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Small Signal Stablity Analysis in SMIB & 3 Machine 6 Bus System using GWO Optimization Technique

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***Abstract:** A power system is a complicated network which has the task of fulfilling various consumer power demands continuously. But in its process too many disturbances occurs. These disturbances may be a common single line to ground fault, double line, double line to ground fault, three phase fault or it could be small signal disturbances. To eliminate it is utmost importance to resume the continuity of power supply which in turn ensures its reliability. Hence, a power system is always equipped some kind of controllers to come back to its original operating status after this disturbances.*

Here, a SMIB system more specifically a Modified Phillip-Heffron's model is presented which has Static Synchronous Series Compensator (SSSC) as the controller. To further improve its dynamic performance a nature inspired optimization technique is utilized. This is Grey Wolf Optimization (GWO). The system is tested for electrical power deviation, power angle deviation and speed deviation under two different cases. The first case is when reference voltage setting is increase by 5% step and the second case is the step increase of 10% in mechanical torque. The results of GWO based SSSC are compared and tabulated with SMIB without any controller and with Gravitational Search Algorithm (GSA) based SSSC.

The further analyses consider the more real scenario of multi machine system (MMPS) which has 3 machine and 6 bus. It utilizes GWO based coordinated damping controller consisting of SSSC and PSS. This model is tested under different fault conditions as mentioned above and then its results are compared with MMPS without any controller and with conventional power system stabilizer (CPSS). For simulation both the above model of SMIB and MMPS MATLAB/SIMULINK is used.

Keywords: Power System:Power System Stabilizers (CPSSs); Single Machine Infinite Machine Systam;3 machine 9 bus System: Grey Wolf Optimization (GWO)

I. INTRODUCTION

A. Introduction

Load demand has been increasing at a fast rate and it is difficult to fulfill it. Hence, the solution for it is to interconnect many power systems together. These are tied via the tie lines and usually these are weak in nature. This is the reason for the introduction of low frequency oscillations and if these persist can cause loss of synchronism. To eliminate these oscillations a damping controller is required[2]. This has led to take a closer look and analysis the power system so as to maintain its stability within the margin while maintain its security. Previously, keeping the power system away from its stability limits ensure the better dynamic control over the whole system. Other studies were also carried out in the area so as to address the problem stability.

There are namely these types of stability in power system, large and small signal. Large signal stability is also known as transient stability. In case of small signal stability when there is no proper damping it occurs. While when power system encounters the serious transient disturbance like short circuit or the tripping of line it is the case of large signal stability. Starting Operating state and severity of disturbances influences the stability. The configuration of the system is so set in order to be in the stable state following set of chosen contingencies [1]. With the development of new and better technology to tackle this issue, we now have Flexible AC transmission devices (FACTS). These are electronic based modern devices. This family of devices has the capability of controlling the factors which affects the performance of the power system. It has ability of repeatability and smoother control resulting in less response time and efficient. The following work is more focused around compensating series reactance of the line in order to improve the stability especially transient stability. The big family of FACTS includes Static Synchronous Series Compensator (SSSC), Interline Power Flow Controller (IPFC), Thyristor Controlled Series Capacitor (TCSC), Thyristor Switched Series Capacitor (TSSC), Thyristor Controlled Series Reactor (TCSR) and Thyristor Switched Series Reactor (TSSR). But here SSSC has been chosen to show its usefulness in addressing the given problem of stability [15].

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There number of techniques where SSSC has been associated with several optimization techniques like particle swarm optimization (PSO), genetic algorithm (GA), fuzzy logic etc. A new technique is discussed to achieve the given goal which is known as Grey Wolf Optimization (GWO). This algorithm is based on the social behavior of the grey wolf pack. The process is inspired from the various features of social pack of these creatures for hunting and preying. This kind of problem in single machine Infinite bus (SMIB) system can be solved with much ease as compared to the system where more than one machine is involved i.e. a multi machine system. It is more practical system where observation of such problems can lead to practical solution. Although, SMIB study did give the idea of characteristics of machine subjected to different conditions. The following context consists of two work theory, one is related to SMIB and other is related to Multi Machine Power System (MMPS). In SMIB the low frequency oscillations are damped out with the implementation of SSSC which is optimized using the GWO algorithm. In the next set of section a MMPS model is developed in which conventional Power system Stabilizer (CPSS) is used is integration with SSSC for inter area oscillation. This MMPS designed with 3 machine interlinked by 6 buses. The machines are named G_1, G_2, and G_2. Here, the power system is modeled with CPSS coordinated by SSSC which is tuned using GWO and to compare it was also simulated with CPSS only and without it. The results have been tabulated and compared with different conditions[7].

B. Objective Function

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

For SMIB

$$J = \int_0^{t_1} |\Delta\omega| . t . dt \quad (1)$$

For multi machine system

$$J = \int_0^{t_1} \left(\sum|\Delta\omega_L| + \sum|\Delta\omega_I|\right) . t . dt \quad (2)$$

$\Delta\omega_L$=inter area Δω

$\Delta\omega_I$=Oscillations local modes

t_1= 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],

$K_i^{min} \leq K_i \leq K_i^{max}$ (3)

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

$T_{2i}^{min} \leq T_{21i} \leq T_{2i}^{max}$ (5)

$T_{3i}^{min} \leq T_{31i} \leq T_{3i}^{max}$ (6)

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

II. SYSTEM MODEL

A. Power System with SSSC linear Dynamic Model

The linearization of nonlinear model gives the linear Heffron-Philips model of a SMIB systemincluding SSSC around a nominal 0perating point.

