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GA based conventional and PID power system stabilizer for stability analysis of SMIB system

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ABSTRACT

In this paper, low frequency oscillations in power system under the different operating conditions have been solved through conventional power system stabilizer and PID based power system stabilizer. The tuning of the parameters of the PSSs are considered as optimization problem, and the parameters are tuned using genetic search algorithm. Here forth –order linear and non-linear model of the synchronous machine (model 1.1) which includes both the generator main field winding and the damper winding in q-axis is considered for finding out the sensitivity of electromechanical modes of single machine infinite bus system. The effectiveness of automatic voltage controller, and Conventional and PID -power system stabilizer are identified through eigen value analysis and participation factor method. The non-linear simulation results show the effectiveness and capability of two schemes of PSS for power system stability improvement under various disturbances.

Introduction

The stability, steady state operation and continuity of the operation of power systems are dependent on the capability of the generators to work in synchronism and to return to the synchronous speed when subjected to the disturbances and various operating environment. The third –order dynamic model and Philips –Heffron linear model of the synchronous machine is normally used for stability analysis of power system [2], in which the model only takes into account the generator main field winding. The linearized approach for stability analysis of power system using PSS and FACTS controller are explained different literatures with 3rd order system. [2], [3]. For the better analysis of single machine infinite bus system, in this paper, the fourth-order complex dynamic model and linearized model of synchronous machine has been considered which includes both the generator main field winding and the damper winding on q-axis.

The application of power system stabilizers (PSS) for improving small signal oscillation and the dynamic stability of a power system with long transmission lines , generating units equipped with high-gain and fast-acting excitation system. Different type of arrangement of lag- lead compensator based PSS [7] are used for detailed analysis of the power system. Two-stage lead compensator with washout filter and gain is most commonly structure of PSS is used for analysis purpose [11],[13].

The PSSs are designed through different intelligent techniques such as Artificial Neural Network, Fuzzy logic , Neuro-Fuzzy [6],[8] and the gain and time constants of PSS are optimized through different computational optimization techniques likes : Genetic algorithm, particle swarm optimization etc.[5],[9].

In this paper fourth order linear model of the synchronous machine with high gain AVR, conventional PSS and of newly proposed PID based PSS have been designed using genetics search algorithm under different loading condition of the system. Here eigen value analysis, damping factor and participation factor are calculated for identification of the sensitivity of electromechanical modes using both type of PSSs. The non-linear simulation is performed for comparison analysis of SMIB with and without PSSs under various disturbance and various operating conditions.

Power system

The power system is represented by Single machine infinite bus power system with PSS as shown in Fig.1. Where and are generator terminal voltage and infinite bus voltage respectively. The and are transmission line reactance and transformer reactance respectively.

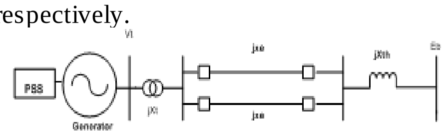

Fig 1. SMIB with PSS

Dynamic model of power system

The synchronous generator is represented by non-linear equations which includes both the generator main field winding and the damper winding on q-axis [11].

$$\dot{\delta}=\omega_B\left(\omega_m-\omega_{m0}\right) \quad (1)$$

$$\dot{\omega}_m=\frac{1}{2H}\left(-k_d(\omega_m-\omega_{m0})+T_m-T_e\right) \quad (2)$$

$$\dot{E}'_q=\frac{1}{T'_{do}}\left[\left(-E'_q+\left(x_d-x'_d\right)i_d\right)+E_{fd}\right] \quad (3)$$

$$\dot{E}'_d=\frac{1}{Tq'_o}\left(-E'_d-\left(x_q-x'_q\right)i_q\right) \quad (4)$$

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The IEEE type –ST1 excitation system can be described by

$$\dot{E}_{fd} = -\frac{1}{T_A} E_{fd} + \frac{K_A}{T_A}(V_{ref} - V_i) \qquad (5)$$

