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SMALL SIGNAL STABILITY ANALYSIS OF POWER SYSTEM NETWORK USING WATER CYCLE OPTIMIZER

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Abstract—**the low frequency electromechanical oscillations caused by swinging generator rotors are inevitable in interconnected power systems. These oscillations limit the power transmission capability of a network and, sometimes even cause a loss of synchronism and an eventual breakdown of the entire system, thus making the system unstable. Power system stabilizer is used to damp out these oscillations and hence improve the stability of the system. In this paper, nature inspired Water cycle algorithm based stabilizer design is carried out to mitigate the power system oscillation problem. The proposed controller design is formulated as an optimization problem based on damping ratio and Eigen value analysis. The effectiveness of the proposed controller is tested by performing nonlinear time domain simulations of the test power system model under various operating conditions and disturbances. The system performance with Water cycle algorithm is also compared with conventional lead-lag controller design.**

Index Terms— **Eigen value analysis, Low frequency oscillation, Multi machine infinite bus system, Water Cycle optimization.**

I. INTRODUCTION

Low frequency oscillations (0.1 to 2 Hz) after a disturbance in a power system, if not properly damped, it can lead the system to unstable condition. A Power System Stabilizer (PSS) is one of the cost effective damping controller to improve the power system stability. The main objective of PSS is to add damping to the electromechanical oscillations by controlling the generator excitation using auxiliary signal. In recent years, several techniques based on modern control theory have been applied to PSS design, refer simply to the reference number, as in [1]-[3].These includes variable structure control, adaptive control and intelligent control. Despite these techniques, power system researchers still prefer the conventional lead lag controller design. Conventional PSS are designed using the theory of phase compensation in frequency domain and it can provide effective damping performance only for a particular operating condition and system parameters. Also, the fuzzy logic and neural networks had been implemented in damping controller design. But these controllers suffer from the following drawbacks: There is no systematic procedure for the fuzzy controller design and also the membership functions of the controller are tuned subjectively, making the design more complex and time consuming. With respect to neural based controller, it is more difficult to understand the behavior of the neural network in implementation refer simply to the reference number, as in [5]. Recently, as an alternative to the conventional and uncertainty methods, Bio inspired optimization techniques are considered as powerful techniques to obtain optimal solution in power system optimization problems. These techniques include Evolutionary programming, simulated annealing, bacterial foraging, Harmony search algorithm, Ant colony optimization, Genetic algorithm and Water cycle algorithm. In this project Water cycle algorithm based PSS designs are implemented in optimizing the power system stabilizer parameters, suitable for multi-machine stability enhancement.

II. TEST SYSTEM MODEL

A. Test multi machine power system modeling

The test three machine nine bus power system model taken for modeling, analysis and simulation. The Heffron-Phillips block diagram of synchronous generator model was used refer simply to the reference number, as in [3].

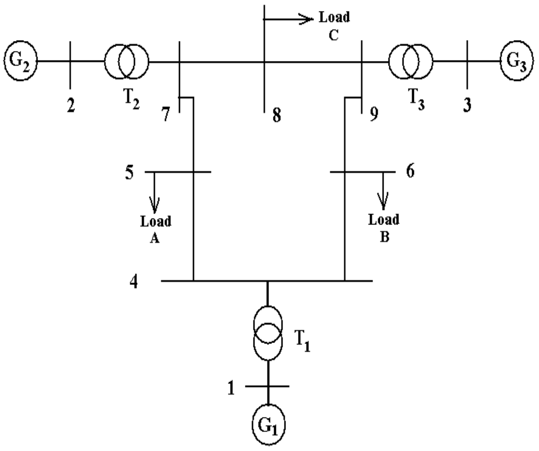

Fig.1. Three machine nine bus power system models.

$x=Ax+Bu$ (1)

Where x = Vector of State variables.

A, B = State vector matrix and Input matrix respectively.

B. Power system stabilizer structure

In this paper a dual input PSS is used, the two inputs to dual-input PSS are $\Delta\omega$ and ΔPe, with two frequency bands, lower frequency and higher frequency bands, unlike the conventional single-input ($\Delta\omega$) PSS. PSS3B is found to be the best one within the periphery of the studied system model. This dual input PSS configuration is considered for the present work and its block diagram representation is shown in Figure 2. Refer simply to the reference number, as in [4].

