UPFC for Enhancement of Angle Stability Using Optimization Technique

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ABSTRACT— this paper deals with the damping of power system oscillations using the FACTS device Unified power flow controller (UPFC). This enhances the small signal angle stability. It combines the features of both static synchronous compensator (STATCOM) and static synchronous series compensator (SSSC). The main function of UPFC is power flow control and secondary functions are enhancement of small signal stability, transient stability, voltage control and oscillation damping. Firefly algorithm for optimizing the parameters of damping controller using Integral square error (ISE) technique has been implemented in this paper. Integral time absolute error also calculated. A single machine infinite bus system is considered for case study and it is implemented in MATLAB simulink. The Simulation results clearly indicate the effectiveness and validity of the proposed method.

INDEX TERMS—- Unified Power Flow Controller (UPFC), Single Machine Infinite Bus System (SMIB), Integral Square Error (ISE), Integral Time Absolute Error (ITAE).

I. INTRODUCTION

Due to rapid power demand and the expansion in generation and transmission is controlled with less availability of resources and due to environmental constraints, power systems are nowadays more complex than before. Low frequency oscillations are caused by remotely located power systems interconnection in the range of 0.2–3.0 Hz. If inadequate damping is provided, these oscillations may keep growing in magnitude until it loses its synchronism. In order to damp these power system oscillations and increase system stability UPFC based damping controller is used [1].

In recent years, the rapid progress in the field of power electronics had opened new chance for the FACTS devices controllability and power transfer limits .By modulating the bus voltage, phase shift between buses, and transmission line reactance, FACTS devices can cause a considerable increase in power transfer limits during steady-state. Because of the tremendously fast control action associated with FACTS-device operations, they have been very commonly used for operation in power system damping enhancement [2]. An unified power flow controller (UPFC) is the most capable device in the FACTS concept. It has the ability to adjust the three control parameters, i.e. the bus voltage, Transmission line reactance and phase angle between two buses either simultaneously or independently [3].

II. UPFC: STRUCTURE AND OPERATION

UPFC consists of a series converter and a shunt converter connected by a common dc link capacitor as shown in figure 1.It can concurrently perform the function of transmission line real/reactive power flow control in addition to UPFC bus voltage/shunt reactive power control. The shunt converter of the UPFC controls the UPFC bus voltage/shunt reactive power and the dc link capacitor voltage. On the other hand the series converter of the UPFC controls the transmission line active power flows by injecting a series voltage of adjustable magnitude and phase angle.. The phase angle of series voltage can be chosen independently from line current between 0 and 2π, and its magnitude is variable between zero and a defined maximum value. The parallel part known as STATCOM injects an almost sinusoidal current of variable magnitude at the point of connection [4].

Fig.1, Configuration of UPFC.

UPFC has four control inputs signals as m_b, δ_e, δ_b m_e It offers major probable merits for the static and dynamic operation of transmission lines since it combines the features of both the Static Synchronous Compensator (STATCOM) and the Static Synchronous Series Compensator (SSSC). In this paper, an UPFC based controller is included to give the UPFC more flexibility and to increase its capability to damp the power system oscillations and to increase the life period of the UPFC controller.

III. ANGLE STABILITY

Stability is defined as the ability of the power system to return or regain its normal operating conditions after being subjected to some disturbances. If the disturbance is small it is called small signal stability and if it is large it is called large signal stability or transient stability. Angle stability deals with maintaining synchronism between generators.

Small signal stability is the capability of the power system to maintain synchronism under small turbulence. Such disturbances occur continually on the system because of small variation in load and generation.

Instability may result in two forms:

1.Steady increase in rotor angle due to lack of sufficient synchronising torque.
2.Rotor angle oscillation of increasing amplitude due to lack of sufficient damping torque.

For a generator connected radially to a large power system in the absence of Automatic voltage regulator(constant field voltage)the instability is due to lack of sufficient synchronising torque.

The nature of system response to small disturbances depends on a number of factors including the initial operating conditions, the transmisssion system strength, and the type of generator excitation controls used.The system is stable in the first swing but becomes unstable as a result of growing oscillations at the end state is approached.

IV. PHILIPS HEFFRON MODEL

Fig.2.Philips Heffron model of SMIB system

The synchronous machine is a fourth order model and a familiar Philips-Heffron block diagram of linearised model of the system. The relations among these variables are expressed in terms of the six constants K1-K6.

These constants with the exception of K3, which is only function of the ratio of impedance, are function of the operating real and reactive loading as well as the excitation levels in the machine. The linearised equations describing the given system are given below.