Where the electrical torque can be expressed by

$$T_e = E'_d i_d + E'_q i_q + \left(x'_d - x'_q\right) i_d i_q \qquad (6)$$

Where Re=0; the equations for i_d, i_q, v_q, v_d are represented by

$$i_d = \frac{E_b \cos\delta - E'_q}{\left(x_e + x'_d\right)} \qquad (7)$$

$$i_q = \frac{E_b \sin\delta + E'_d}{\left(x_e + x'_q\right)} \qquad (8)$$

$$v_q = -x_e i_d + E_b \cos\delta \qquad (9)$$

$$v_d = x_e i_q - E_b \sin\delta \qquad (10)$$

$$V_i = \sqrt{{v_q}^2 + {v_d}^2} \qquad (11)$$

Linear model of power system with PSSs

For the design of PSSs parameters, the dynamics model of the synchronous machine is linearized about its initial conditions. The fourth-order model of the synchronous machine is considered and K1 to K10 constant are derived from equations (1) to (11) as mention in section A. For the different operating conditions the constants of the machine are changed so corresponding, the locations of poles in left-half of the s-plane and sensitivity of electro mechanical modes are changed.

Linear model

By linearized the equations of i_d and iq and substituting these equations in (9) to (11) and equations (1) to (6), yield the linearized equations. The expressions are represented by state space form $\dot{X} = AX + Bu$ where X and u represents the state of system and input of the system respectively.

$$\begin{bmatrix} \Delta\dot{\delta} \\ \Delta\dot{\omega} \\ \Delta\dot{E}'_q \\ \Delta\dot{E}'_d \\ \Delta\dot{E}_{fd} \end{bmatrix} = \begin{bmatrix} 0 & \omega_B & 0 & 0 & 0 \\ -\frac{K1}{2H} & \frac{K_D}{2H} & -\frac{K2}{2H} & -\frac{K3}{2H} & 0 \\ -\frac{K5}{T'_{d0}} & 0 & -\frac{1}{T'_{d0}K4} & 0 & \frac{1}{T'_{d0}} \\ \frac{K7}{T'_{q0}} & 0 & 0 & -\frac{1}{T'_{q0}K8} & 0 \\ -\frac{K_A K9}{T_A} & 0 & -\frac{K_A K6}{T_A} & -\frac{K_A K10}{T_A} & -\frac{1}{T_A} \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta\omega \\ \Delta E'_q \\ \Delta E'_d \\ \Delta E_{fd} \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{1}{2H} \\ 0 \\ 0 \\ K_A/T_A \end{bmatrix} \begin{bmatrix} 0 & \Delta T_m & 0 & 0 & V_{ref} \end{bmatrix} \qquad (12)$$

Initial conditions calculations

The initial conditions of the synchronous machine are calculated for different operating conditions. In this paper three operating conditions are considered such as light loading, normal loading and heavy loading. Here .and and corresponding, the initial conditions are given by table 1. The initial conditions are used for calculation of, K1 to K10 constant of the machine and using these, the eigen values, damping ratio, right eigen vector, left eigen vector and participation factors are calculated. The table.1 represents the initial conditions of different parameters of the machine.

Optimization problem

Power system stabilizer

The problem of stability of power system due to the disturbance such as, sudden change in loads, change in transmission line parameters, fluctuation in the output of the turbine and faults conditions, etc, and the use of fast acting high gain automatic voltage regulator (AVR) have invited the problem of low frequency oscillations (typically in the range of 0.2 Hz to 3.0 Hz) under various operating conditions and configurations. These oscillations limit the power transmission capability and an eventual breakdown of the entire system. The application of power system stabilizer (PSS) can help in damping out of this oscillation and helps to improve system stability [10].

Conventional PSS

The output response of the PSS is shown as a feedback element from generator speed and is described by in form [11],[12].

$$V(s) = \frac{K pss T_o s}{1 + T_o s}\left|\frac{(1+T_1 s)(1+T_3 s)}{(1+T_2 s)(1+T_4 s)}\right| \Delta\omega_m(s) \qquad (13)$$

The first term in equation (13) is a reset term that is used to washout the compensation effect after the time lag T_0. The second term of $Y(s)$ is a lead compensation pair that can be used to improve the phase lag through the system from V_{ref} generator shaft speed ω_m.

PID- PSS

One of the most powerful but complex controller mode combines the proportional, integral, and derivative mode.

This mode eliminates the offset of the proportional mode and provides fast response[13]. In present work, PID base PSS is proposed with feedback element from generator speed and is represented by in form [4]

$$V(s) = \left[K_p + \frac{K_I}{s} + K_D s\right]\Delta\omega_m(s) \qquad (14)$$

Above PSSs are designed for the different operating points, and time constants and gain of PSSs is optimized using genetic algorithm.

