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# Damping of Power System Oscillations Using SSSC-based Supplementary controller

S.C.Swain[1] , Srikanta Mahapatra[2], Sidhartha Panda[3]

[1] Associate Prof., School of Electrical Engineering, KIIT University, Bhubaneswar, Odisha
Email id- saratswain132@gmail.com

**Abstract.** Power-system stability improvement by a static synchronous series compensator (SSSC)-based controller is studied in this paper. Conventionally, the lead-lag structure was used to modulate the injected voltage. But, in this paper, PID controller is also considered. The design problem of the proposed controller is formulated as an optimization problem and Differential Evolution Algorithm is used to find out the optimal controller parameters. Different disturbances are applied to the single-machine infinite bus system. Only remote signals with required time delays are taken into account in this paper. The simulation results are presented and the two structures are compared under various loading conditions and disturbances to find out the better structure.

**Keywords: FACTS, Static Synchronous Series Compensator, Differential Evolution Algorithm, PID Controller, Lead-Lag Structure.**

## 1 Introduction

The main function of power system is to convert energy from one of the naturally available forms to electricity. But, electrical energy cannot be stored in large quantities. So, to maintain the balance between what is demanded and generated, many equipments and controllers are used which further introduces non-linearity in power system. This non-linearity gives rise to many instability problems. Electrical power oscillations are a type of these instability problems. The root cause of electrical power oscillations are the unbalance between power demand and available power at a period of time. Power system oscillations are inherently present in the system. It mainly occurs when large power systems are interconnected by relatively weak tie lines. If no adequate system damping is available , then these oscillations causes large fluctuations in output power , current and voltage. This enables the protection system to isolate the unstable machine from the system which is undesirable. [1]

Recent developments in power electronics introduced Flexible AC Transmission Systems i.e. FACTS. It has a property of higher controllability in power systems by means of power electronics devices [2]. SSSC is the FACTS device that is under consideration in his paper. It is a series device and has the capability to increase or decrease the overall reactive voltage drop across the line, thereby controlling the power flow as given in [3,4].

Despite much advancement, the lead-lag structure based controller and proportional-integral-derivative (PID) based controllers remain an engineer's choice for many industrial applications. These controllers are preferred because of their structural simplicity, favorable ratio between performance and cost and reliability. Along with these, it also offers simplified dynamic modelling, lower user-skill requirements, and minimal development effort, which are issues of substantial importance to engineering practice as given in [5]. In [6], the PI, PID and PIDD controllers were compared and it was found that PID controller proved to be more efficient under every loading condition and applied disturbances. This paper presents a comparison between the lead-lag based controller and PID controller. These controllers are used to modulate the injected voltage into the SSSC. Both the controllers are subjected to various disturbances and loading conditions. It was found that the PID controller based SSSC model gives better result i.e. it was able to damp out the power oscillations in lesser time.

DE algorithm is a stochastic optimization method minimizing an objective function that can model the problem's objectives while incorporating constraints. This evolution strategy called DE has been recently proposed by Storn [7]. The algorithm mainly has three advantages; finding the true global minimum regardless of the initial parameter values, fast convergence, and using a few control parameters. DE is simple, fast and easy to use. It is quite effective in nonlinear constraint optimization including penalty functions and is useful for optimizing multi-modal search spaces as given in [8]. DE uses weighted differences between solution vectors to change the population whereas in other stochastic techniques such as genetic algorithm (GA) and expert systems (ES), perturbation occurs in accordance with a random quantity. It has been applied to several engineering problems in different areas [9,10]. In this paper, DE optimization technique is used to find out the optimal parameters of the PID controller. The optimized values of lead-lag structure parameters are referred from [11].

## 2 System Model

A single machine infinite-bus system with SSSC is shown in fig.1. The system comprises a synchronous generator connected to an infinite-bus through a step-up transformer followed by a SSSC placed in between two double circuit transmission line. The generator is a subsystem which contains hydraulic turbine & governor (HTG) and excitation system. A non-linear hydraulic turbine model, a PID governor system and a servomotor constitutes the HTG system whereas the excitation system consists of a voltage regulator and DC exciter.

