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GWO Optimized Single Machine Infinite Bus System & Two Area Four Machine System

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Abstract— Low frequency oscillations cause a disturbance in power system and it is very common. Hence it is important to study and present good solution for it. In the presented piece of work low frequency oscillation issue has been addressed with the help of two different model of power system i.e. with single machine infinite bus system (SMIB) and with multi machine system (MMPS). The first type of model utilizes the Static Synchronous Series Compensator (SSSC) as damping controller and it is then further optimized by the use of Grey Wolf Optimization (GWO) technique. It was analyzed under nominal, light and heavy loading conditions. Then it was simulated in MATLAB and its results were compared with SMIB with no controller and with CPSS based SMIB. In the second type of power system Kundur two area four machine system is considered. Each machine utilizes Power System Stabilizer (PSS) as its damping controller and is being optimized by GWO for better response. It was examined for Inter area mode of oscillation, Local area mode of oscillation & plus change in speed effect was observed for all the machines. The results after simulation of it are compared with MMPS using no controller and with CPSS only.

Keywords— Power System; Power System Stabilizers (CPSSs); Single Machine Infinite Machine System; Two Area Four Machine System; Grey Wolf Optimization (GWO)

I. INTRODUCTION

A. Introduction

Demand for power has increased rapidly and is difficult to meet. Therefore, the solution is to connect multiple power systems together. These are tied across the leashes and are usually inherently weak. This is the reason for the introduction of low frequency oscillations; if they persist, this may result in a loss of synchronization. To eliminate these vibrations, a damping controller is required. This has led to a more thorough inspection and analysis of the power system to ensure stability within limits and safety. Keeping the power system away from its stability limits allows for better dynamic control of the entire system. Other studies have been conducted in this area to study the stability of problems. One of the ways to deal with it is the use of conventionally used PSS (CPSS) for damping this low frequency oscillation. But it has its disadvantages too. It was overcome with the help of optimizing PSS and using the other devices for damping. With advent in power electronics FACTS (Flexible AC transmission) devices has also found its place in it.[5]

FACTS increases the reliability of alternative networks and reduces power, quality and transmission costs. FACTS has several advantages, such as: Stabilization time, vibration damping, stability and tension. Depending on the type and equipment, as well as the specific voltage level and local network conditions, the FACTS installation can increase the transmission capacity from 40 to 50%. FACTS orders are not subject to wear and require less maintenance. [8]

In the present context SMIB has been developed which utilizes SSSC as its damping controller. As it has already been used for the similar purpose and is quite been optimized several times by Genetic algorithm, fuzzy logic like optimization techniques, this time a fresh technique is used which is Grey Wolf Optimization (GWO) technique. It was analyzed under nominal, light and heavy loading conditions. Then it was simulated in MATLAB and its results were compared with SMIB with no controller and with CPSS based SMIB.

To further study the low frequency oscillation issue the system is extended from single to multi area. Now it has two area and each area has 2 machine in it. It is basically a Kundur 2 area 4 machine system. Each machine utilizes PSS as its damping controller and is being optimized by GWO for better response. It was examined for Inter area mode of oscillation and Local area mode of oscillation plus change in speed effect was observed for all the machines.

B. Objective Function

The problem is given as an integral time absolute error of the speed deviations $\Delta\omega$. The objective function to be minimized is termed as J and is given as below,

For SMIB

$$J = \int_0^{t_{sim}} |\Delta\omega| dt \tag{1}$$

For multi machine system

$$J = \int_{t=0}^{t=t_{sim}} (\sum |\Delta\omega_{14}| + \sum |\Delta\omega_{34}|) \cdot t \cdot dt \tag{2}$$

$\Delta\omega_{14}$ =inter area $\Delta\omega$, $\Delta\omega_{34}$ =Oscillations local modes, t_{sim} = Simulation time range

Therefore, the problem of design focuses on minimizing of both the fitness function at the same time which are bounded by the set of parameters as shown below[25][20],

$$K_i^{min} \leq K_i \leq K_i^{max} \tag{3}$$

$$T_{1i}^{min} \leq T_{1i} \leq T_{1i}^{max} \tag{4}$$

$$T_{2i}^{min} \leq T_{2i} \leq T_{2i}^{max} \tag{5}$$

$$T_{3i}^{min} \leq T_{3i} \leq T_{3i}^{max} \tag{6}$$

$$T_{4i}^{min} \leq T_{4i} \leq T_{4i}^{max} \tag{7}$$

II. SYSTEM MODEL

A. SMIB System with SSSC Controller

The proposed model of SMIB system with SSSC controller is shown in fig. 1 below. The system comprises a generator connected to an infinite bus. The generator presented by SG and generator terminal voltage is presented by V_t & infinite bus voltage presented by V_b . The SSSC containing a transformer, voltage source inverter & dc-storage capacitor. The SSSC injected voltage to transformer is V_{Bt} . The voltage source converter have two control variables as modulation index m_b & phase angle δ_b . [8]