Problem Formulation

In this paper, different parameters of the conventional PSS and PID-PSS are optimized under different operating conditions. In the conventional power system stabilizer, and PID –power system stabilizer, the time constants $A.$ T_1, T_2, T_3 and the gains $A.$ $Kpss$, $A.$, and $A.$ are optimized using genetic search algorithm respectively. In the both type of PSS, the input feedback signal is rotor speed, and under the steady state operation, the output of the PSS is zero. Under the disturbance conditions, the output of PSS is modified according to the change in the speed during dynamic environment. The optimization flow chart is as shown in figure 2.

Optimization function

In this study, it is objective to minimize the optimization function J. The best system response is obtained when the PSSs parameters are optimized and minimizing the maximum eigen values over a certain range of operating conditions. Optimized J subject to:

$$\begin{aligned} T_1^{min} &\le K_1 \le T_1^{max} \\ T_2^{min} &\le K_2 \le T_2^{max} \\ T_3^{min} &\le K_3 \le T_3^{max} \\ T_4^{min} &\le K_4 \le T_4^{max} \\ K_p^{min} &\le K_p \le K_p^{max} \\ K_I^{min} &\le K_I \le K_I^{max} \\ K_D^{min} &\le K_D \le K_D^{max} \end{aligned} \qquad (15)$$

The output of the PSSs is produced such that the deviation in rotor speed would be reduced and improve in the system response in terms of settling time and overshoots.

Eigen Values and Participation Factor

In this paper, the linear model of the system has been considered and eigen values of the Matrix A is calculated with both type of the PSSs under the different operating conditions.

For the effective operation of the stabilizer, the participation factor methods are used for identification of the eigen values associated with electromechanical modes. The magnitude of the participation factors are calculated using right eigenvector and left eigenvector [10].

Genetics Algorithm

Now days, for control system problem, the GAs has been used for optimization of the parameters where plant is complex and difficult to optimize the system through conventional optimization methods. GAs is the part of the evolutionary algorithm family, and powerful stochastic search algorithm based on the mechanism of natural selection and natural genetics. GAs work with population of binary string, searching many peaks in parallel. By employing genetics operator, they exchange the information between the peaks, hence reducing possibility of ending of at a local optimum. GAs are more flexible and simple than other search methods because they require only information concerning the quality of the solution produced by each parameters set and not like many traditional optimization methods that require derivative information or complete knowledge of the problem structure and parameters. GAs differs from other optimization methods in the following ways [14]:

(1) GAs search from a population of points, not a single point that equips them with inherent parallel computational ability. This population can climb over hills and move across valleys. GAs can therefore discover a globally optimal point.

(2) GAs use payoff information directly for the search direction, not derivatives or other auxiliary knowledge. GAs therefore can deal with nonsmooth, non continues, and non differentiable, functions that are experienced in real life optimization problems.

(3) GAs use probabilistic transition rules to select generation, not deterministic rules, so they can reach a complicated and uncertain area to find the global optimum.

Results and discussion

For the different operating conditions, the oscillations of the electro mechanical modes of the machine is identified with conventional PSS and PID-PSS , and stability of the system has been studied.

The initial conditions, eigen values, damping factors and participation factors of the system are calculated using MATLAB/programming. The non linear simulation is also carried out using non-linear dynamics model described by equations (1) to (11), which are implemented using MATLAB/simulink environment [1]. The detailed data of the power system used in this study is given by Appendix. With attention to the conventional PSS the time constant of the wash out filter is selected 10 sec. For three operating conditions, the objective function J is optimized through GA toolbox. Using each set of C-PSS's gain $T_1, T2, T3, T4$ and PID-PSS's gain $Kpss, K_p$, K_I and K_D, the time domain simulation is performed and fitness value is determined.

By changing the GA parameters such as population size, crossover rate and function, mutation rate and function, No. Generation, etc, the new set of gains are developed, and best fitness values are selected.

The appropriate choice of the GAs parameters affects the convergence rare of the algorithm. The parameters are selected for expected solution is given by table 3. The gains of the C-PSS and PID-PSS are tuned separately and optimized parameters have been shown by table 2. The eigen values and damping factor are associated to the electromechanical modes without PSS and, with C-PSS and PID-PSS have been shown in table 4.

