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TLBO Tuned SSSC Controller for Improvement of Power System Stability Performance

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Abstract: The operation of power system is quite complicated right from transmission to distribution to the end users. In between the operation of it, many ill conditions arouse interfering with the process. The power system goes through lots of events out, which may cause disturbances to its operation. One such of issues is of low frequency oscillations typically range from 0.1 Hz to 2 Hz. These low frequency oscillation are further be classified as Local and inter-area mode with the frequency ranging from 0.7 to 2 Hz and 0.1 to 0.8 Hz respectively. To damp out these oscillations high gain voltage regulators are employed. But these alone are not sufficient. Hence, for the efficient performance and response controller is designed based on the devices of FACTs (Flexible AC Transmission) family. These devices possess good operation characteristics. In the present context Static Series Synchronous Compensator is being employed. To realize and observe the performance of SSSC based damping controller a Single machine infinite bus system is developed based on Phillips-Haffron model. The given controller is employed in the model in the platform provided by MATLAB/SIMULINK. Then, its analysis was carried out. Further, the performance of the SSSC based controller is improved with the uses of newly developed Teacher Learner Based Optimization (TLBO) technique. The system developed was analyzed with two different cases of change in mechanical torque input and reference voltage setting with different parameters values. The observations have been tabulated for speed deviation, power angle deviation and electrical power deviation respectively in each case with different steps of variations. Finally, the results for these conditions are compared with SMIB system without SSSC and it was verified that it performance in stabilizing the system has bettered with the inclusion of TLBO based SSSC controller.

Keywords: Static Synchronous Compensator; TLBO Algorithm; Phillips Haffron Model of SMIB System; FACTS devices

I. INTRODUCTION

Flexible AC transmission systems (FACTS) are the static devices for AC transmission to enhance treatment and network transmission performance. FACTS are defined by the IEEE standard as "an electronic control system on the basis and other static devices which allows control of one or more parameters of the alternative transmission system to improve controllability and improve the ability of transmission."FACTS will increase the reliability of the AC networks as well as reduce the costs of the power supply along with the quality and transmission of power. In recent years, the current assessment of the thyristor developed into higher ratings makes the power electronics capable of applying applications with high power dozens, hundreds and thousands of MW.FACTS have several advantages such as: transfer capacity improvement, control of energy flow, transient stability, power damping, voltage stability and control. Depending on the type and equipment selected and the specific voltage level and the conditions of the local network, the transmission capacity improvement of up to 40-50% can be achieved by the FACTS installation. FACTS controllers are not subject to wear and require less maintenance.[12] In recent years, technological advances in power electronics have facilitated the development of electronic devices that offer the ability to process large amounts of energy; therefore, the use and application of this technology in the power supply systems have significantly increased. These devices, known as Flexible AC Transmission Systems (FACTS), are based on power electronics converters and offer the possibility to make quick adjustments and check the electrical system. FACTS devices can be connected in series, in parallel or in a combination of both[4]. The FACTS technology is simple to apply to the collectors to regulate and control variables such as impedance, current, voltage, and phase angle. Series Compensators, Shunt Compensators, Compensators Series Shunt Series and Series Compensators: Various types of FACTS controller is available as SSSC, UPFS, TCSC, STATCOM according to their applications.[5] The static synchronous series compensator (SSSC) is one such which is based on a fixed-voltage converter system that generates an adjustable AC voltage in quadrature with the 1ine current. In this way, the SSSC emu1ates as an inductive or capacitive reactance and control the energy management in transmission lines accordingly [9].The various intelligent technique use in with FACTS controller. Some optimization technique is conventional and some modern technique as GA, PSO, GSA, ABB,PSO-GSA etc. In this paper we use TLBO algorithm and this is very important algorithm to find optimize solutions [2]

II. SYSTEM MODEL

A. *Linear Dynamic Model of the Power System with SSSC*

Fig.1 Shows the modified Phillips Haffron Model of the SMIB System [3]