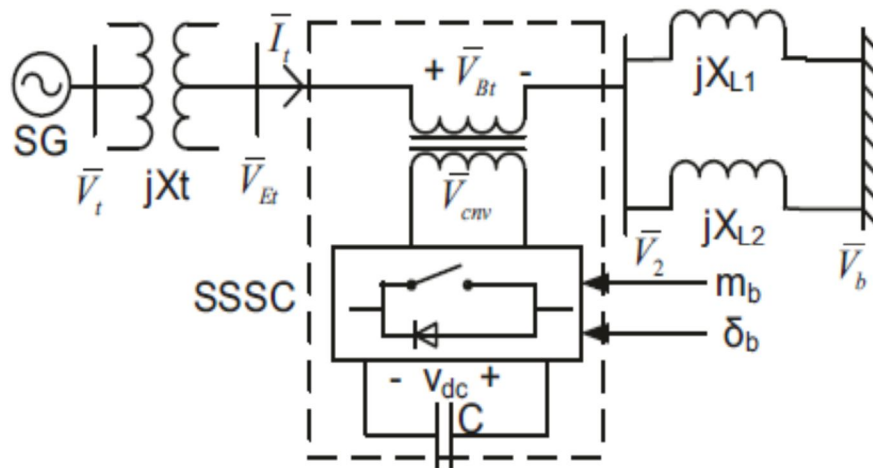


Fig.1: SMIB System with SSSC[3]

B. Kundur Two Area Four Machine System

Fig.6.4 shows two area and four generator G_1, G_2, G_3 & G_4 where area 1 connected generator G_1, G_2 & area2 connected generator G_3, G_4 . Each generator connected with transformer. In this system two areas connected through tie lines. All the generators are connected with governors and turbines, which excitors. The system response shows two types of conditions as inter-area mode of oscillation and local-area mode of oscillation.[4]

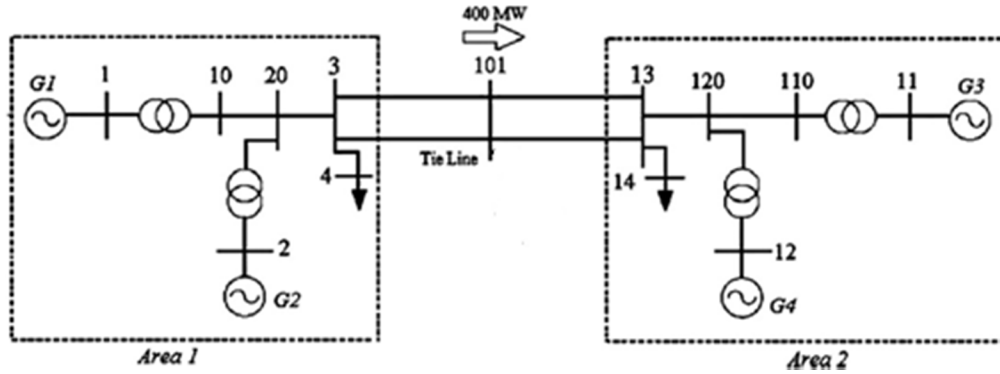


Fig.2: Single Line Diagram of Two Area Four Machine Systems [31]

C. Power System Stabilizer (PSS)

The power system considered here for study receives control command from PSS via exciter. The excitation system with PSS taken here is IEEE type STI.[4]

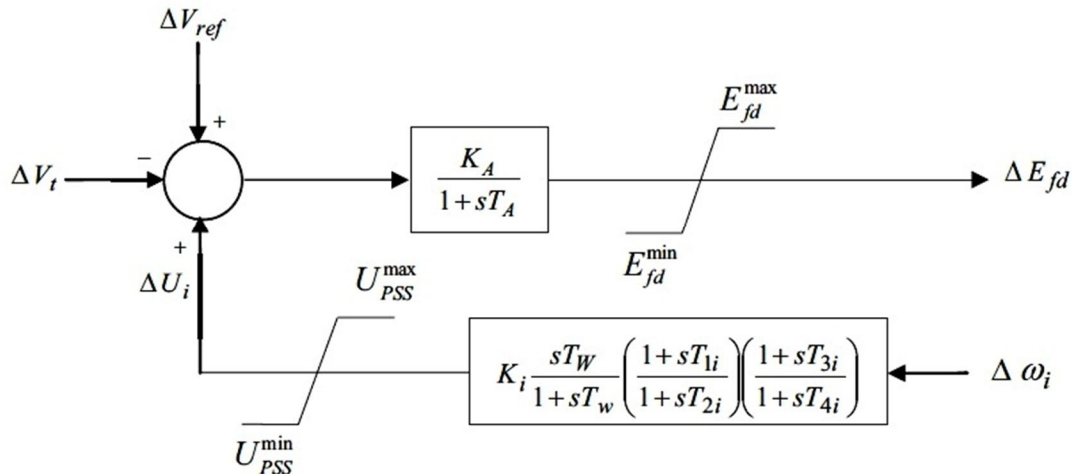


Fig.3: Structure of Excitation System with PSS

The output of PSS V_{PSS} is provided to excitation system where it will add to V_{ref} which is the reference voltage of excitation system.