The SSSC consists of a converter that is connected in series with the transmission line. It operates without an external energy source as a series compensator whose output voltage is in quadratic with and controllable independently of the line current. The voltage injected (Vq) by the **SSSC** is (almost) in quadrature with the transmission line current such that it emulates the behaviour of a series inductor or capacitor. The injected voltage is modulated by using the two type of controllers.

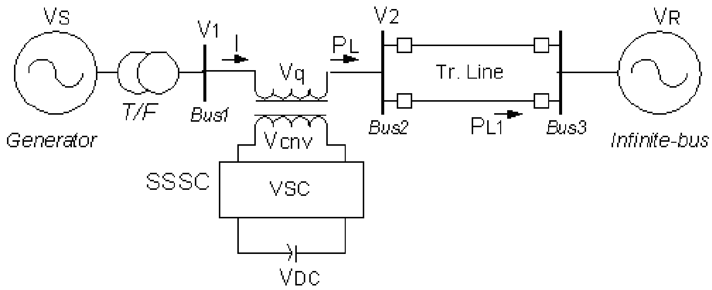


Fig. 1 Single-machine infinite-bus power system with SSSC

## 3 The Proposed Approach

### 3.1 Structure of SSSC-based Damping Controller

One of the structures used in this paper to modulate the SSSC injected voltage is the lead-lag structure as shown in fig.2. Input signal to the structure is speed deviation and its output is the injected voltage. This structure consists of a gain block, washout block and two stage lead-lag block. The two stage lead-lag block provides the appropriate phase-lead characteristics to compensate for the phase lag between input and the output signals. The washout block acts as a high pass filter to allow signals associated with oscillations to pass as it is. The delay block produces a delay according to the type of input signal. Input signal can be of two types i.e. remote and local. In this paper, only remote signal is considered. In case of remote signal input , both sensor time constant and the signal transmission delays are included.

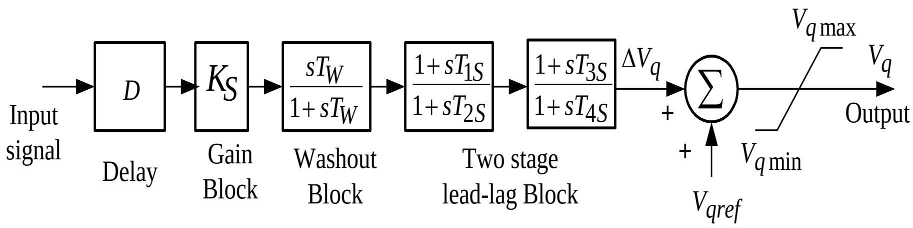


Fig. 2. The Lead-Lag structure

Another structure considered is PID controller whose structure is given in fig. 3.

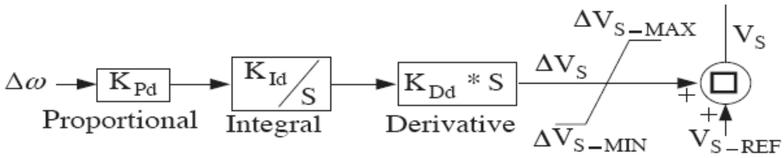


Fig. 3 The structure of the PID controller

The proportional mode adjusts the output signal in direct proportion to the controller input. An additional integral mode corrects for any offset that may occur between the desired value and the process output automatically over time. The derivative action should always improve the dynamic response. It depends on the slope of the error.

This paper compares the performance of DE-based lead lag structure with DE-based PID structure. Time constants K, $T_{1S}$, $T_{2S}$ and $T_{3S}$, $T_{4S}$ were taken from a paper [20] whereas constants such as $K_p$, $K_I$, $K_D$ were optimized using DE algorithm.

### 3.2 Problem Formulation

In the present study, the values of $K_p$ and $K_i$ are to be determined. During steady state conditions ΔVq and Vqref is constant. During dynamic conditions the series injected voltage Vq is modulated to damp system oscillations. The effective Vq in dynamic conditions is:-

$$V_q = V_{qref} + \Delta V_q.$$

SSSC-based controllers are required to damp power system oscillations after the system is subjected to large disturbances. The objective function is to minimize the deviation in rotor speed , line power and power angle in which the oscillations are reflected. As, remote signal is considered in this paper, so, the input signal is taken to be rotor speed deviations. Here, the objective function is considered to be an integral time absolute error of the speed deviations and is expressed as:-

$$J = \int_{t=0}^{t=t_{sim}} |\Delta\omega| \cdot t \cdot dt$$

## 4 Differential Evolution Algorithm

The DE algorithm is a population based algorithm like genetic algorithms using the similar operators; crossover, mutation and selection. The main difference in constructing better solutions is that genetic algorithms rely on crossover while DE relies on mutation operation. This main operation is based on the differences of randomly sampled pairs of solutions in the population.