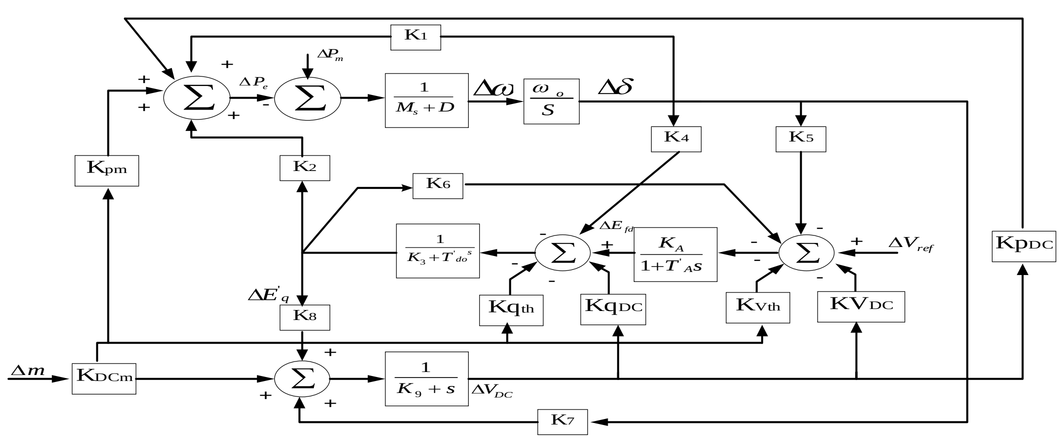

Fig.1: Heffron-Phillips model along SSSC[3]

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B. Multi Machine Power System

In the above single line diagram there are three generating units G1, G2 and G3. Also, there are 6 buses in the system (B1, B2, B3, B4, B5, B6). G1 is considered to be the largest unit out of the three which is connected to B1 and hence it is the slack bus. G2 and G3 are connected on bus B2 and B3 respectively. Load 1, 2, 3 and 4 are the loads connected on bus bar 1, 2, 3 and 4.

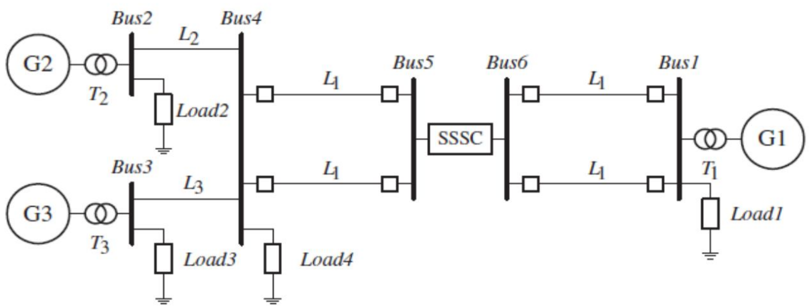

Fig.2: 3 Machine 6 Bus System Single Line Diagram[8]

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

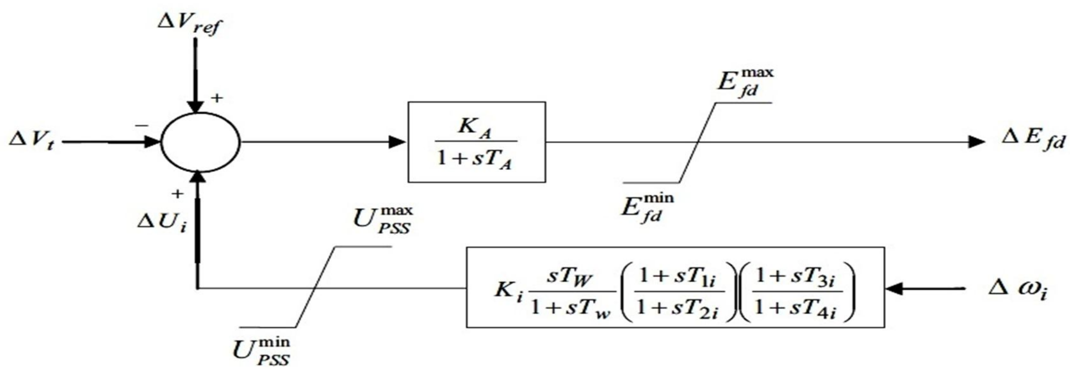

Fig.3: Structure of Excitation system with PSS

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[12].

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.

With reference to the above statement these wolfs live pack and are basically from canidae family. As these, live in pack they have a leader who is Alpha indicating their strict social dominant hierarchy. As Alpha is the leader, most of the decision for group is taken by him. And, hence his decision should be followed by other members of the pack. The common decision involves sleeping place, hunting, waking time etc. The Alpha may not be the strongest member of the pack but the best to manage the whole group. This implies that the discipline and organization in the pack is considered prior to the strength[10].

Group hunting is among the many features of their social environment. The main phases in hunting are,

1) Tracking the prey, then chasing them and at last approaching them.
2) The act of pursuing, encircling and harassing of prey until it stop moving.
3) Last is attack on prey.