III. PSS TUNED BY GWO

A. Grey Wolf Optimization (GWO)

This optimization technique is given by Mirjalili. It imitates the grey wolf hierarchy leadership as they are known for group hunting[11].

It is among the newest set of meta-heuristic optimization algorithms. It was developed for solving the double layer grids problem which takes into account the non linearity. Its results are superior to the other algorithms in set. For the first time to learn Multi Layer Perception (MLP) it was used.

B. Mathematical model and Algorithm

It is a versatile algorithm. Wolves lives in social pack and hunts too in pack. This is the very appealing behavior of algorithm. GWO mimics this. Here is the outline of the process showing how it does it[1].

1) *Social Hierarchy*: The fittest solution is Alpha (α), second best solution is Beta (β) and third best solution is Delta (δ). Apart from these all the candidate solutions falls under Omega (ω).

2) Prey Encircling:

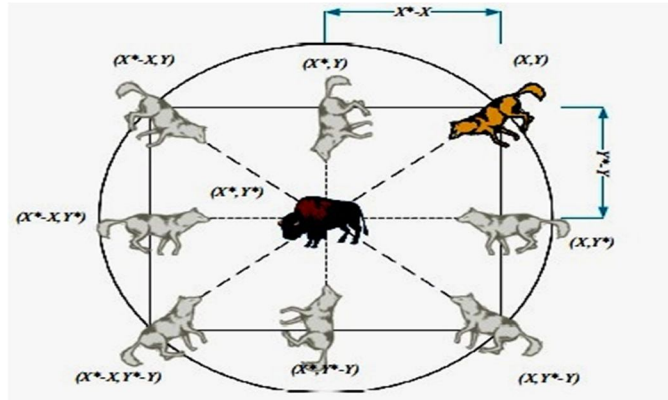


Fig. 4: 2D position vector with possible next location

In the above fig.4, it is clear that as the position of prey (X^*, Y^*) changes a grey wolf will also change its position (X, Y). Adjustment in \vec{A} and \vec{C} different places around the best agent is reached w.r.t. present position. Like, to reach (X^*-X, Y^*) , $\vec{A}=(1,0)$ and $\vec{C}=(1,1)$ is set.

- 3) *Hunting*: To simulate the hunting by grey wolf mathematically, it is assumed that the Alphas i.e. best candidate solution; beta and delta have the better knowledge regarding prey possible location.
- 4) *Attacking*: The moment prey stop moving, grey wolf initiate attacking it i.e. the step after hunting. It is the process of exploitation. The value of \vec{a} is reduced so as to get mathematical realization of it.

C. GWO Flow Chart

Fig.5 shows flow chart of gray wolf optimization technique

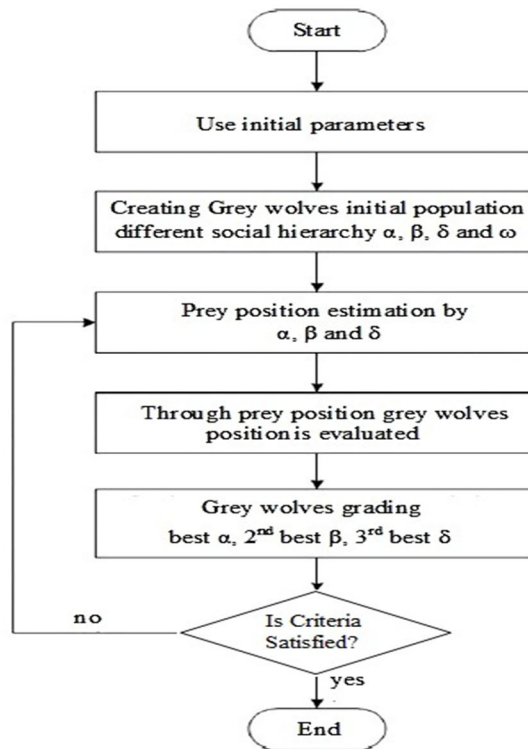


Fig.5.: GWO Flow Chart

IV. RESULT AND DISCUSSIONS

The simulation studies are carried out is a single machine infinite bus (SMIB) system and multi-machine system. SMIB system the behavior of the system find out three conditions as no control, with CPSS & SSSC tuned by GWO technique, is tested under different operating conditions viz., nominal loading, light loading, heavy loading. In different loading conditions system tested with two cases. In multi-machine system we tested system with local area mode of oscillation and inter-area mode of oscillation & generator deviation without controller, with CPSSs & GWOPSS. SMIB and MMPS both systems developed in MATLAB/SIMULINK situation and system implement by GWO algorithm.

A. Condition-1 SMIB System

Table 1 & 2 shows the SSSC parameters optimized by GWO algorithm and different loading condition values.