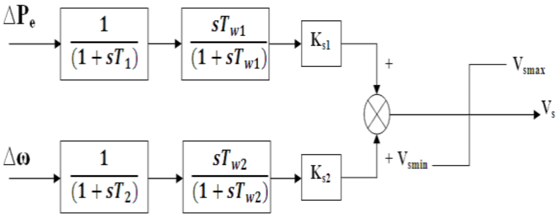

Fig. 2. IEEE type PSS3B structure.

Hence Ks, T1, T2 are the PSS parameters which should be computed using CPSS and optimally tuned using Water cycle optimizer PSS.

III. PROPOSED OPTIMIZATION CRITERION

To increase the damping over a wide range of operating conditions and configuration of power system, a robust tuning of controllers must be implemented. The objective functions are represented as,

$$J_1=\mathrm{Max}[\sigma_i],\ \sigma_{i\in}\quad \sigma_{EMODE} \tag{2}$$

$$J2=\mathrm{Min}[\zeta i],\ \zeta i\in\quad \zeta_{EMODE} \tag{3}$$

EMODE in equations (2) and (3) represent the electromechanical mode of oscillations.

The maximum value of real part [Max(σi)] of the Eigen value will be located in right half of s- plane, making the system unstable. The weekly damped electromechanical mode will have minimum value of damping ratio [Min(ζi)] among all the damping ratios of the system. The objective is to minimize the objective function [J1] and maximize the [J2]. It involves shifting the real part of the *ith* electromechanical Eigen value to stable locations in left half of complex s-plane and the damping ratio of the weakly damped electromechanical mode of oscillations will be enhanced to make the system more stable. The single machine Heffron-Phillips generator model is extended to perform the modeling of multi machine system. Because of the interaction among various generators in the multi machine system, the branches and loops of the single machine generator model become multiplied. For instance, the constant K_1 in the single machine model becomes K_{1ij}, i=1,2…n; j=1,2….n in the multi machine modeling. In this work, n will be equal to 3, representing the number of generators in the multi machine system considered. Similarly all the K constants (K1 to K6), damping factor D, inertia M and the state variables used in the single machine model are generalized for n-machine notation as in [1], [3].

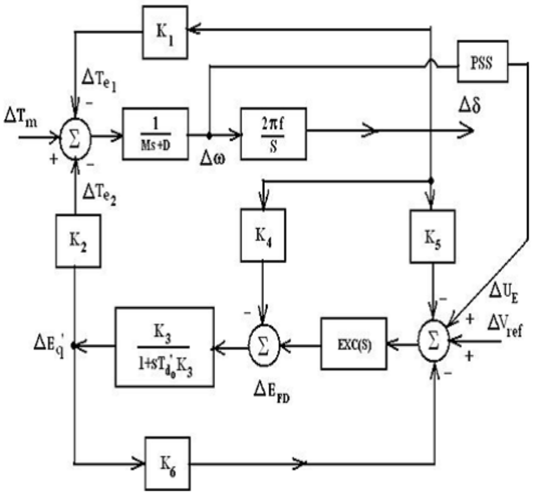

Fig .3. Heffron Philips generator model

The power system stabilizer optimization parameters (Ks, T1, and T2) are taken as constants for the proposed optimization problem.

$$Ksmin \le Ks \le Ksmax \tag{4}$$

$$T1min \le T1 \le T1max \tag{5}$$

$$T2min \le T2 \le T2max \tag{6}$$

The typical values for the optimized parameters are taken as [0.1-60] for k, [0.2-1.5] for T1 and [0.02-0.15] for T2 .The time constant Tw is considered as 10.0s [20].The damping ratio of the *i*th critical mode is given by

$$\zeta i= - \sigma i/\sqrt{\sigma i^2+\omega i^2} \tag{7}$$

Where Eigen value is given by $\lambda i = \sigma i+j\omega i$

The objective function J1 and J2 in equation (2) and (3) along with the constraints in (4), (5), (6) is the proposed optimization criterion formulated in this paper to enhance the system stability.

IV. PROPOSED METAHEURISTIC OPTIMIZATION METHOD

The idea of the proposed Water Cycle Algorithm (WCA) is inspired from nature and based on the observation of water cycle and how rivers and streams flow downhill towards the sea in the real world. The evaporated water is carried into the atmosphere to generate clouds which then condenses in the colder atmosphere, releasing the water back to the earth in the form of rain or precipitation. This process is called the hydrologic cycle. Refer simply to the reference number, as in [7].