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B. Algorithm Pseudo code and GWO Flow Chart

1) Grey wolves population is created initially let it be X_i (i=1,2, ..., n)
2) α, A and C is initialized.
3) Search agent fitness is calculated, X_α= best search agent X_β= 2nd best search agent X_δ= 3rd best search agent
4) while (t< maximum iteration count)

for each search agent

Current search agent position is updated by

$\vec{X}(t+1) = \frac{\vec{X}_1+\vec{X}_2+\vec{X}_3}{3}$

end for

α, A and C are updated

all search agents are fitness are calculated

X_α, X_β and X_δ are updated

t=t-1

end while

return X_α

IV. RESULT AND DISCUSSIONS

In this section, the results of the developed simulation model under different contingencies are presented and discussed. There are two types of the proposed model as a single machine infinite bus system & multimachine system. In SMIB system define with Modified Heffron-Phillips model with SSSC. The result tested with two cases 5% step increase in reference voltage settings & 10% step increase in mechanical torque power input at a different speed, power angle, electrical power angle deviation at without controller, with GSA, with GWO technique. In multimachine system define with 3 machine 6 bus system & tested at various cases three-phase fault, double line to ground fault(L-L-G),line to ground fault(L-G),line to line fault(L-L),line outage, small disturbance, signal transmission delay at various mode inter-area mode of oscillations, local area mode of oscillation, variation of SSSC injected voltage.

A. Case-1 SMIB System

Table1: SSSC Parameters Tuned by GWO

S.N.	System	SSSC Parameter Tuned by GWO		
		K	T_1	T_3
1.	SMIB System	73.4989	0.0036159	0.0428

Fig. 4 shows the convergence rate of objective functions of SMIB system.

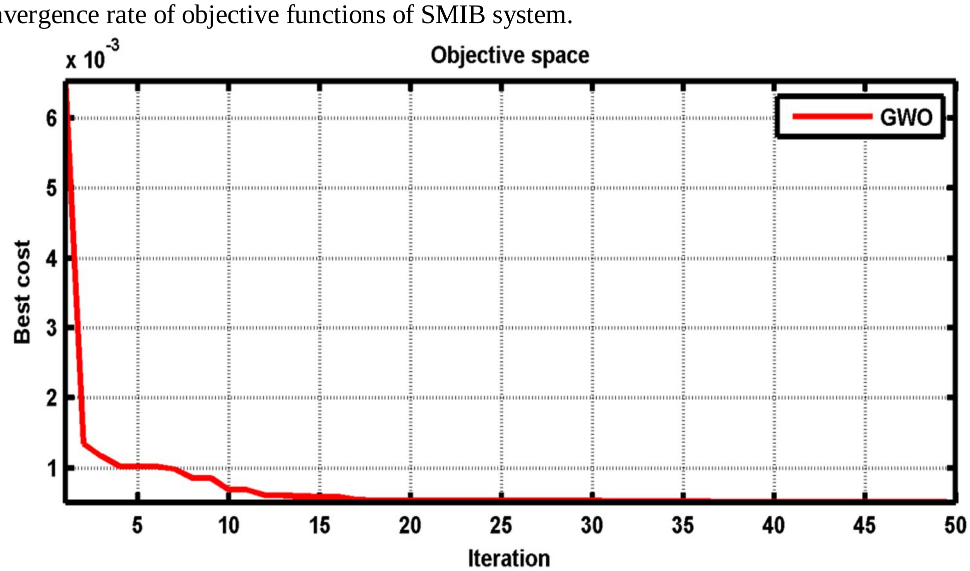

Fig. 4: Convergence of Objective Function for Best Cost in SMIB System

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1) *Case-1 10 % Step Increase in Mechanical Torque Input & 5 % Step Increase in Reference Voltage Setting:* For completeness, the effectiveness of the SSSC controllers is additionally tested by considering a disturbance in mechanical torque input & reference voltage setting. The reference voltage setting (V_{ref}) & mechanical torque input is increased by a step of 10% & 5% at t =1 s. Finally, SSSC tuned by GWO shows superior response & improve the stability of the power system. These positive results of the proposed GWO optimized SSSC based controller can be attributed to its faster response with less overshoot compared to that of GSA