An optimization task consisting of D parameters can be represented by a D-dimensional vector. In DE, a population of NP solution vectors is randomly created at the start. This population is successfully improved by applying mutation, crossover and selection operators [7].

The main steps of the DE algorithm is given below:

*Initialization*
*Evaluation*
**Repeat**
*Mutation*
*Recombination*
*Evaluation*
*Selection*
**Until** *(termination criteria are met)*

## 5 Results and discussions

The model of the system given in fig1. has been developed in Sim Power System blockset in MATLAB environment. The system consists of a of 2100 MVA, 13.8 kV, 60Hz hydraulic generating unit, connected to a 300 km long double-circuit transmission line through a 3-phase 13.8/500 kV step-up transformer and a 100 MVA SSSC. The DE is used to optimize the parameters of the controller.

**Table 1.** Optimal values of the parameters of the controller.

| Signal/Parameters | $K_P$ | $K_I$ | $K_D$ |
|---|---|---|---|
| Remote | 71.9696 | 1.5479 | 1.0000 |

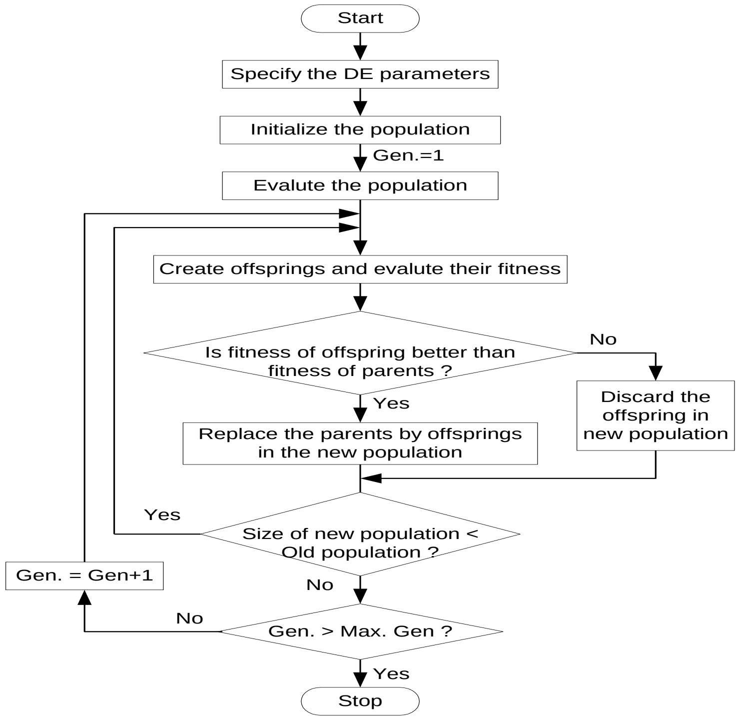


Fig. 5 Flow chart of proposed DE optimization approach

**Case 1: Nominal loading ($P_e$=0.8 pu)**

The robustness of the proposed controllers is tested under light loading condition. . A 3-phase self clearing fault of 100 ms duration is applied at the middle of one transmission line connecting bus 2 and bus 3, at $t$ = 1.0 s. The speed response, power and the injected voltage plots are given in fig 6, fig 7and fig 8. It is observed that the PID controller gives the best result in this loading condition.

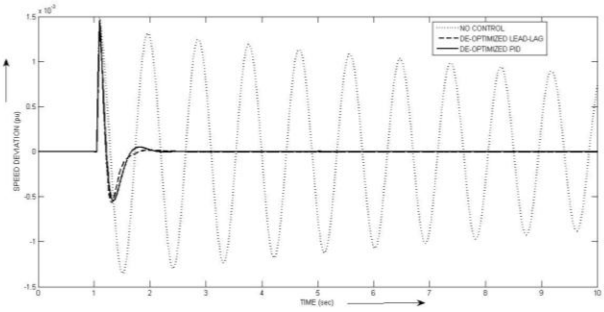


Fig. 6. Speed deviation response for 100 ms 3-ph fault in transmission line with nominal loading.

