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Small signal stability enhancement of SMIB via GWO tuned SSSC Controller

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Abstract

The following piece of work is focused around the response of single machine infinite bus system (SMIB) concerning the Low-frequency oscillation (LFO). If this kind issue is not dealt in time, they may become a severe problem for the system. Hence, it should be damped out as quickly as possible. To realize this situation, SMIB system based on Heffron–Phillips model has been developed and assessed concerning this mentioned problem. As a damping control, a lead-lag structure-based Static Synchronous Series Compensator (SSSC) is employed in a system whose parameters are tuned with the help of Grey Wolf Optimization (GWO) algorithm. This algorithm mimics the social and hunting behaviour of wolfs living in a pack. To show the effectiveness of this proposed method, its time-domain simulation results were compared with the SMIB employing SSSC based on Particle Swarm Optimization (PSO) algorithm where SSSC based on GWO has shown to better than PSO. The assessment is carried out with respect to the different step-change in mechanical Torque input™ and reference voltage setting (Vref).

Keywords: SMIB, LFO, GWO

Introduction

There are namely these types of stability in power system, large and small signal. High signal stability is also known as transient stability. In the case of small-signal stability, when there is no proper damping, it occurs. While when power system encounters the serious transient disturbance like a short circuit or the tripping of line, it is the case of high signal stability. Starting Operating state and severity of disturbances influence the stability. The configuration of the system is so set to be in the stable state following set of chosen contingencies [1]

There quantity of methods where SSSC has been related with several optimization methods 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 performance of the grey wolf pack. The process is inspired by the various features of the social pack of these creatures for hunting and preying.

This kind of problem in SMIB arrangement can be solved with much ease as compared to the system where more than one machine is involved i.e. a multi-machine operation. It is a more practical system where observation of such problems can lead to a practical solution. Although, SMIB study did give the idea of characteristics of machine subjected to different conditions

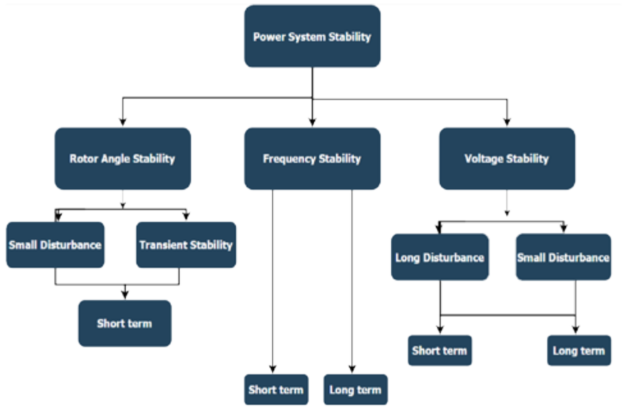

Fig. 1: Classifications of Power system

OBJECTIVE FUNCTION

The objective function that is imperative for the ongoing effort is to minimize speed modification. SMIB has the objective function as a complete error in the speed modification of the part-time type; it is the time integral of the absolute errors of the speed change for the kind of interregional vibrations. The main goal of the SMIB,

$$j = \int_{0}^{t_{sim}} t|\Delta w(t)|dt \qquad (1)$$

Minimize J subjected to

$$K^{min} \leq K \leq K^{max} \qquad (2)$$

$$T_1^{\ min} \leq T_1 \leq T_1^{\ max} \qquad (3)$$

$$T_3^{min} \leq T_3 \leq T_3^{max} \qquad (4)$$

Proposed system

The system is designed in such a manner to be able to account for the encounter of it with the low-frequency oscillations (LFO). Here, the SMIB is developed first by incorporating the SSSC in its structure. The very SSSC here is used for damping the so-called LFOs and hence is the controller for this purpose. The performance of it has been bettered with the use of a specific technique of optimization. Here this is GWO. As mentioned at the beginning of this, it is simulated in the SIMULINK environment. To show its effectiveness of the same system is also optimized using PSO, and thus its comparison was made with the proposed scheme. This was done on the basis of certain conditions taken account to see the system response which

- Increase in mechanical torque input (Te) by 30% and 100% respectively.
- Increase in reference voltage setting by 30% and 100% respectively.
- Variation in parameter under 30% step increase in reference voltage setting (Vref).