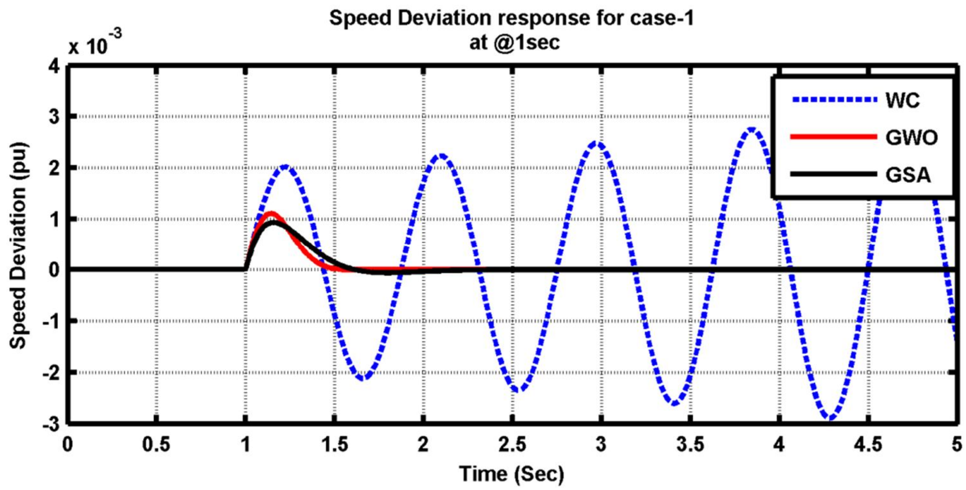

Fig. 5: Speed Deviation in SMIB System for Mechanical Torque Input

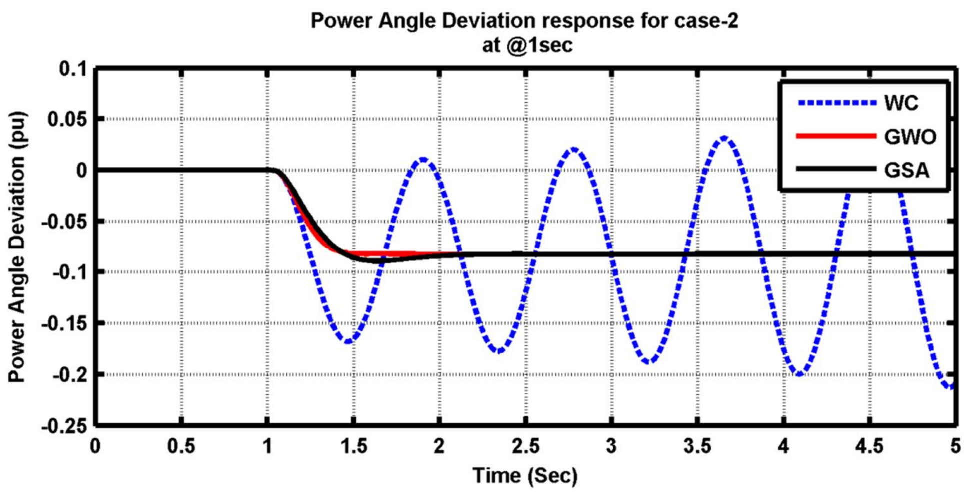

Fig. 6: Power Angle Deviation in SMIB System for Reference Voltage Setting

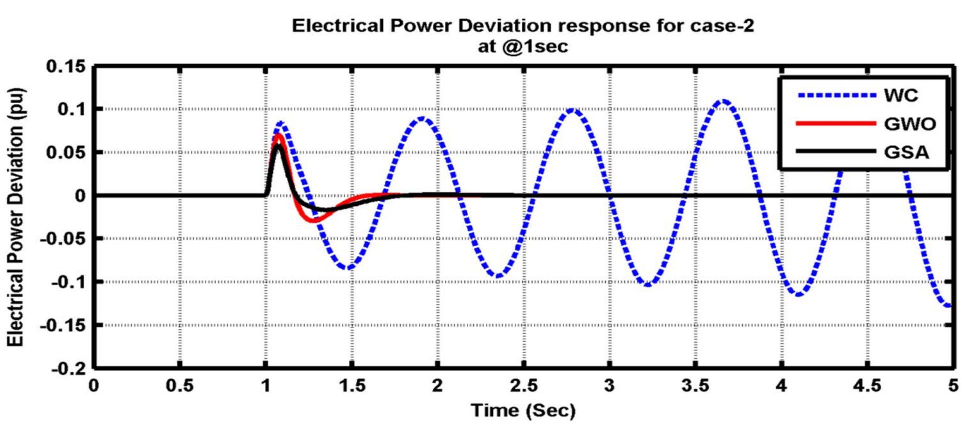

Fig. 7: Electrical Power Deviation in SMIB System for Reference Voltage Setting

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Table 2: 10% Step Increase in Mechanical Torque Input 5 % Step Increase in Reference Voltage Setting at SMIB System

S.N.	Types of Deviation	Without SSSC (Settling Time) Seconds	With GSA SSSC (Settling Time) Seconds	With GWO SSSC (Settling Time) Seconds
1.	Speed Deviation	Highly Oscillatory	2.1069	1.4928
	Power Angle Deviation	Highly Oscillatory	2.0165	1.4414
	Electrical Power Deviation	Highly Oscillatory	1.7480	1.5545

B. Condition-2: Multi-Machine System(3 Machine 6 Bus System)

Fig. 8 shows the convergence rate of objective functions of MMPS system & table 3,4 shows SSSC & PSS parameters optimized by GWO