Table 1: SSSC Controller Parameters for SMIB System Tuned by GWO[6]

S.N.	System	SSSC Parameter Tuned by GWO				
		K	T ₁	T ₂	T ₃	T ₃
1.	SMIB System	700	10	2.4068	0.3246	0.759693

Table 2: Parameters of Various Loading Conditions

S.N.	Loading Conditions	P _e (p.u.)	Q _e (p.u.)	V _t (p.u.)
1	Nominal	1.0	0.127	1.0
2	Light	0.8	0.0808	1.0
3	Heavy	1.2	0.6068	1.1

Fig.6 shows the convergence rate of objective functions of SMIB system.

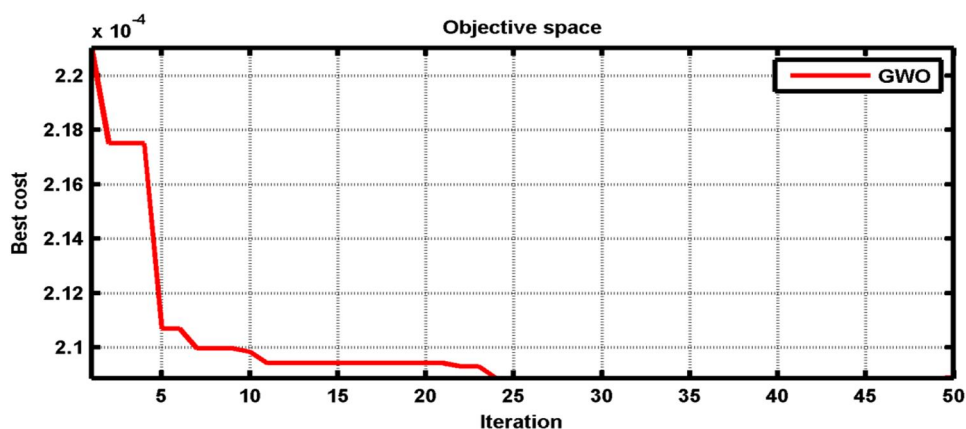


Fig. 6: Convergence of Objective Function for Best Cost in SMIB System

- 1) *Case-1 A Mechanical Torque Input 0.2 p.u. is Applied at 1.0 Sec and Removed at 1.083 Second at Nominal, Light & Heavy Loading Condition:* Initially, SSSC has no controller for damping then CPSS & gray wolf optimization(GWO) tuned SSSC controller is used when the system applies a case-1. For these cases, the various response find out as the rotor speed deviation, active power response & terminal voltage response with time are shown in fig.7 to 9. Without controller the rotor speed and active power, & terminal voltage response is oscillatory but system response under controller show satisfactory result and GWO

optimized SSSC controller settle down very fast and result obtain at very good conditions. Table3 shows comparison table of various response.