The equation below gives the state space form of the above model.

$$\Delta\delta = \omega_o \Delta\omega$$

$$\Delta\omega = (-K_1\Delta\delta - D\Delta\omega - K_2\Delta E_q)$$

$\Delta\delta$ is the rotor angle deviation

$\Delta\omega$ is the rotor speed deviation

From the above block diagram the terminal voltage error signal which forms the input to voltage transducer is given by $\quad \Delta E_t = K_5\Delta\delta + K_6\Delta\psi_{fd}$

The coefficient K6 is always positive whereas K5 can be either positive or negative depending on the operating conditions and the external network impedance.

With automatic voltage regulator action the field flux variations are caused by the field voltage variations .

V. SMIB WITH INSTALLED UPFC

Fig.3. SMIB Including UPFC

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Consider the single machine infinite bus system with UPFC installed. UPFC is connected in the one of the parallel lines. This model permits the control of real and reactive power flow through a line. By controlling m_b , the magnitude of series injected voltage can be controlled. By controlling δ_b, the phase angle of series injected voltage can be controlled, by controlling m_e, the output voltage of the shunt converter can be controlled and by controlling δ_e , the phase angle of output voltage of the shunt converter can be controlled

VI. PHILIPS HEFFRON MODEL OF SMIB INCLUDING UPFC
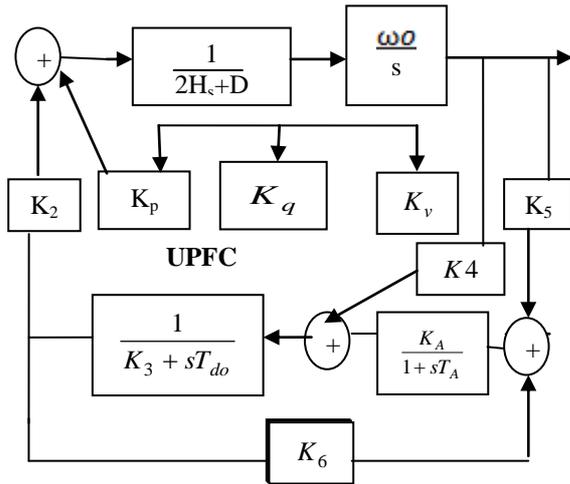
Fig.4.Philips Heffron model of SMIB including UPFC

A typical power system comprises a number of generating units connected to a set of loads through transmission lines.

The Figure shows the Philips Heffron model of the single machine infinite bus system including the voltage transducer and AVR/exciter blocks installed with UPFC. In this representation, the dynamic characteristics of the system are expressed in terms of the so-called K constants (K1-K6)

The control vector ΔF is defined as follows

$$\Delta F = \begin{bmatrix} \Delta V_{dc} & \Delta m_e & \Delta \delta_e & \Delta m_b & \Delta \delta_b \end{bmatrix}^T$$

Where

Δm_b : Deviation in pulse width modulation index of
series converter. By controlling m_e the magnitude
of series injected voltage can be controlled.

$\Delta \delta_b$: Deviation in phase angle of injected voltage.

Δm_e : Deviation in pulse width modulation index of

shunt Converter.

$\Delta \delta_e$: Deviation in phase angle of shunt inverter voltage.

The parameters K_p, K_q, K_v of unified power flow controller are stated as given below.

$$K_p = [\frac{K_{pd}}{M} \quad \frac{K_{pe}}{M} \quad \frac{K_{p\delta e}}{M} \quad \frac{K_{pb}}{M} \quad \frac{K_{p\delta b}}{M}]$$

$$K_q = [\frac{K_{qd}}{T_{d0}'} \quad \frac{K_{qe}}{T_{d0}'} \quad \frac{K_{q\delta e}}{T_{d0}'} \quad \frac{K_{qb}}{T_{d0}'} \quad \frac{K_{q\delta b}}{T_{d0}'}]$$

$$K_v = [\frac{K_A}{T_A} K_{vd} \quad \frac{K_A}{T_A} K_{ve} \quad \frac{K_A}{T_A} K_{v\delta e} \quad \frac{K_A}{T_A} K_{vb} \quad \frac{K_A}{T_A} K_{v\delta e}]$$

VII. OBJECTIVE FUNCTION

The main objective is to minimize the rotor angle deviation and rotor speed deviation thereby enhancing small signal angle stability. In this paper, Integral Square Error (ISE) Error of the rotor angle deviation ($\Delta\delta$) is taken as the objective function. The parameters of UPFC are tuned by using Firefly algorithm. For the comparison, ITAE value is calculated by using the optimized parameters obtained by ISE for various conditions.