The smallest river branches are the small streams where the river begins to form. These tiny streams are called first-order streams. Wherever two first-order streams join, they make a second-order stream. Where two second-order streams join, a third-order stream is formed and so on until the rivers finally flow out into the sea.

$$\text{Raindrop}=[x_1,x_2,x_3,\ldots..x_n] \tag{8}$$

$$\text{If}|X^i_{sea}-X^i_{river}|<d_{max}\quad i=1,2,3,..,N_x-1 \tag{9}$$

Where dmax is a small number (close to zero). Therefore, if the distance between a river and sea is less than dmax, it indicates that the river has reached/joined the sea. In this situation, the evaporation process is applied and as seen in the nature after some adequate evaporation the raining (precipitation) will start. A large value for dmax reduces the search while a small value encourages the search intensity near the sea. Therefore, dmax controls the search intensity near the sea (the optimum solution).

$$X^{new}_{stream}=LB+rand*(UB-LB) \qquad (10)$$

Where LB and UB are lower and upper bounds defined by the given problem, respectively. Again, the best newly formed raindrop is considered as a river flowing to the sea. The rest of new raindrops are assumed to form new streams which flow to the rivers or may directly flow to the sea. In order to enhance the convergence rate and computational performance of the algorithm for constrained problem is used only for the streams which directly flow to the sea. This question aims to encourage the generation of streams which directly flow to the sea in order to improve the exploration near sea (the optimum solution) in the feasible region for constrained problems. Refer simply to the reference number, as in [7], [8].

A.Constraint handling

In the search space, streams and rivers may violate either the problem specific constraints or the limits of the design variables. In the current work, a modified feasible-based mechanism is used to handle the problem specific constraints based on the following four rules [17]:

Rule1: Any feasible solution is preferred to any infeasible solution.

Rule2: Infeasible solutions containing slight violation of the constraints (from 0.01 in the first iteration to 0.001 in the last iteration) are considered as feasible solutions.

Rule 3: Between two feasible solutions, the one having the better objective function value is preferred.

Rule 4: Between two infeasible solutions, the one having the smaller sum of constraint violation is preferred.

B. The steps of WCA

Step 1: Choose the initial parameters of the WCA: Nsr, dmax, Npop, max_iteration.

Step 2: Generate random initial population and form the initial streams (raindrops), rivers, and sea.

Step 3: Calculate the value (cost) of each raindrops.

Step 4: Determine the intensity of flow for rivers and sea.

Step 5: The streams flow to the rivers.

Step 6: The rivers flow to the sea which is the most downhill place.

Step 7: Exchange positions of river with a stream which gives the best solution.

Step 8: Similar to Step 7, if a river finds better solution than the sea, the position of river is exchanged with the sea.

Step 9: Check the evaporation condition using the Psuocode.

Step 10: If the evaporation condition is satisfied, the raining process will occur.

Step 11: Reduce the value of dmax which is user defined parameter.

Step 12: Check the convergence criteria. If the stopping criterion is satisfied, the algorithm will be stopped, otherwise return to Step 5.

The Water cycle algorithm is easier to implement and it provides the global solution required for parameter optimization in complex engineering problems. It provides an optimal solution for the damping controller parameters, so that the system stability is enhanced to a greater extent possible.

V SIMLATION AND STABILITY ANALYSIS

For the modeling and simulation, MATLAB tool is used. In this work, the power system stabilizers are installed in the generator. The stimulated graph of system without PSS in speed deviation and power angle respectively, and Conventional Power System Stabilizer (CPSS) is compared with Water cycle Algorithm Power System Stabilizer (WCAPSS) in the figures (6, 7) respectively.