Simultaneously change in mechanical Input and

The non-linear simulation is performed. Here 5 % change in mechanical input and 0.1 p.u. change in Vref simultaneously apply to the generator and the response of has been plotted .Attention to the table 4, for the third operating condition, without PSS, the eigen value is positive and oscillations of the frequencies are increased as per figure 5,which shows instability of the system. The stability of the system has been improved using PSSs. Using the C-PSS and PID-PSS, the eigen value, damping factor and oscillation frequency are -2.5513 , 0.4546 , 0.797 Hz and -4.597, 0.533 ,1.162 Hz respectively. Figure 3, 4 and 5 show the oscillation of rotor angle and speed of the generator are clearly damp out with PSSs.

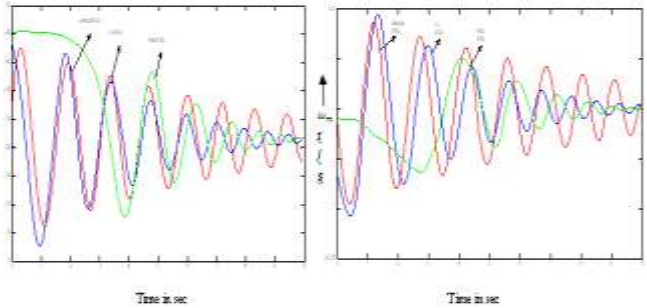

Fig. 3. First operating condition

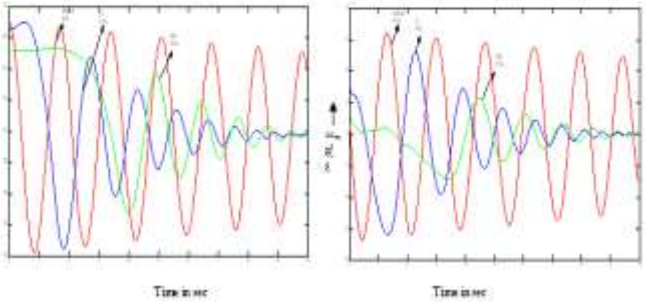

Fig. 4. Second operating condition

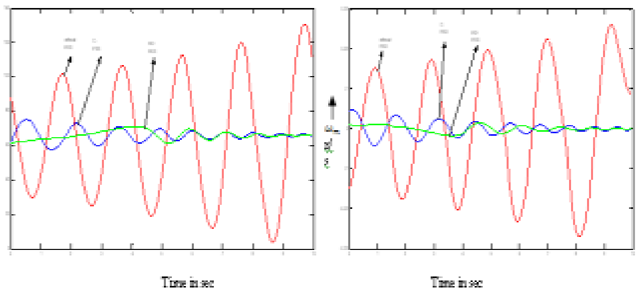

Fig.5.Third operating conditions

Change in

In this case , considered the infinite bus voltage increase about 0.1. p.u., for three different operating conditions and the oscillation in have been shown in figure 6, 7 and 8. Using the C-PSS and PID-PSS , the oscillation of frequency are very nicely damp out and stability of the power system is also increased compared to the without PSSs in the system.