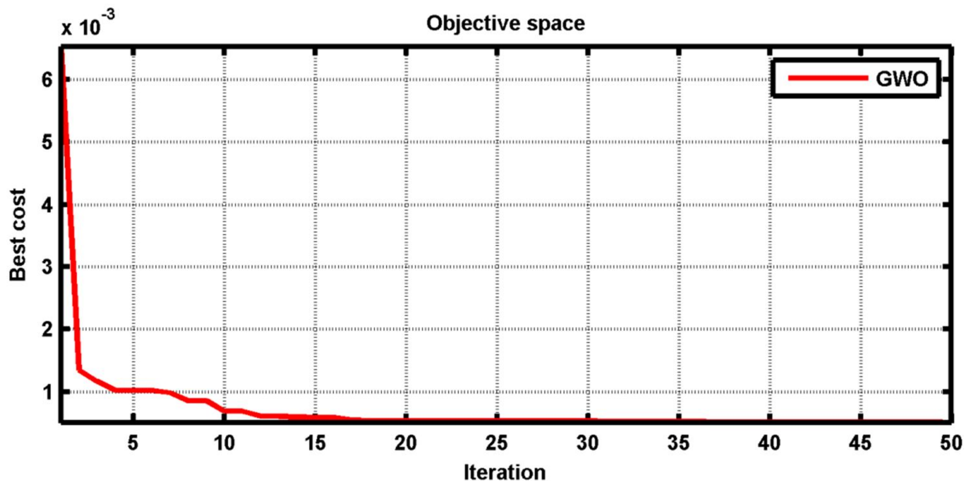

Fig. 8: Convergence of Objective Function for Best Cost in Multimachine System

Table 3: SSSC Parameters Tuned by GWO

S.NO.	Parameters	K	T_1	T_2	T_3	T_4
	SSSC	32.2106	3.2532	3.2574	2.6826	8.1381

Table 4: 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}
		10.7838	7.8073	4.0340	2.0506	2.5979
2	PSS_2	K_{21}	T_{21}	T_{22}	T_{23}	T_{24}
		73.3871	3.2836	3.9248	4.2172	3.6642
3	PSS_3	K_{31}	T_{31}	T_{32}	T_{33}	T_{34}
		72.0643	9.4737	7.9172	8.2412	6.4456

Fig.9-14 shows various graph at different cases In this case at t = 1 s, in between bus 1 and bus 6 a 3-cycle, 3-phase self-clearing fault,L-L-G, L-G ,L-L fault and small disturbances is applied with as regards to bus6. Various figure represents the system responses with this kind of disturbance and numerous kinds of the response given as inter-area mode, local-area mode of oscillation and SSSC injected voltage. These figures clearly demonstrate that the responses are oscillatory in nature if the controllers aren't within the system. The system response with none controller is diagrammatical during a blue line with the legend 'No Control', the system response with CPSS is diagrammatical during a line with legend 'CPSS' and so as to represent the proposed system then SSSC optimized by GWOPSS. The system response with GWOPSS is diagrammatical during a black line with legend 'GWOPSS'. It's evident from that proposed SSSC controller tuned by GWOPSSS offer higher dynamic response having lesser subsidence time.

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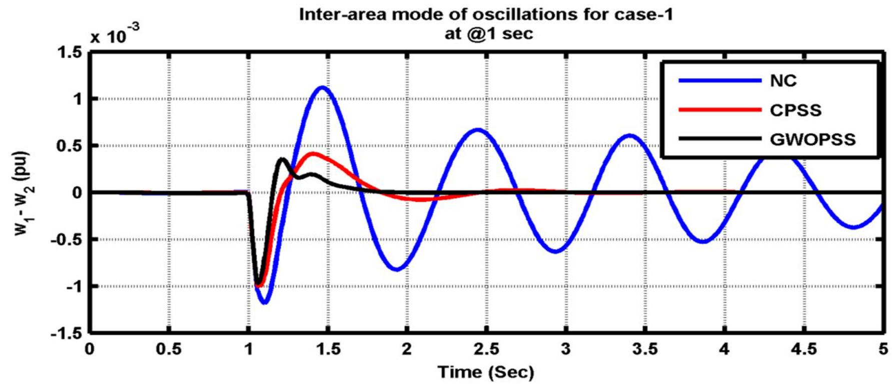