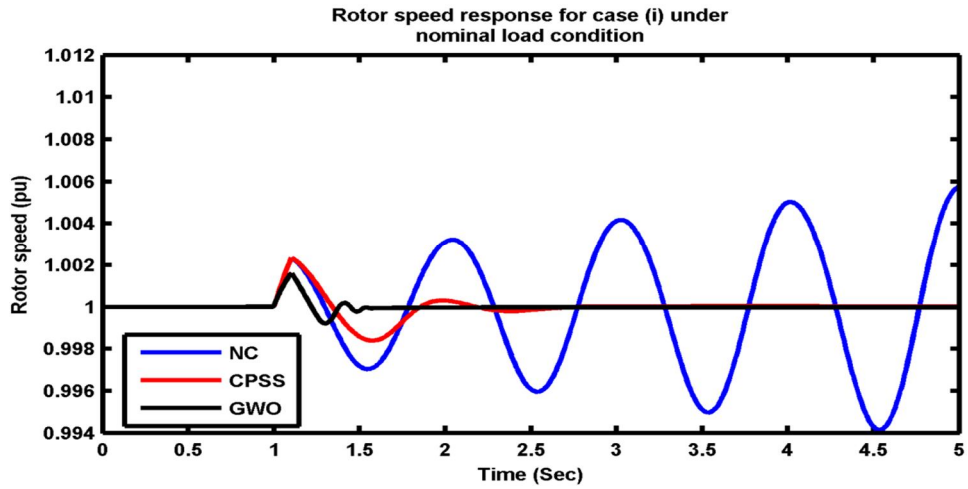


Fig. 7: Rotor Speed Response under Nominal Condition for Case-1

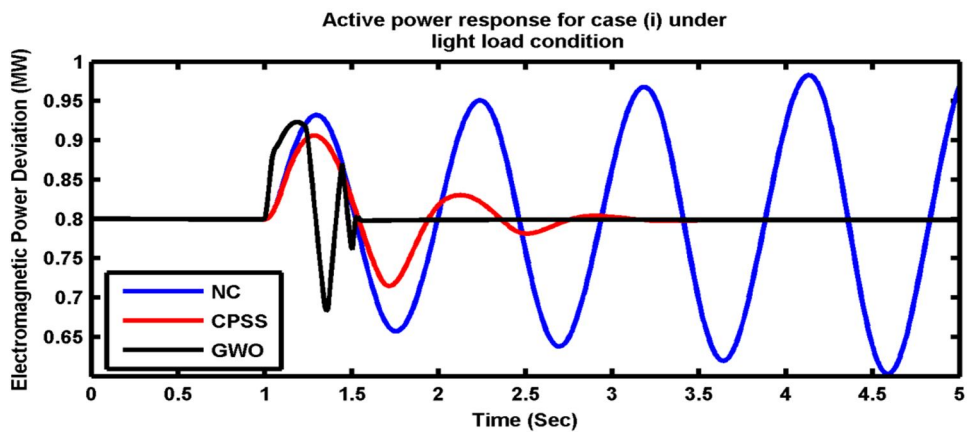


Fig. 8: Active Power Response under Light Loading Condition for Case-1

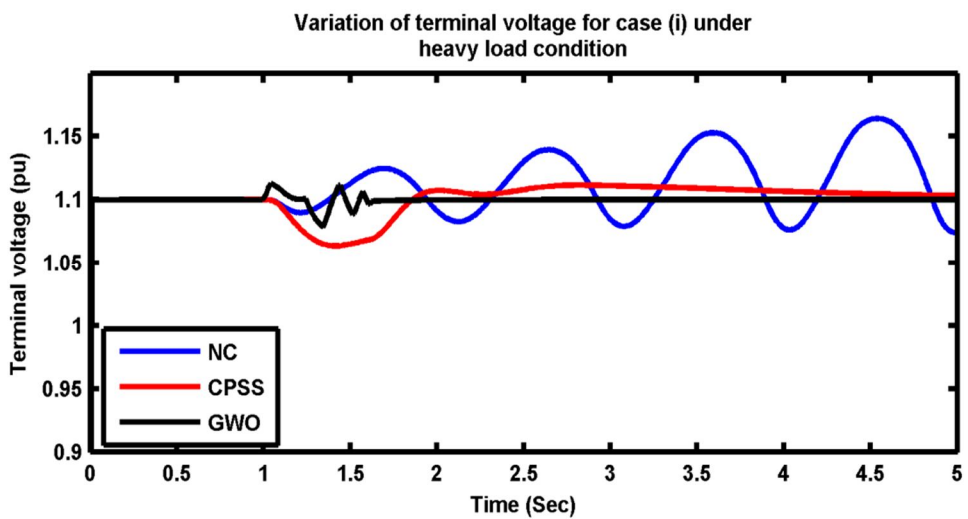


Fig. 9: Terminal Voltage Response under Heavy Loading for Case-1

Table-3 Various Response with Different Loading with Case-1

S.N.	Types of Response	Without SSSC (Settling Time) Seconds	With CPSS (Settling Time) Seconds	With GWO SSSC (Settling Time) Seconds
1.	Rotor Speed	Highly Oscillatory	2.6984	1.6839
	Active Power	Highly Oscillatory	3.0804	1.5385
	Terminal Voltage	Highly Oscillatory	2.8766	1.5913

2) *Case-2: Three Phase Short Circuit Fault Applied at The Middle of Transmission Line a 1.0 Second and the Fault Cleared at 1.083 Sec at Nominal, Light & Heavy Loading Condition:* The various response as rotor speed response, active power response & terminal voltage response with time are shown in fig.10 to 12. We apply three phase fault at middle of transmission line. Without controller system not stable and show very high oscillatory response and then applied CPSS controller response better but not satisfied. Finally GWO SSSC controller system improve the system stability and settle very fast. Table 4 shows a comparison table of the different controller.