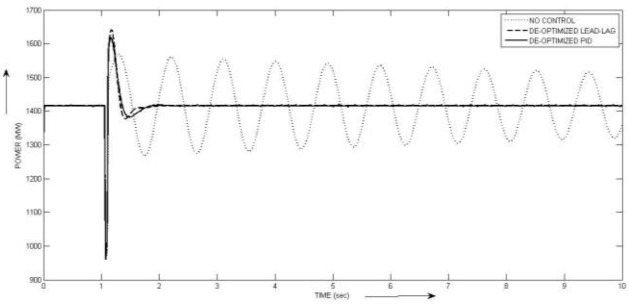


Fig. 7. . For tie-line power flow response for 100 ms 3-ph fault in transmission line with nominal loading.

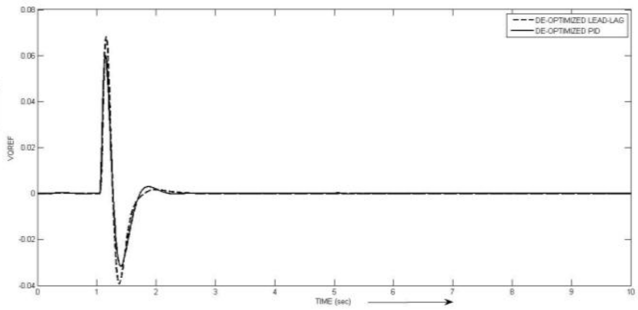


Fig.8. SSSC injected voltage variation in nominal loading condition.

**Case 2: Light loading ($P_e$=0.45 pu)**

The robustness of the proposed controllers is tested under light loading condition. A 3-phase fault is applied at Bus 3 at t=1.0 sec. The fault is cleared in 1-

cycle and the original system is restored after the fault clearance. It is observed that the DE-Optimised PID controller gives the best as compared to others. The speed response , power and the injected voltage plots are fig 9, fig 10, fig 11.

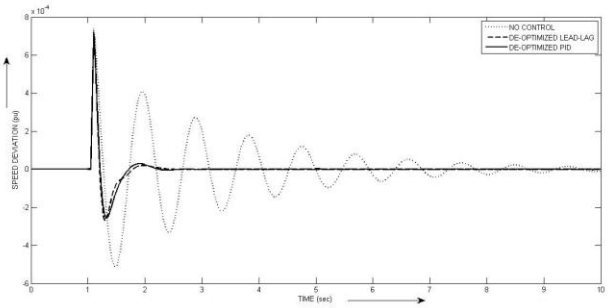


Fig. 9. Speed deviation response for 100 ms 3-ph fault in transmission line with light loading.

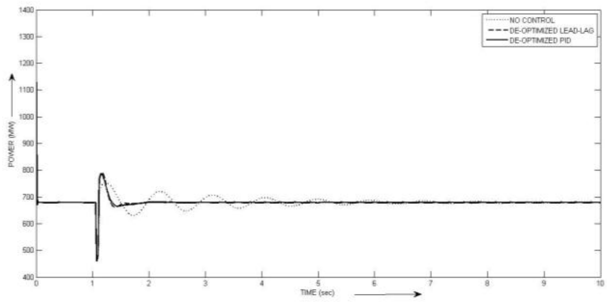


Fig. 10. For tie-line power flow response for 100 ms 3-ph fault in transmission line with light loading.

