite bus consisting of two transmission lines in parallel through a transformer. The mechanical share of the system consists of a double stage steam turbine; a generator unit along with a rotating exciter (EX) mounted on a common single shaft as shown in Figure 3. The series capacitor compensation level of 55% is set for a reactance of \( X_{L1} \). Here different cases are taken for testing the working capability level of SSSC controller.

**Fig. 3:** IEEE SBM model aggregated with SSSC and Wind.
V Design of Controller For Ssr Mitigation:

This section deals with the SSSC control circuits to reduce the SSR effects. The SSSC being a well-known series-connected FACTS controller is based on a voltage source converter (VSC). Figure 4 illustrates a typical SSSC model with a VSC, a DC link capacitor, and an interfacing transformer. A Filtering stage (not indicated here) is used to alleviate the harmonic content of VSC output which is to be the controlled injected voltage in the power system network.

Fig. 4: SSR damping control structure

The SSSC can be regarded as an advanced type of controlled series compensation. Figure 4 displays the main control system of the SSSC. \( V_{qref} \) is the series reactive voltage desired and it determines the reactive power exchange for the series compensation. To be more precise, by injecting the series voltage, namely \( V_q \), the SSSC provides a variable reactance \( X_q \) in series to the transmission line, which is indeed used to change the line reactance. In this way an active means of compensation, power flow control, and power oscillation damping is achieved. The variable reactance of the SSSC is given as follows, where \( I \) denotes the line current.

\[
X_q = \frac{V_q}{I} \tag{6}
\]

The SSSC control system introduced above by itself does not have the ability to damp the power system oscillation individually. However, the SSSC controllable signals can be modulated to achieve the necessary SSR damping by proper coordinated tuning of SSSC along with auxiliary SSR damping controller.

VI Fldc Design For Ssr Mitigation:

The fuzzy logic controller (FLC) which is nonlinear in nature suits well for implementing in power system line under disturbance. FLC uses infinite logic levels from 0 to 1 during disturbances or faults. In the power system area FLC has been used in stability studies, load frequency control, unit commitment and reactive compensation in the distributed networks or failures occurring in the power system network (3,5). Here the proposed controller is designed based on Mamdani’s inference engine. Fuzzification, defuzzification, rule base, and inference engine forms the essential parts of this controller, which are defined as follows:

Fuzzification:

Fuzzification executes a membership function to translate the numeric values of error into linguistic value. Here in this paper speed deviation \( \Delta_w \) (pu) and its derivative \( \Delta_w/\Delta t \) forms the fuzzy input signal. By analysing the 2 input signals at different situations before and after the fault, fuzzy sets for the fuzzy controller are designed. The main configuration of the FLDC is illustrated in figure 5.
The membership functions for inputs and output of the FLDC are given in figure 6. For each input and output, 7 membership functions are taken and fine-tuned based on the available knowledge of the power system.

**Rule base and inference engine:**

The rule base forms the heart of fuzzy controller. The fuzzy control strategy is realized in the inference engine that is in the rule base which includes all possible combinations of outputs for the corresponding inputs. The rule base with 2 proposed inputs is shown in below table.

**Defuzzification:**

Here a crisp numeric value, which forms the control input of power system, is generated by outputs of fuzzy rules. Once the input variables are fuzzified and sent to the fuzzy rule base, the output of rule base is then aggregated and defuzzified. Aggregated means that all of the output fuzzy sets are added in logical way. A crisp control signal is then produced. A common method, namely the Centroid method is implemented here for this purpose where the control signal is calculated as given below (Δu)

\[
\Delta u(k) = \frac{\sum_{i=1}^{n} F_i \cdot S_i}{\sum_{i=1}^{n} F_i}
\]

Where \(F_i\) is the membership grade and \(S_i\) is the membership function’s single on position.

**VII Simulation Results:**

The performance of the proposed controllers is validated on a nonlinear system model using time-domain simulations. The responses of the network is
analysed between PI and Fuzzy Logic Controller. The fault case study is considered for analysing the performance of the proposed controller for mitigation of SSR. At 0.1 sec a three phase to ground fault is created and this disturbance create a SSR oscillation. Figure 7 shows the rotor angle deviation, from which we can observe that the fuzzy logic controller is able to damp oscillation more quickly than the PI Controller. Blue colour characteristics in the Figures(7-11) indicates the result of FLC and red colours indicates the output performance of PI controller. From figure 7 we can conclude that the Fuzzy Controller is able to damp oscillations in the rotor angle deviation more quickly than a PI controller.

**Fig. 7:** Rotor Angle Deviation

Figure 8 Shows the torque between the low-pressure turbine and generator in p.u.

**Fig. 8:** Torque between the low-pressure turbine and generator in p.u.

Figure 9 indicates the output of electrical power from PI controller and Fuzzy Logic Controller and we can conclude that electrical power oscillation damping is becoming quicker in FLC compared to a PI controller. Figure 10 and 11 indicates the rotor speed and rotor speed deviation respectively.

**Fig. 9:** Electrical Power
Conclusion:
The increased usage of wind generation in power system networking results in creation of SSR. In series connected power system SSR is a major problem. This paper proposes a effective control method for damping of SSR using SSSC. The Modified IEEE bench mark system has a wind power plant integrated near generator side. The SSSC is employed to improve the power flow and for mitigation of SSR effect, additional control techniques are incorporated. In this Paper two controller performances has been compared namely PI controller and Fuzzy Logic Controller. The Result shows that the proposed method using a Fuzzy Logic Controller provides the stable performance and it’s able to mitigate SSR effects over a wide range of operational conditions.

REFERENCES