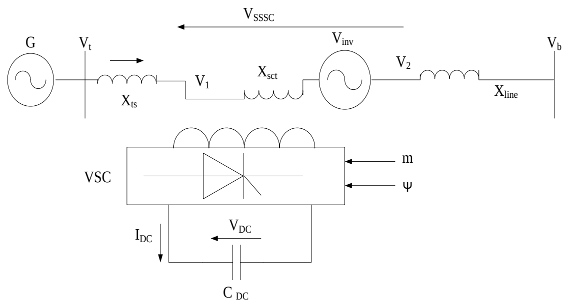

Fig. 2: SMIB Utilizing TLBO Based SSSC

Xts = transformer reactance

Xline = reactance of the transmission line. Further,

Vt = the generator terminals voltage

Vb = the infinite bus voltage.

XSCT = leakage inductance of the transformer

VINV = serial injected voltage

CDC = DC blocking capacitor

VDC = voltage of intermediate circuit

M = index modulation amplitude and

Ψ = series voltage phase angle

Grey wolf optimization (GWO)

This optimization method is specified by Mirjalili. It imitates the grey wolf hierarchy leadership, as they are identified for collection hunting [21].

In relation to the above statement, these wolves live in packs and mostly belong to the dog family. Since they live in packs, they have a leader who is alpha and shows their strictly dominant social hierarchy. Since Alpha is the leader, most group decisions are made by him [2].

The pack also has subordinates. These are betas that help Alpha make decisions. This means that they are consultants. The beta also provides feedback on the alpha. The most reduced positioned wolves are Omega, which follows all other prevailing wolves. Much of the time, Omega likewise assumes the job of the sitter.

On the off chance that the wolf isn't positioned, it has a place with the delta wolves that are over the omega wolves, and this implies they follow the other two columns of the pack. Scoundrels are trackers, seniors, guards, monitors and scouts [5]. Group hunting is amid the various topographies of their social situation. The main phases in hunt are

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

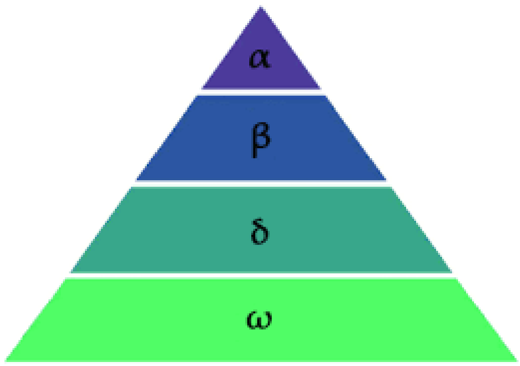

Fig. 3: Grey Wolf Social Hierarchy

Results and Discussion

Result Analysis & Discussion of GWO Tuned SSSC controller

They so far discussed model is designed with SSSC controller, with the tuning of PSO and with GWO granted. It can cover the operation of the system to the extended limits considering all such error causing variations in operating points when SSSC GWO controller is tested under different operating conditions, i.e. as reference voltage setting, mechanical torque and parameter variations input at various at speed deviations (Δω), power angle deviations (Δδ), and electrical power deviations (ΔPe).

The power system performance was examined 30% & 100% step increase with reference voltage setting & mechanical torque input. Also, the system tested with parameter variation 30% step increase with Vref at 50% increase, decrease with machine inertia constant(M), open circuit direct axis transient reactance(Td). The various graphs the change in speed deviation, power angle deviation & electrical power deviation has been shown. Both responses are shown with SSSC only, with PSO-SSSC and with GWO-SSSC.