Fig. 9: Inter-Area Mode of Oscillation in Three Machine System for 3-Phase Fault

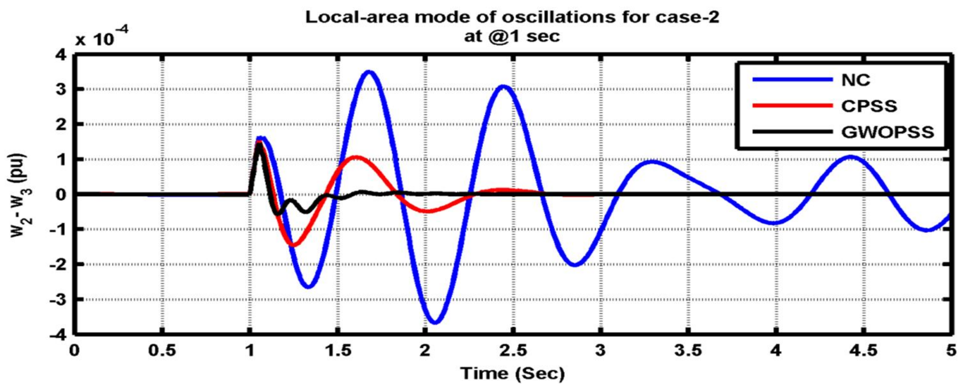

Fig. 10: Local-Area Mode of Oscillation in Three Machine System for L-L-G Fault

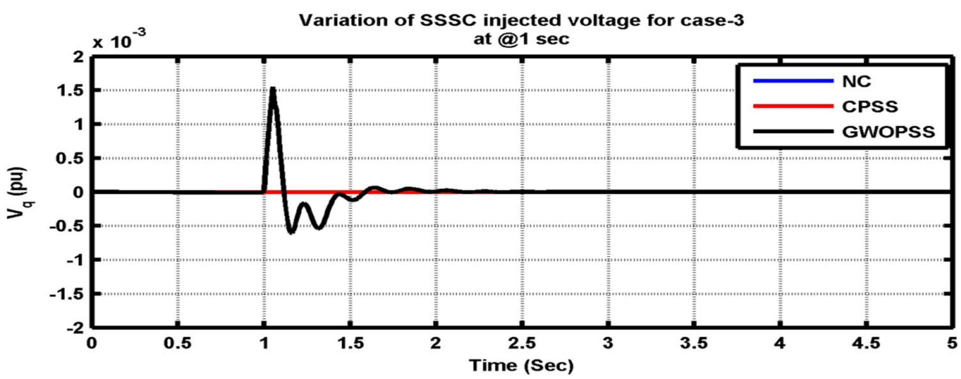

Fig. 11: SSSC Injected Voltage in Three Machine System for L-G Fault

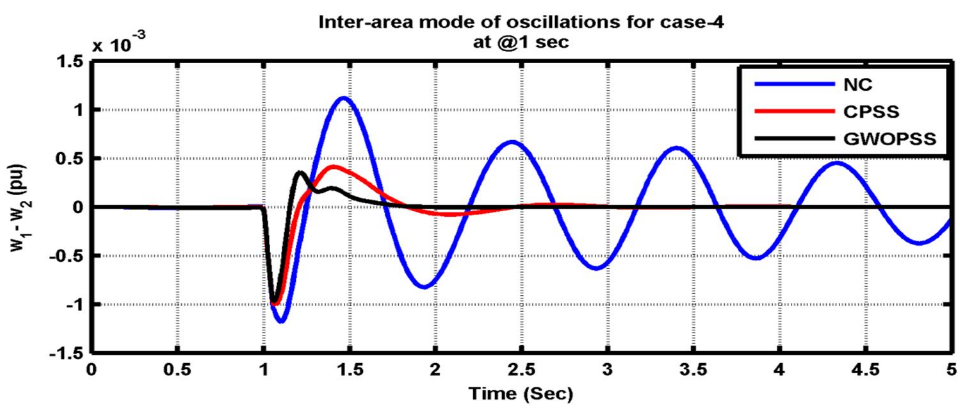

Fig. 12: Inter-Area Mode of Oscillation in Three Machine System for L-L Fault

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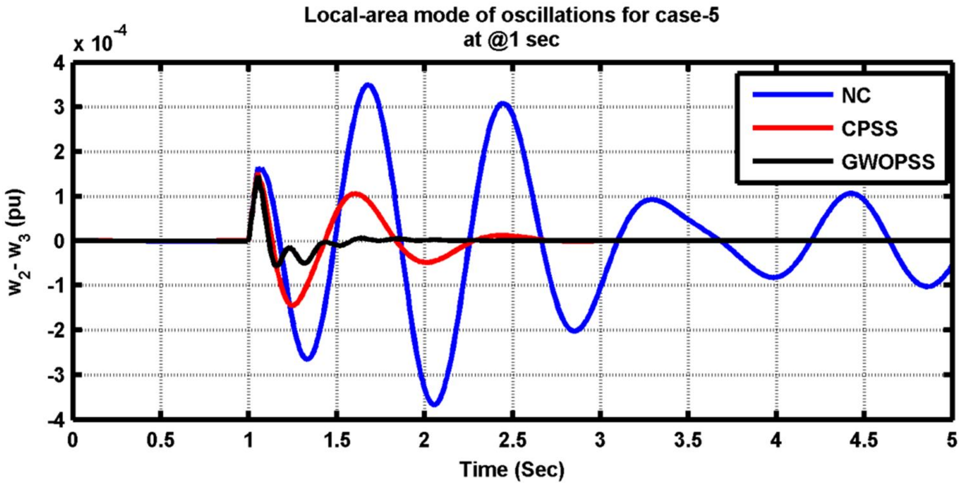

Fig. 13: Local-Area Mode of Oscillation in Three Machine System for Small Disturbance

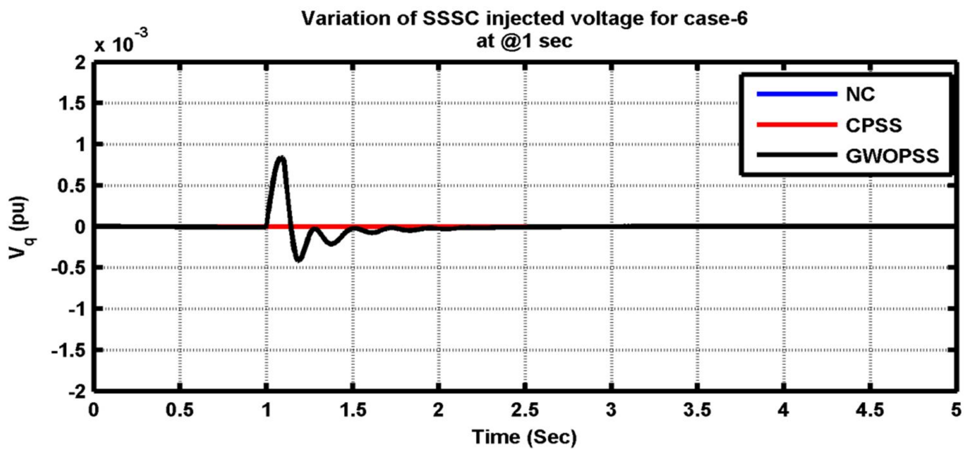

Fig. 14: SSSC Injected Voltage in Three Machine System for Line Outage Disturbance

1) *Signal Transmission Delay applied at 3 Machine 6 Bus Systems:* Fig. 15-17 shows various time delay as 25 ms,75ms & 100ms. The system performance tested with time delay but there is the negligible effect of the system performance.The system shows a superior response in the presence of the proposed controller. That the effect is almost negligible with the variation of the time delays.