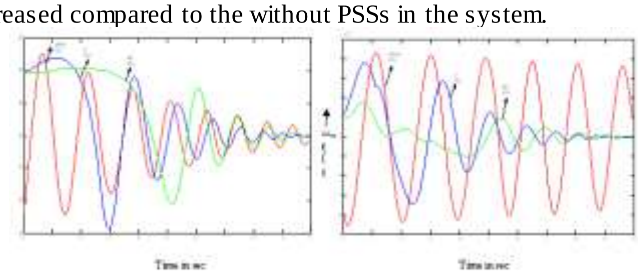

Fig. 6. First operating condition

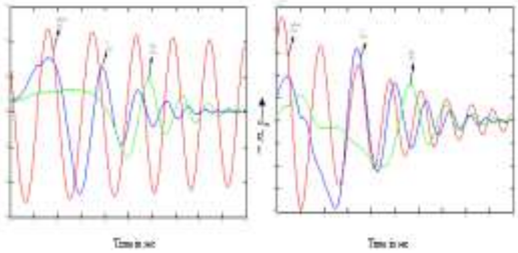

Fig. 7. Second operating condition

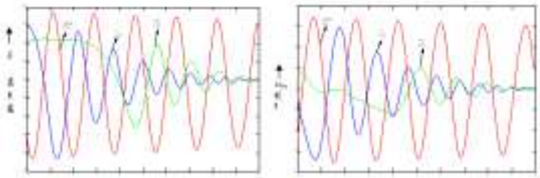

Fig. 9. Third operating condition

Fault condition

A three phase fault at the sending end of the circuits of transmission line and cleared by isolating the faulted circuit simultaneously at the both ends. Here normal operating condition i.e. =0.6 is considered. Figure 9 shows power and angle and rotor speed for the above contingency. It is cleared that without C-PSS and PID-PSS the system is unstable and the oscillation are continuously increased. The figure 10 shows, the GA base, C-PSS and PID-PSS are significantly suppress the oscillations in power angle and rotor speed, and provides good damping characteristics to low frequency oscillation by stabilizing the system quickly.

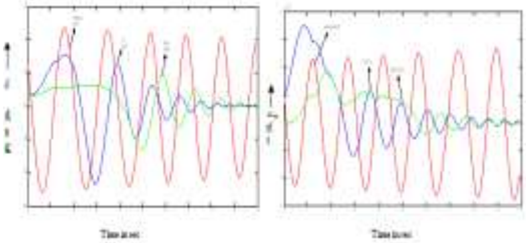

Fig. 10. Third operating condition

Conclusion

In this study, the C-PSS and PID-PSS are presented for the power system dynamic stability improvement. The three different operating conditions are taken and the response of the rotor angle and rotor speed have been analyzed under different types of the faults. The linear programming and non-linear simulation is carried out for details analysis of the power system. The GA was used for finding out the optimized parameter of the PSSs.

From the non - linear analysis, it has been seen that frequency of the oscillation in rotor angle and rotor speed are quickly damp out using PID-PSS compare to the C-PSS and time response parameters like settling time, overshoot have been improved. It is cleared that without C-PSS and PID-PSS , the power system is unstable, while, the GA based, C-PSS and PID-PSS are significantly diminished the oscillations in power angle and rotor speed, an provides good damping characteristics to low frequency oscillation by stabilizing the system quickly.

Appendix

$x_d = 1.7572, x_q = 1.5845, x_d' = 0.4245, x_q' = 1.04, T_{d0}' = 6.66, T_{q0}' = 0.44, H = 3.542, \omega_B = 314\,rad/sec$

$x_t = 0.1364, x_e = 0.8125, K_A = 400, T_A = 0.025, V_t = 1.05, \theta = 21.65, X_{TH} = 0.1363$

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Table 1 Intial condtions

i_{d0}	i_{q0}	v_{d0}	v_{q0}	e_{d0}	e_{q0}	δ_0
−0.122	0.259	0.410	0.967	−0.141	1.019	44.62
−0.383	0.425	−0.674	0.806	−0.232	0.969	61.52
−0.705	0.497	−0.787	0.696	−0.27	0.994	70.16

Table 2 GA Parameter and Values

Parameter	Values/function
Population size	50
Stopping Generation	100
Scaling function	rank
Selection function	Stochastic Uniform
Mutation function	Gaussian
Crossover function	Scattered

Tables 3 optimized parameter using GA

	Operating Points		
Parameters	1	2	3
T_1	0.97	1.089	1.83
T_2	0.994	0.849	2.419
T_3	0.633	0.362	0.432
T_4	0.0161	0.078	0.173
$Kpss$	7.562	7.691	7.962
K_p	0.062	0.0256	0.0255
K_I	0.18	0.269	0.256
K_D	12.58	11.618	12.618

Table 4

Eigen values and damping factor

	Without-PSS		C-PSS		PID-PSS	
Operating points	Eigen Values	ζ	Eigen Values	ζ	Eigen Values	ζ
1	$-0.120 \pm j5.8554$	0.0205	$-1.3374 \pm j4.1464$	0.3070	$-2.1147 \pm j6.0033$	0.3322
2	$0.0011 \pm j6.4006$	-0.002	$-1.5133 \pm j3.931$	0.3593	$-2.9971 \pm j6.6502$	0.4109
3	$0.1687 \pm j6.900$	-0.024	-2.5513 ± 5.0078	0.4546	-4.597 ± 7.2993	0.5330