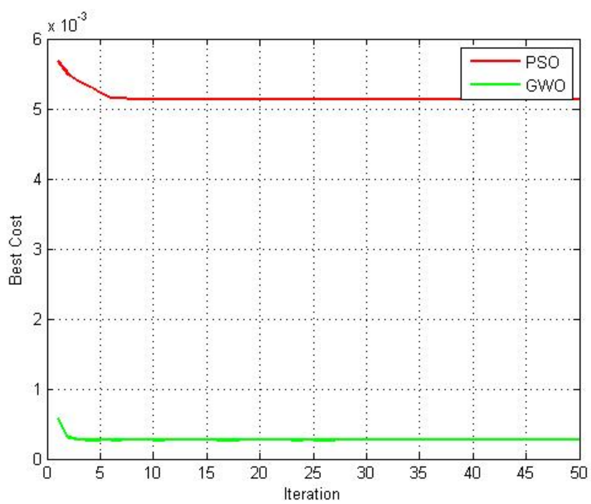

Fig. 4: GWO and PSO Convergence Characteristic W.R.T. Disturbance

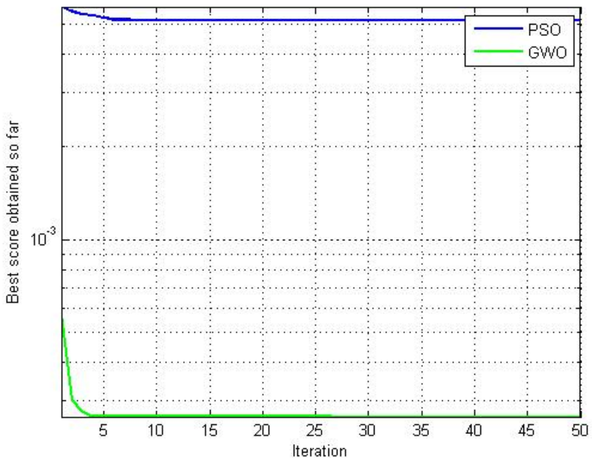

Fig. 5: Semi Log GWO and PSO Convergence Characteristic W.R.T. Disturbance

Condition-1:30% Step Increase in Mechanical Torque Input(Tm) and reference voltage setting(Vref) @ 1sec

Case:1 Speed deviations(Δω) with a 30% increase in Tm

As in fig. show the performance given GWO-SSSC is far superior as compared to a system with only SSSC and with PSO-SSSC. The difference is clear from the settling time (t) of all. In it the system with only SSSC though less but still oscillatory in nature, for PSO-SSSC t=3.977s and with GWO-SSSC t=0.432s.

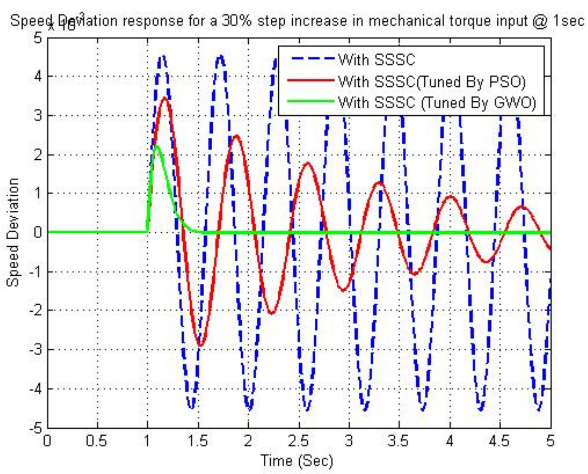

Fig. 6: Δω with Tm increased by a step of 30%

Power angle deviations (Δδ) with a 30% increase in Tm

As in fig. 1.7 the performance given GWO-SSSC is far superior as compared to a system with only SSSC and with PSO-SSSC. The difference is clear from the settling time (t) of all. In it the system with only SSSC though less but still oscillatory in nature, for PSO-SSSC t=3.951s and with GWO-SSSC t=0.371s.