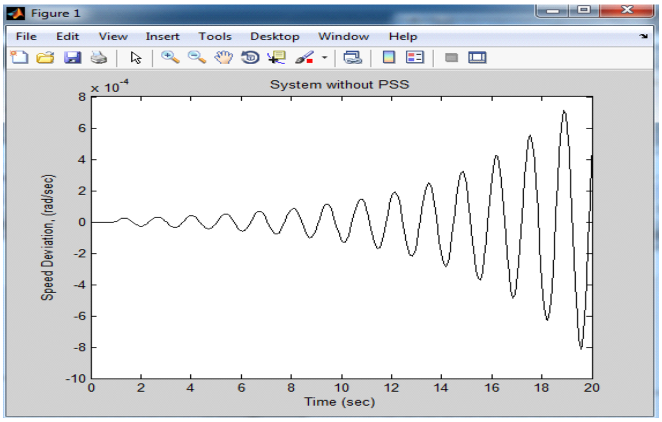

Fig.4. Speed deviation response of a system without PSS

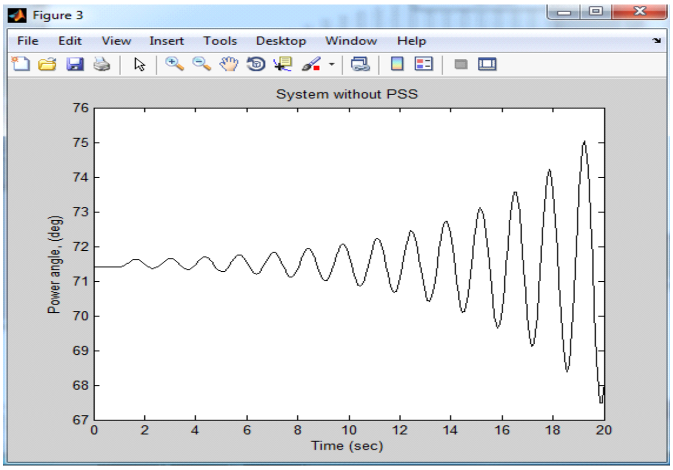

Fig. 5. Power angle response of a system without PSS

S.NO	OPERATING CONDITIONS	WITHOUT PSS	CPSS	WCA-PSS
1	P=1, Q=0.1 and ΔP_d =0.01p.u	**0.2966 ± 4.8628i** -10.3949 ± 3.4290i	-14.1448 -7.1461 ± 4.4872i **-0.0465 ± 4.8489i** -0.1001	-18.5538 -4.6662 ± 7.3193i **-1.1551 ± 4.3497i** -0.1004
2	P=1, Q=0.1 and ΔP_d =0.02p.u, 10% increase in M and Tdo1	**0.2803 ± 4.6255i** -10.3698 ± 1.3819i	-14.5637 -6.7712 ± 3.7803i **-0.0296 ± 4.6273i** -0.1001	-18.7470 -4.6187 ± 6.8452i **-1.0970 ± 4.1349i** -0.1005
3	P=0.9, Q=0.15, and ΔP_d =0.015p.u, 10% increase in exciter gain and time constant	**0.2302 ± 4.8184i** -9.4195 ± 5.3876i	-11.5951 -7.4993 ± 5.4010i **-0.0590 ± 4.7997i** -0.1001	-17.0254 -4.4797 ± 7.8585i **-1.1966 ± 4.2590i** -0.1005

Table I Closed loop Eigen values without PSS, CPSS and WCA based PSS

S.NO	OPERATING CONDITIONS		WITHOUT PSS			CPSS	WCA-PSS
		PO(p.u)	Ts(Sec)	PO(p.u)	Ts(Sec)	PO (p.u)	Ts (Sec)
1	P=1, Q=0.1 and ΔP_d=0.01p.u	0.06959	3.179	1.523	2.595	1.29	2.15
2	P=1, Q=0.1 and ΔP_d =0.02p.u, 10% increase in M and Tdo1	0.05074	3.205	1.033	2.622	0.071	2.229
3	P=0.9, Q=0.15, and ΔP_d =0.015p.u, 10% increase in exciterK_a and T_a	0.01819	3.374	0.035	2.729	0.0244	2.396

Table II Percent Overshoot and settling time in dynamic response for Speed Deviation

The performance of the system is evaluated by considering different operating conditions. The electromechanical modes and the damping ratios obtained for different conditions both with and without proposed controllers in the system are given in Table !. When Water cycle algorithm is not incorporated in PSS, it can be seen that some of the modes are poorly damped and in some cases, are unstable. It is also clear that the system damping with the proposed Water cycle based tuned PSS controller are significantly improved. Moreover, it can be seen that electromechanical mode controllability via Water cycle algorithm based PSS controller is higher than without PSS and CPSS based Controller. Table II and III shows the percentage overshoot and settling time in dynamic response for speed deviation and power angle deviation. The settling time is less for Water cycle based PSS Controller than other controllers.