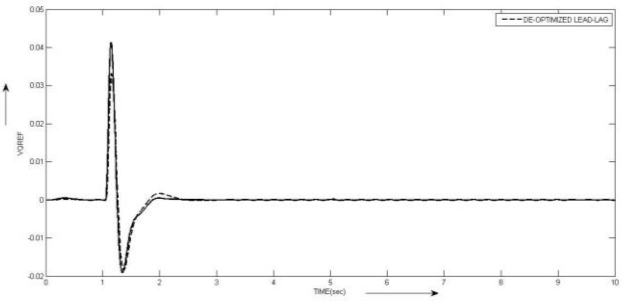


Fig.11. SSSC injected voltage variation in light loading condition

**Case-3: Heavy loading ($P_e = 1$pu)**

The robustness of the proposed controller is tested under heavy loading condition .This is done by disconnecting the load near bus 1 at t=1.0 s for 100 ms and by changing the generator to heavy loading condition. The speed response, power and the injected voltage plots are given in fig 12,fig 13 and fig 14. It is observed that PID controller gives the best result in this loading condition.

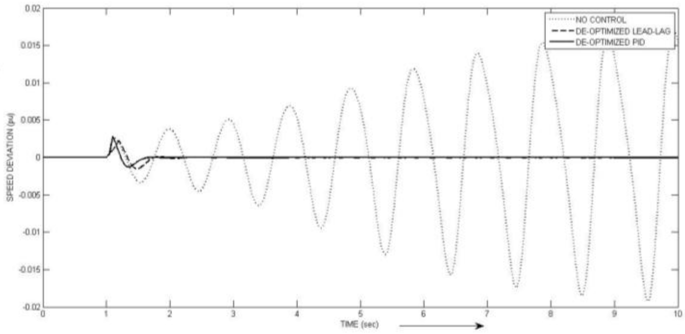


Fig.12 Speed deviation response for 100 ms 3-ph fault in transmission line with heavy loading.

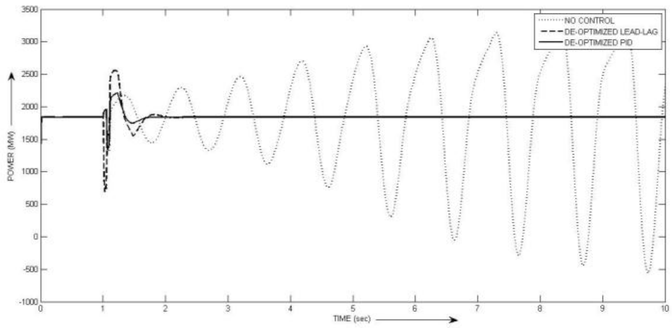


Fig. 13. For tie-line power flow response for 100 ms 3-ph fault in transmission line with heavy loading.

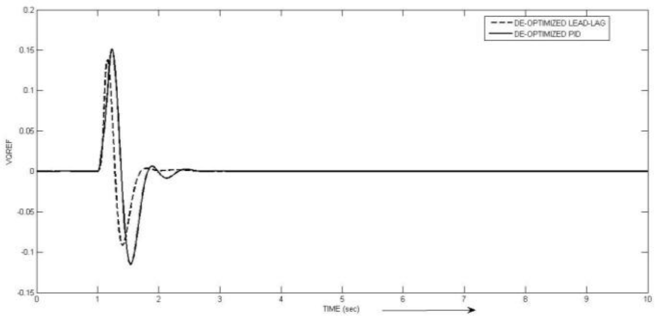


Fig.14. SSSC injected voltage variation in heavy loading condition

## 6 Conclusion

Power system stability enhancement is improvement using SSSC-based damping Controller is studied. Two controller structures were considered in this paper. The optimal parameters of the PID controller were searched by the Differential Evolution Algorithm. The controller was tested under different loading conditions and the results of the controllers were compared. It is found that PID controller gives best result in all loading conditions as compared to lead-lag structure based controller.

## 6 Appendix

System data: All data are in pu unless specified otherwise. The data is taken from [11,12].