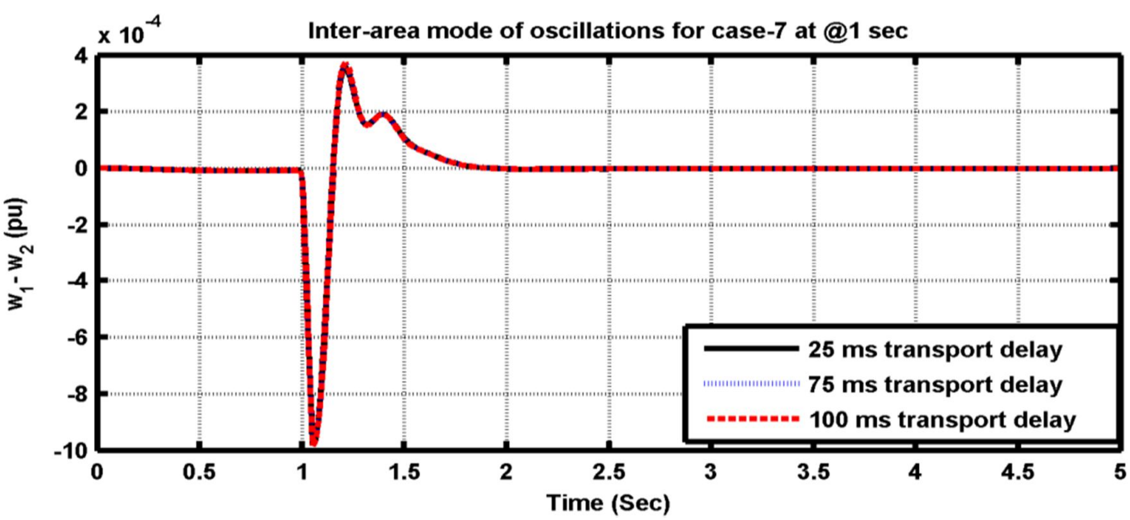

Fig. 15: Inter-Area Mode of Oscillation in Three Machine System for Signal Transmission Delay

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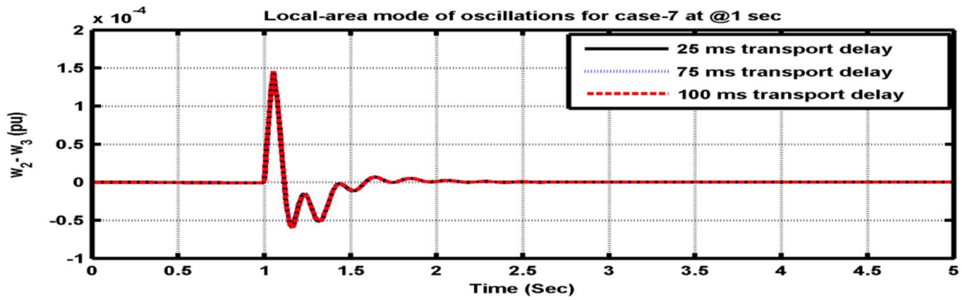

Fig. 16: Local-Area Mode of Oscillation in Three Machine System for Signal Transmission Delay

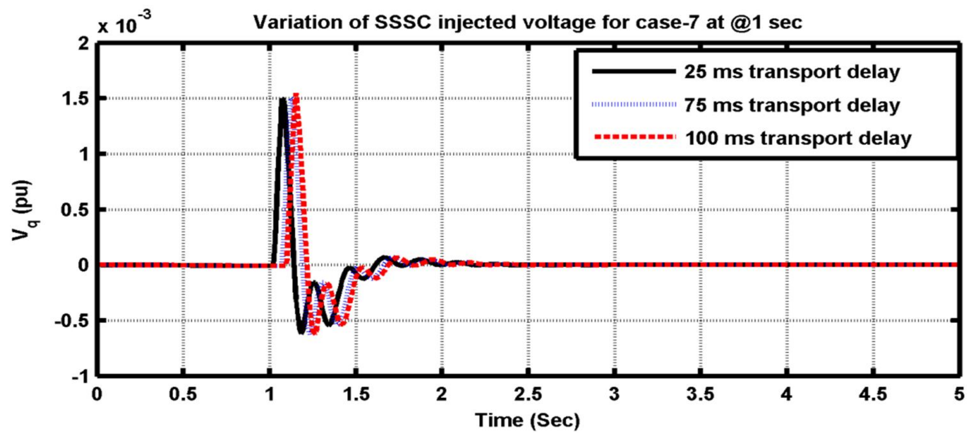

Fig. 17: SSSC Injected Voltage in Three Machine System for Signal Transmission Delay

Table 5: MMPS System at Without Controller and with CPSS and GWO SSCC Controller at Different Types of Loading at Different Types of Fault