The parameters of the damping controller are obtained using Water cycle algorithm. The Water cycle algorithm is made to run several times and then optimal set of stabilizer parameters is selected. The final values of the optimized parameters with and without Water cycle based PSS.

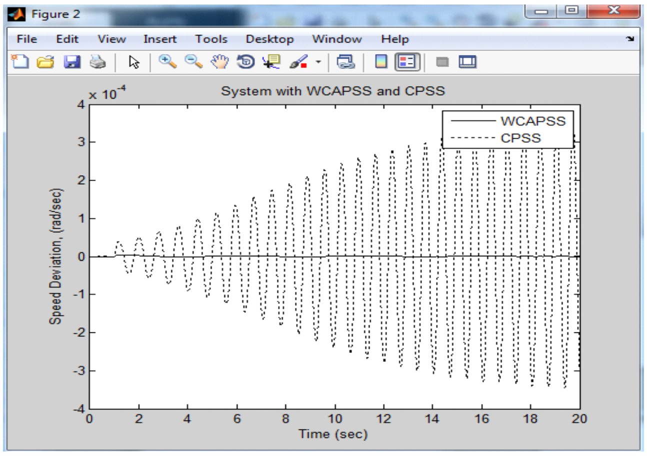

Fig.6.Speed deviation response of a system with WCAPSS and CPSS

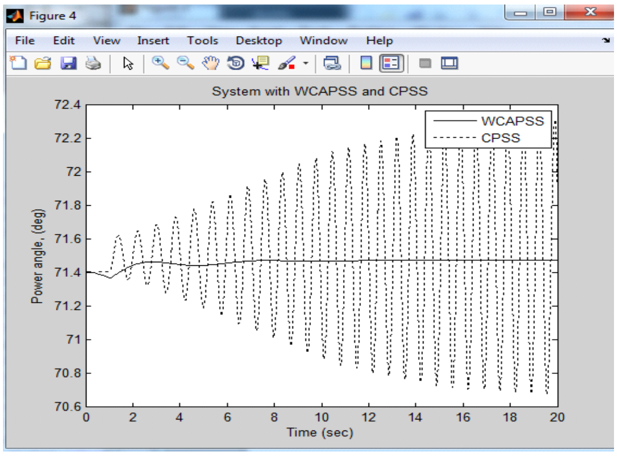

Fig.7.Power angle response of a system with WCAPSS and CPSS

S.NO	OPERATING CONDITIONS			WITHOUT PSS		CPSS	WCA-PSS
		PO(p.u)	Ts(Sec)	PO (pu)	Ts(sec)	PO (p.u)	Ts (Sec)
1	P=1, Q=0.1 and ΔP_d =0.01p.u	1.106	3.376	2.199	2.908	1.777	2.535
2	P=1, Q=0.1 and ΔP_d =0.02p.u, 10% increase in M and Tdo1	0.995	3.313	2.0215	2.581	1.717	2.285
3	P=0.9, Q=0.15, and ΔP_d =0.015p.u, 10% increase in exciter K_a and T_a	0.5255	3.376	1.120	2.796	0.77	2.439

Table III Percent Overshoot and settling time in dynamic response for Power angle deviation

The following are the dominant features of WCA based controller observed in this paper with regard to stability improvement.

Better placement of closed loop Eigen values in stable locations for all operating conditions involved.

Provide more damping to the system for all conditions. (i.e.)Damping ratios more than the threshold level (ξT= 0.07) and also more than the damping ratios of other controllers.

Rotor speed and power angle deviation overshoots are minimized and deviations are settled at a quicker time compared to other controllers for all conditions considered.

Optimal solution got at lesser iterations (generations) compared to others.

VI. CONCLUSION

This paper provides an efficient solution to damp the low frequency electromechanical oscillations experienced in the multi machine power system model. The salient features of the work carried out in this paper for multi machine system stability enhancement are as follows:

The stability analysis has been carried out based on the computed Eigen values, damping ratios and also based on the error deviations minimization.

Also, oscillations damping analysis involving wide variations in operating conditions have been performed based on the damping performance of the proposed controllers.

A detailed state space modeling of the test power system has been performed. In order to compute the optimal controller parameters, a tri objective optimization criterion has been formulated and the proposed algorithms have been implemented effectively.

Multi machine power system stability is improved to a greater level.

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