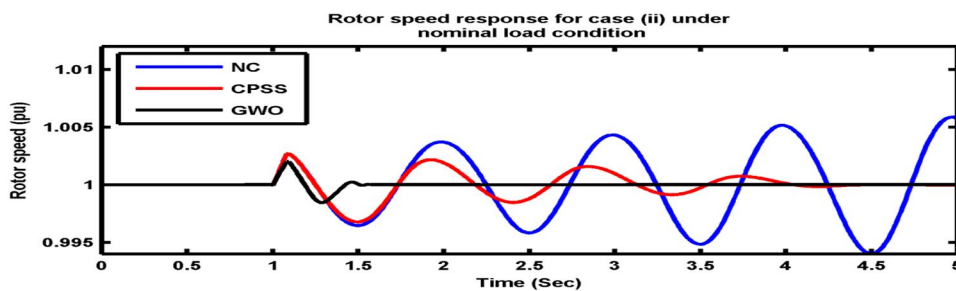


Fig. 10: Rotor Speed Response under Nominal Condition for Case-2

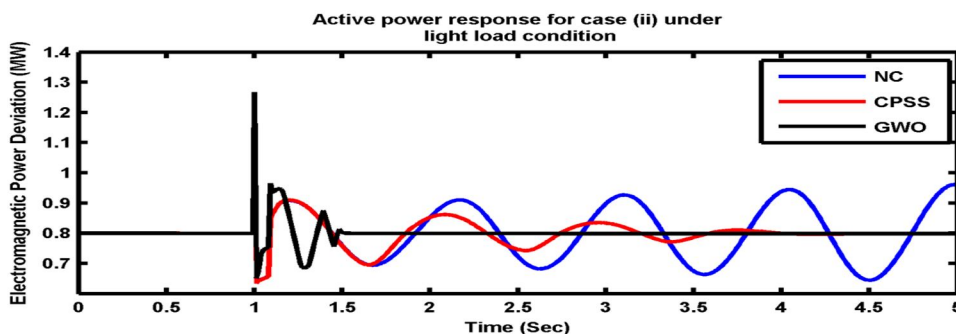


Fig. 11: Active Power Response under Light Loading Condition for Case-2

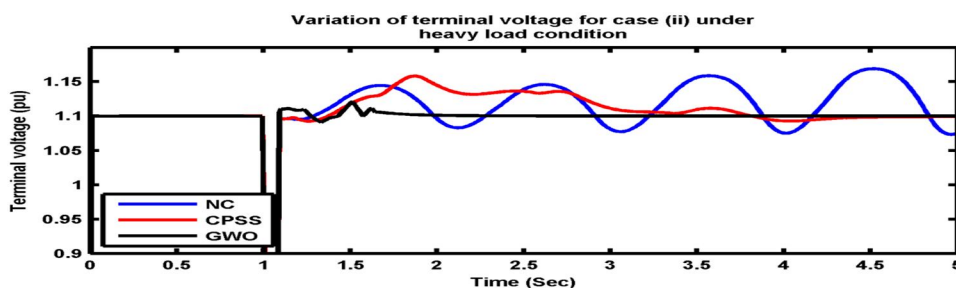


Fig. 12: Terminal Voltage Response under Heavy Loading Condition for Case-2

Table-4 Various Response with Different Loading with Case-2

S.N.	Types of Response	Without SSSC (Settling Time) Seconds	With CPSS (Settling Time) Seconds	With GWO SSSC (Settling Time) Seconds
1.	Rotor Speed	Highly Oscillatory	4.3264	1.5372
	Active Power	Highly Oscillatory	3.9130	1.4893
	Terminal Voltage	Highly Oscillatory	2.8766	1.5913

B. Condition-2: Multi-Machine System(Kundur Two Area Four Machine System)

Fig. 13 shows the convergence rate of objective functions of MMPS system & table 5 shows PSS parameters optimized by GWO

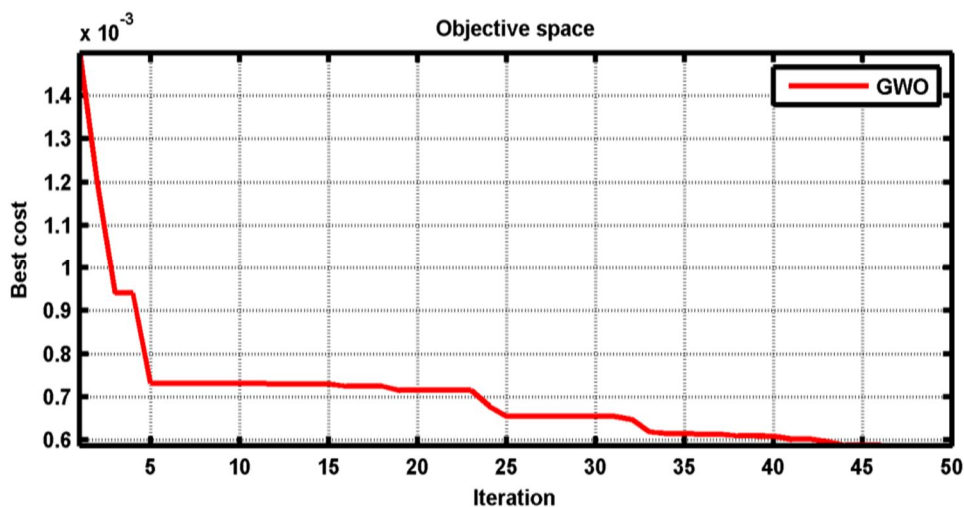


Fig. 13: Convergence of Objective Function for Best Cost in Multimachine System

Table 5: PSS Parameters Tuned by GWO in MMPS System

S.NO.	Number of PSS	Parameters of PSS				
1	PSS ₁	K ₁₁	T ₁₁	T ₁₂	T ₁₃	T ₁₄
		37.5870	0.0537	0.0324	3.6963	5.6933
2	PSS ₂	K ₂₁	T ₂₁	T ₂₂	T ₂₃	T ₂₄
		35.265	0.0497	0.0212	3.569	6.214
3	PSS ₃	K ₃₁	T ₃₁	T ₃₂	T ₃₃	T ₃₄
		68.7228	0.0669	0.0293	2.2303	5.6745
4	PSS ₄	K ₄₁	T ₄₁	T ₄₂	T ₄₃	T ₄₄
		82.0414	0.0518	0.0244	3.4792	5.1969

1) *Nonlinear Time –Domain Simulation:* There is so many time domain simulation is presented at Kundur two area four machine system. The PSS parameters of all machine is optimized with CPSS & GWO algorithm. In this condition a 100 ms three phase fault applied. The fault applied only 0.1 second. The various response analyses as inter-area mode of oscillation, local-area mode of oscillation & speed deviation of generator G₁ to G₄.