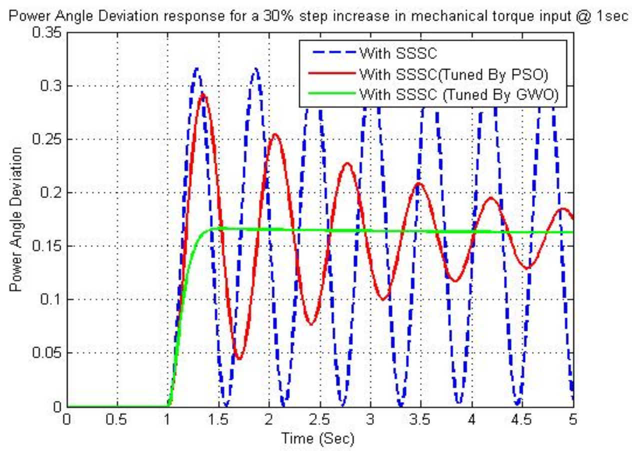

Fig.7: Δδ with Tm increased by a step of 30%

Electrical power deviations (ΔPe) with a 30% increase in Tm

As show fig. the performance given GWO-SSSC is far superior as compared to a system with only SSSC and with PSO-SSSC. The difference is clear from the settling time(t) of all. In it the system with only SSSC though less but still oscillatory in nature, for PSO-SSSC t=3.952s and with GWO-SSSC t=0.421s.

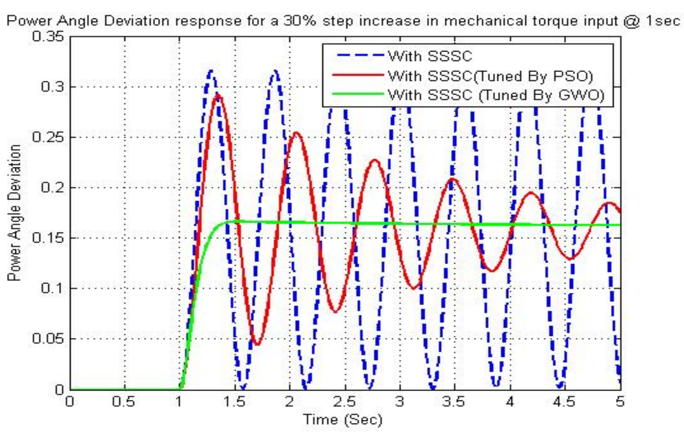

Fig. 8: ΔPe with Tm increased by a step of 30%

Case- 4 Speed deviations (Δω) with a 30% increase in Vref

As in fig. 1.9 the performance given GWO-SSSC is far superior as compared to a system with only SSSC and with PSO-SSSC. The difference is clear from the settling time(t) of all. In it the system with only SSSC though less but still oscillatory in nature, for PSO-SSSC t=3.974s and with GWO-SSSC t=3.089s.

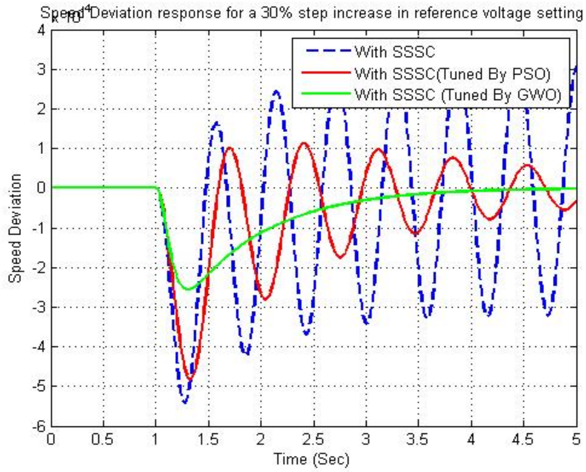

Fig. 9: Δω with Vref increased by a step of 30%

Power angle deviations (Δδ) with a 30% increase in Vref

As in fig. 1.10 the performance given GWO-SSSC is far superior as compared to a system with only SSSC and with PSO-SSSC. The difference is clear from the settling time (t) of all. In it the order with only SSSC though less but still oscillatory in nature, for PSO-SSSC t=3.891s and with GWO-SSSC t=2.853s.