S. N.	Types of Fault	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	3-Phase	Inter-Area Mode of Oscillation	Highly Oscillatory	2.7442	1.7454
		Local-Area Mode of Oscillation	Highly Oscillatory	2.6576	1.8945
2	L-L-G	Inter-Area Mode of Oscillation	Highly Oscillatory	2.7766	1.7570
		Local-Area Mode of Oscillation	Highly Oscillatory	2.6576	1.8945
3	L-G	Inter-Area Mode of Oscillation	Highly Oscillatory	2.7442	1.7434
		Local-Area Mode of Oscillation	Highly Oscillatory	2.6576	1.8944
5	Small Disturbance	Inter-Area Mode of Oscillation	Highly Oscillatory	2.7442	1.7434
		Local-Area Mode of Oscillation	Highly Oscillatory	2.6576	1.8945
6	Line Outage Disturbance	Inter-Area Mode of Oscillation	Highly Oscillatory	2.4637	2.1538
		Local-Area Mode of Oscillation	Highly Oscillatory	2.6217	2.2792

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V. CONCLUSIONS

The system is tested with two cases as SMIB system & multimachine system. In SMIB system system a Modified Heffron-Phillips model with SSSC is developed here and it is optimized using GWO. System tested in two cases in first case reference voltage setting is increased by 5% step and then it is tested with step increase of 10% in mechanical torque input.All condition GWO optimized shows superior response. In multimachine system the system of 3 machine 6 bus system is tested, with GWO technique at different faults which are three-phase fault, double line to ground fault(L-L-G),line to ground fault(L-G),line to line fault(L-L),line outage, small disturbance, signal transmission delay at various mode inter-area mode of oscillations, local area mode of oscillation, variation of SSSC injected voltage. Overall a robust performance is achieved when PSS is coordinated by SSSC. On application of GWO, its performance further increases.

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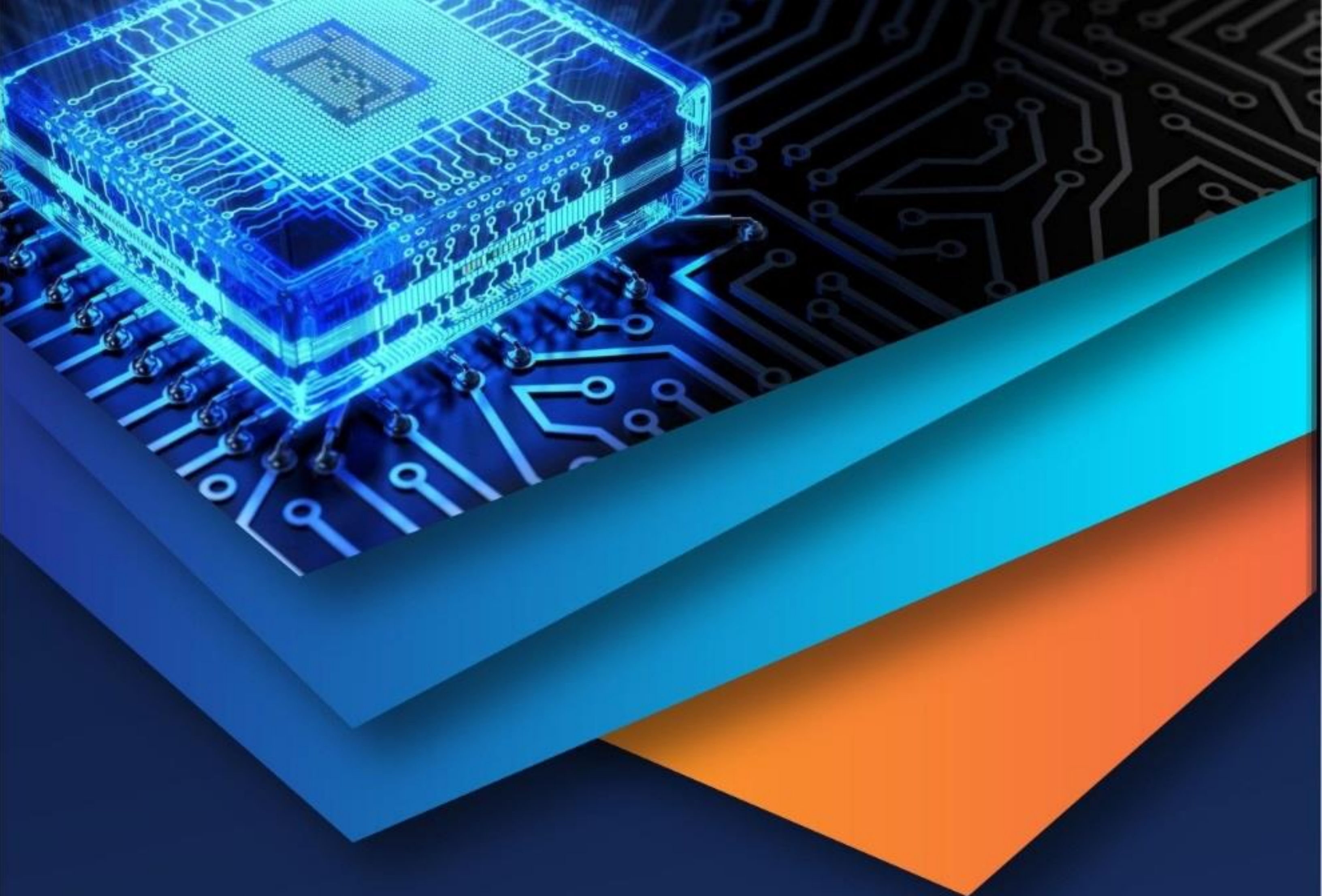

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