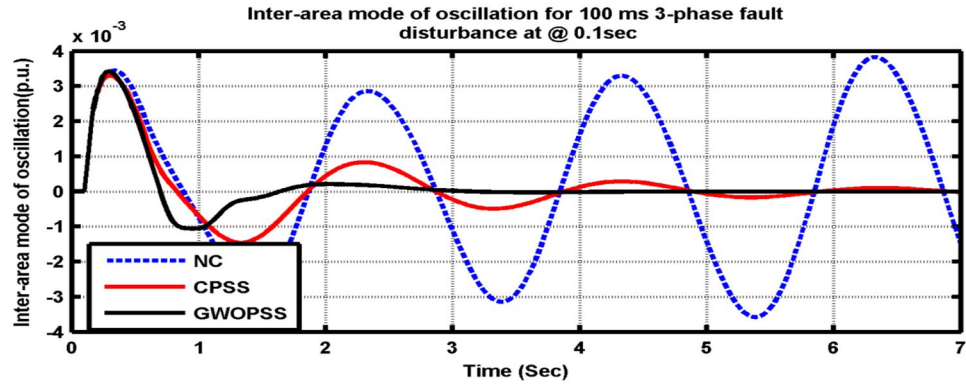


Fig. 14: Inter-Area Mode of Oscillation in Three Machine System for 3-Phase Fault

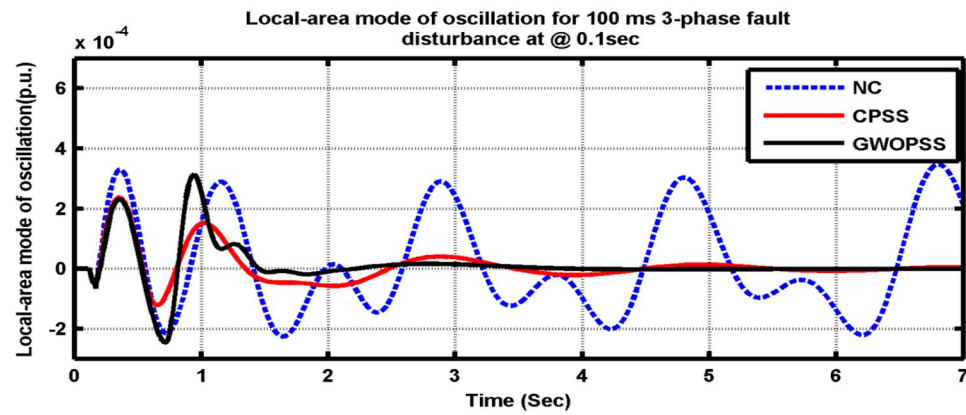


Fig. 15: Local-Area Mode of Oscillation in Three Machine System for 3-Phase Fault Disturbance