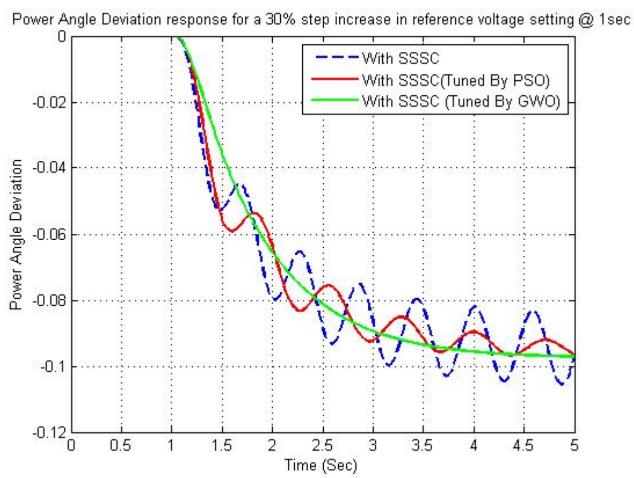

Fig. 10: Δδ with Vref increased by a step of 30%

Electrical power deviations (ΔPe) with a 30% increase in Tm

As in fig. 1.11 the performance given GWO-SSSC is far superior as compared to a system with only SSSC and with PSO-SSSC. The difference is clear from the settling time(t) of all. In it the system with only SSSC though less but still oscillatory in nature, for PSO-SSSC t=3.977s and with GWO-SSSC t=2.137 s.

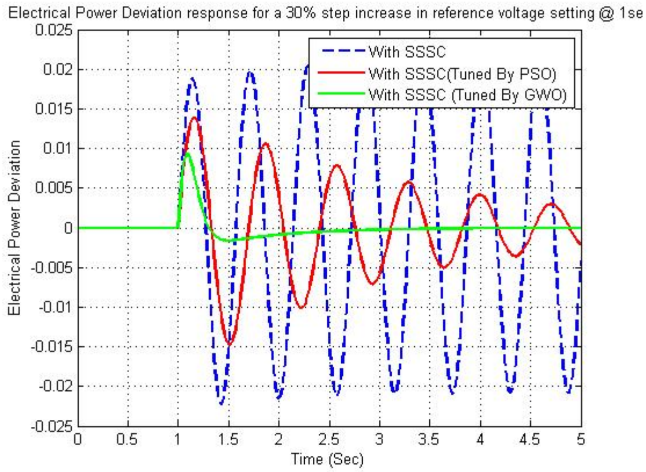

Fig. 11: ΔP_e with V_{ref} increased by a step of 30%

Discussion

The table shows various value settling time at 30%, 100% Step Increase in Tm and Vref. Time Constant at Mechanical Torque Input and Reference Voltage Setting. All condition shows when only SSSC, PSO-SSSC and GWO-SSSC are employed individually in the system; stability improves, and an oscillation dies out quickly. So GWO-SSSC control very quickly stabilizes the system.

Table 1: Response for 30% & 100% Step Increase in Tm and Vref

S.No.	**Operating conditions**	**Deviation**	**only SSSC (Settling time, in s)**	**PSO-SSSC (Settling time, in s)**	**GWO-SSSC (Settling time, in s)**
1.	30% Step Increase in T_m	ω	Poorly damped	3.977	0.432
		δ	Poorly damped	3.951	0.371
		P_e	Poorly damped	3.952	0.421
2.	30% Step Increase in V_{ref}	ω	Poorly damped	3.974	3.089
		δ	Poorly damped	3.891	2.853
		P_e	Poorly damped	3.977	2.137
3.	100% Step Increase in T_m	ω	Poorly damped	3.982	0.447
		δ	Poorly damped	3.977	0.723
		P_e	Poorly damped	3.969	0.441
4.	100% Step Increase in V_{ref}	ω	Poorly damped	3.978	3.233
		δ	Poorly damped	3.926	3.023
		P_e	Poorly damped	3.979	2.325

Conclusion

Here, Heffron–Phillips model of a SMIB with SSSC and realized in MATLAB/Simulink. Then it was simulated under the different operation of conditions different reference voltage settings and mechanical torque input along with the variation in different machine's parameters. The response of the system was observed in terms of settling time after speed, power angle and electrical power have deviated from their original values. Under these, all conditions system with only SSSC is displaying the oscillatory response. The difference could be observed in settling time with PSO-SSSC and GWO-SSSC

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