Minimize

$$J = ISE$$

$$K1^{min} \leq K1 \leq K1^{max}$$
$$T1^{min} \leq T1 \leq T1^{max}$$
$$T2^{min} \leq T2 \leq T2^{max}$$
$$T3^{min}_s \leq T3 \leq T3^{max}$$
$$T4^{min} \leq T4 \leq T4^{max}$$

The Integral square error is calculated as shown Below

$$ISE = \int^{tsim} (\Delta\delta^2(t)(dt)$$

Where
$tsim$: Total simulation time period
T1, T2, T3, T4 : Lead-Lag time constants
Ks is the gain constant
Typical ranges of the optimized parameters are
[0.01– 100] for K and [0.01–1] for T1, T2, T3 and T4

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VIII. FIREFLY ALGORITHM

Firefly-inspired algorithm can be developed by idealize some of the flashing characteristics of fireflies

The idealized rules are:

1. All fireflies are unisex so that one firefly will be attracted to other fireflies regardless of their sex.
2. Attraction is proportional to their brightness, thus for any two flashing fireflies, the less bright one will move towards the brighter one.
3. The attractiveness is proportional to the brightness and they both decrease as their distance increases. If there is no brighter one than a particular firefly, it will move randomly.

The brightness of a firefly is determined or affected by the landscape of the objective function.

A. Light Intensity and Attractiveness:

The two important issues of Firefly algorithm are:

1. The variation of light intensity
2. Formulation of the attractiveness.

The brightness is associated with the encoded objective function. It will determine the attractiveness of firefly. The attractiveness must be judged by other fireflies as it vary with the distance between the firefly i and firefly j, as the distance from source increases the light is absorbed by the media. So the light intensity decreases so we should allow the attractiveness to vary with the degree of absorption.

According to the inverse square law, the light intensity is given by

$$I(r) = \frac{l}{r^2}$$

Where is the intensity at source, For a given medium with a fixed light absorption coefficient γ, the light intensity I varies with the distance r, that is

$$I = I_o e^{-\gamma r}$$

As a firefly's attractiveness is proportional to the light intensity, the attractiveness of a firefly is

$$\beta = \beta_o e^{\gamma r^2}$$

The distance between the fireflies i and j is given by

$$r_{i,j} = \sqrt{(x_i - x_j)^2 - (y_i - y_j)^2}$$

The movement of a firefly i is attracted to another more attractive firefly j is determined by

$$x_i = x_i + \beta_o e^{\eta_{i,j}^2}(x_i - x_j) + \alpha \varepsilon_1$$

Where the second term is due to the attraction and the third term is due to randomization.

IX. SIMULATION RESULT

To check the adequacy of UPFC damping controller simulation of the SMIB model of the power system is carried out by giving 10% change in voltage setting V_{ref} of the excitation system.

After simulation, the optimal parameters of the UPFC based controller using Fire Fly algorithm is given in table below.

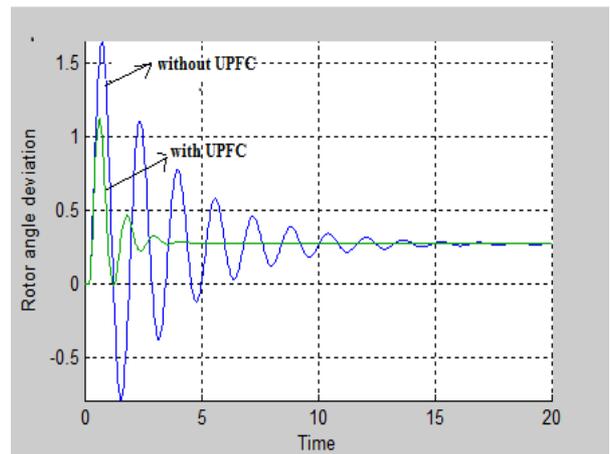| Parameter	Ks	Tw	T1	T2	T3	T4
FFA-UPFC	47	10.0	1.49	0.977	0.28	0.84

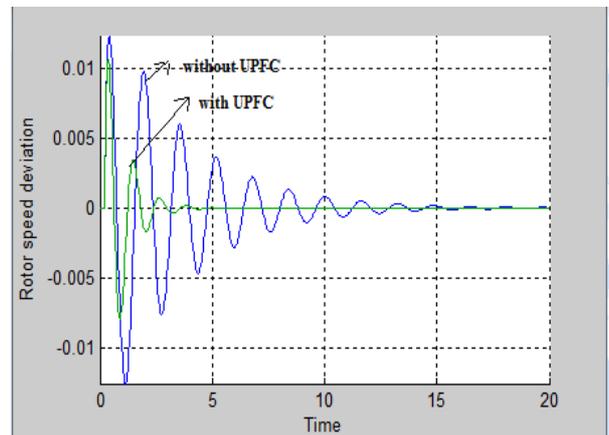Fig.5 Time response plot of Rotor angle deviation

Fig. 6 Time response plot of Rotor speed deviation

X. CONCLUSION

In this paper, damping of power system oscillations using single machine infinite bus system is presented. The parameters of UPFC is tuned by firefly algorithm .The objective function is defined based on the integral square error technique

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and integral time absolute error also calculated. The objective is to minimize the rotor angle deviation and rotor speed deviation and to increase their damping. Based on the simulation result it can be concluded that UPFC provides better damping for a wide range of operating conditions.

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