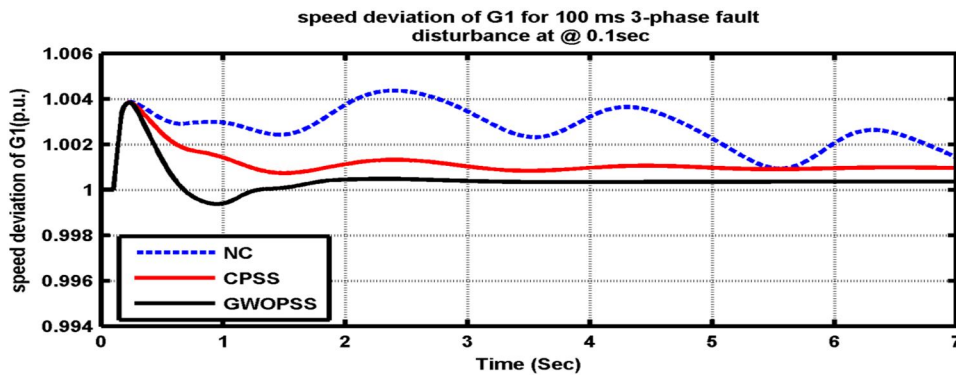


Fig. 16: Speed Deviation of Generator G_1 for 3 Phase-Fault Disturbance

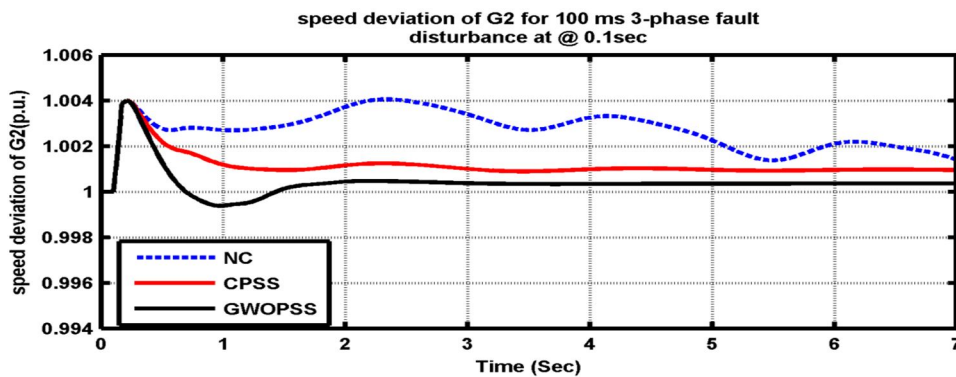


Fig. 17: Speed Deviation of Generator G_2 for 3 Phase-Fault Disturbance

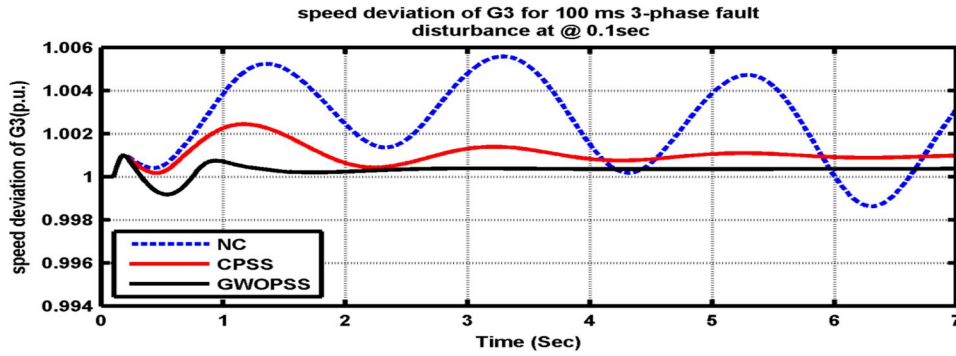


Fig. 18: Speed Deviation of Generator G₃ for 3 Phase-Fault Disturbance

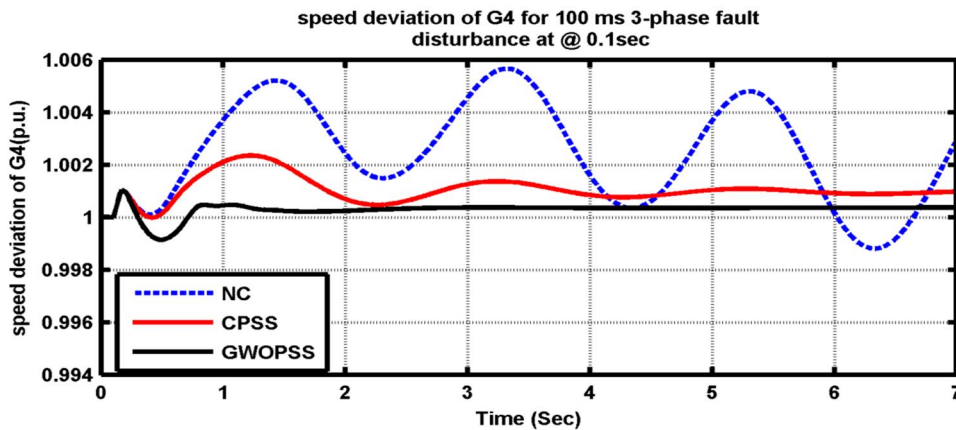


Fig. 19: Speed Deviation of Generator G₄ for 3 Phase-Fault Disturbance

Table 6.: MMPS System under Three-Phase Fault Condition

S.N.	Types of Oscillation	Without Controller (Settling Time) Seconds	With CPSS Controller (Settling Time) Seconds	With Coordinated (SSSC+PSS) Tuned by GWO (Settling Time) Seconds
1	Inter-Area Mode of Oscillation	Highly Oscillatory	6.7125	2.7738
	Local-Area Mode of Oscillation	Highly Oscillatory	6.5053	3.5285
	Speed Deviation of Generator G ₁	Highly Oscillatory	4.8013	2.6970
	Speed Deviation of Generator G ₂	Highly Oscillatory	4.6205	2.5500
	Speed Deviation of Generator G ₃	Highly Oscillatory	6.8120	2.5177
	Speed Deviation of Generator G ₄	Highly Oscillatory	6.8183	2.6270

IV. CONCLUSIONS

In this paper, the results of the developed SMIB & multi machine system model under different contingencies are presented and discussed. The various types of waveform presented at SMIB system at different loading conditions at rotor speed response, active power & terminal voltage without & with CPSS & GWO SSSC controller. All loading as nominal, light & heavy loading cases system shows superior response when using GWO technique. In multi machine system apply two area four machine systems at various mode inter-area mode of oscillations, local area mode of oscillation, speed deviation of generator G_1 to G_4 . Finally the system show robust performance when apply various types of disturbances & loading. The SMIB System also tested with CPSS & GWO tuned SSSC controller. The MMPS system tested with CPSS & GWOPSS controller & so finally when the system tested with show fine response and improves stability of the system. Table 1 to 6 shows various comparison tables and also compare with a different controller. Table also proves that finally damping remove of the system very easily when planned proposed controller.

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