**(i) Single-machine infinite-bus power system**

*Generator:*
$S_B$ = 2100 MVA, $H$ =3.7 s, $V_B$ = 13.8 kV, $f$ = 60 Hz, $R_S$ = 2.8544 e -3, $X_d$ =1.305, $X_d'$= 0.296, $X_d''$= 0.252, $X_q$ = 0.474, $X_q'$ = 0.243, $X_q''$ = 0.18, $T_d$ = 1.01 s, $T_d'$ = 0.053 s, $T_{qo}''$= 0.1 s.,
*Load at Bus2*: 250MW
*Transformer*: 2100 MVA, 13.8/500 kV, 60 Hz, $R_1$ =$R_2$= 0.002, $L_1$ = 0, $L_2$=0.12, $D_1/Y_g$ connection, $R_m$ = 500, $L_m$ = 500
*Transmission line*: 3-Ph, 60 Hz, Length = 300 km each, $R_1$ = 0.02546 Ω/ km, $R_0$= 0.3864 Ω/ km, $L_1$= 0.9337e-3 H/km, $L_0$ = 4.1264e-3 H/ km, $C_1$ = 12.74e-9 F/ km, $C_0$ = 7.751e-9 F/ km
*Hydraulic turbine and governor*: $K_a$ = 3.33, $T_a$ = 0.07, $G_{min}$ = 0.01, $G_{max}$ = 0.97518, $V_{gmin}$ = - 0.1 pu/s, $V_{gmax}$ = 0.1 pu/s, $R_p$ = 0.05, $K_p$ = 1.163, $K_i$ = 0.105, $K_d$ = 0, $T_d$ = 0.01 s,$\beta$ =0, $T_w$ = 2.67 s
*Excitation system*: $T_{LP}$ = 0.02 s, $K_a$ =200, Ta = 0.001 s, $K_e$ =1, $T_e$ =0, $T_b$ = 0, Tc =0, $K_f$ = 0.001, Tf = 0.1 s, $E_{fmin}$ = 0, $E_{fmax}$ = 7, $K_p$ = 0

*SSSC:* Converter rating: $S_{nom}$ = 100 MVA, System nominal voltage: $V_{nom}$ = 500 kV, Frequency: $f$ = 60 Hz, Maximum rate of change of reference voltage ($V_{qref}$) = 3 pu/s, Converter impedances: R = 0.00533, L = 0.16, DC link nominal voltage: $V_{DC}$ = 40 kV, DC link equivalent capacitance $C_{DC}$ = 375 x 10 $^{-6}$ F, Injected Voltage regulator gains: $K_P$ = 0.00375, $K_i$ = 0.1875, DC Voltage regulator gains: $K_P$ =0.1 x 10 $^{-3}$, $K_i$ = 20 x 10 $^{-3}$, Injected voltage magnitude limit: $V_q$ = ± 0.2

## 7 References

1) P. Kundur, N. J. Balu, and M. G. Lauby. Power system stability and control.McGraw-Hill, 1994.
2) Hingorani, N.G., Gyugyi, L., 2000. Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems, IEEE Press, New York.
3) Gyugyi, L., et al., 1997. Static synchronous series compensator: a solid state approach to the series compensation of transmission lines, IEEE Trans. Power Delv. 12, 406-417.
4) Sen, K.K., 1998. SSSC-static synchronous series compensator: Theory, modeling, and applications, IEEE Trans. Power Delv. 13, 241-246.
5) Y.L. Abdel-Magid, M.A. Abido, "Coordinated design of a PSS and a SVC-based controller to enhance power system stability. Electrical Power & Energy Syst, vol. 25, pp. 695-704, 2003.
6) S.C. Swain, S. Mohapatra, S.Panda and Susmita Panda, Design of DE Optimized SSSC-based FACTS controller **,** International Journal of Electronics, Communication and Electrical Engineering (IJECEE), Volume 2 Issue 4 , May 2012.
7) Stron R., Price, K., 1995. Differential Evolution – A simple and efficient adaptive scheme for Global Optimization over continuous spaces, Journal of Global Optimization, 11, 341-359.
8) Dervis Karaboga and Selcuk Okdem, Simple And Global Optimisation Algorithm for Engineering Problems :Differential Evolution Algorithm , Turk J Elec Engin, VOL.12, NO.1 2004.
9) R. Storn, Differential evolution design of an IIR-filter with requirements of magnitude and group delay", Proceedings of the IEEE Conference on Evolutionary Computation, pp. 268-273, 1996.
10) R. Storn, System Design by Constraint Adaptation and Differential Evolution", IEEE Trans. on Evolutionary Computation, Vol. 3, No. 1, pp. 22-34, 1999.
11) Panda, S. Differential evolution algorithm for SSSC-based damping controller design considering time delay, The Journal of Franklin Institute Published by Elsevier Ltd.
12) Sim Power Systems 4.3 User's Guide,
Available: http://www.mathworks.com/products/simpower/