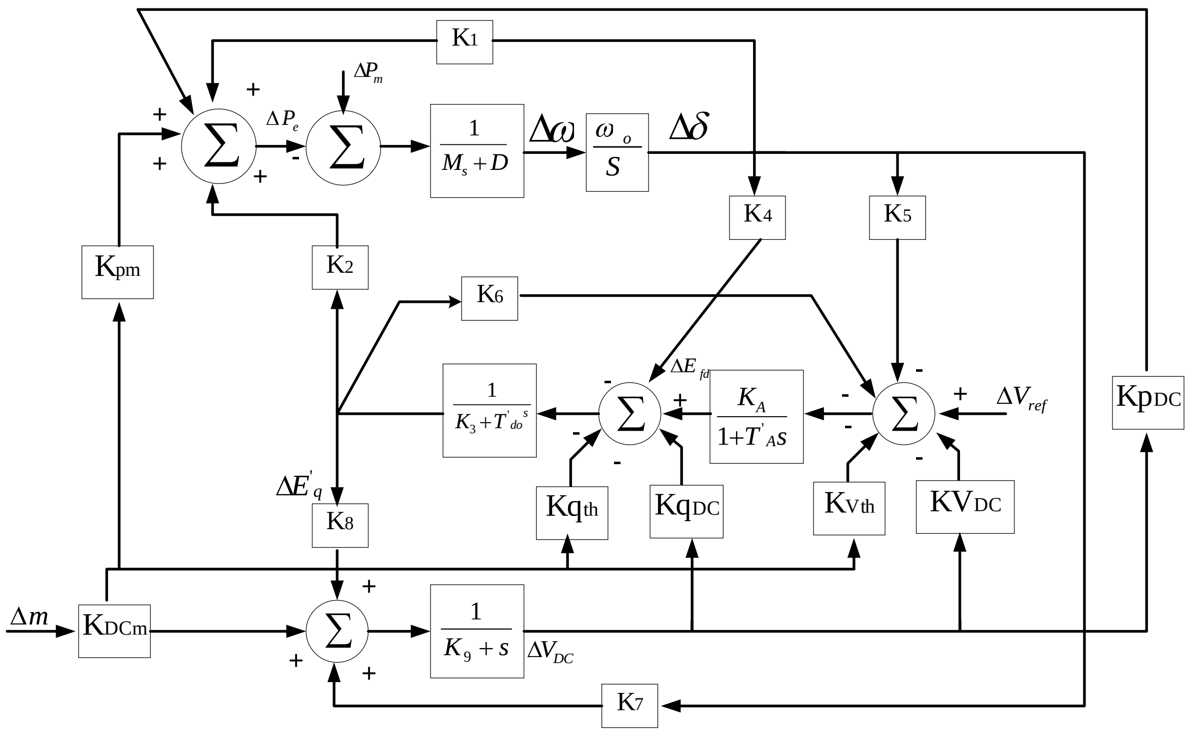

Fig.1 Phillips Haffron Model of the SMIB System

B. *Overview of SSSC Controller*

SSSC is a FACTS device of modern performance quality that uses a voltage source converter connected in series with a transmission line through a transformer. Fig.2 shows SSSC structure and SSSC operates as a series capacitor and the series inductance can be controlled. The main difference is that the input voltage is not related to the intensity of the line and can be managed independently. This function allows the SSSC to work satisfactorily with high loads and with lower loads.[8]

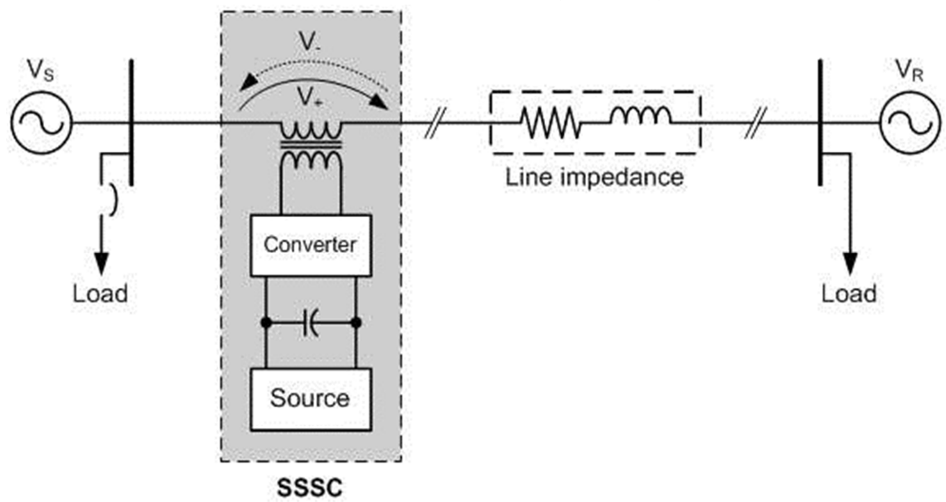

Fig.2 SSSC Structure

1) The Static Synchronous Series Compensator has three basic components: Voltage Source Converter (VSC) – main component.
2) Transformer – couples the SSSC to the transmission line.
3) Energy Source – provides voltage across the DC capacitor and compensate for device losses.

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III. THE PROPOSED APPROACH

A. Structures of SSSC Based Damping Controllers

Fig.3 shows the lead-leg structure of SSSC. The various block of SSSC as gain block, washout block, and a two-stage lead-lag block. A lead-lag operation offers suitable phase leading characteristics for the lag in compensating phase among input and output signals.[8]The input of system is speed and output is system as voltage. The washout block works as high-pass filter and lead-lag block provided as compensation.[13]

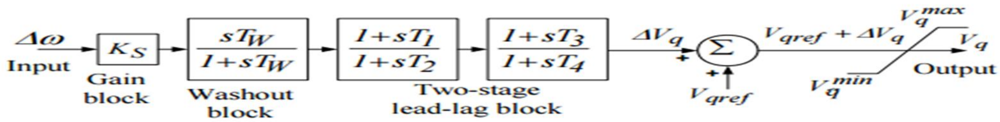

Fig. 3 Structure of SSSC based controller

Objective function for single machine infinite bus system is

$$J = \int_{t=0}^{t=t_{sim}} |\Delta\omega| \cdot t \cdot dt \qquad (1)$$

IV. THE TEACHING LEARNING-BASED OPTIMIZATION (TLBO)

All algorithms based on evo1ution and the intelligence of the swarm are probabilistic algorithms and require common control parameters such as popu1ation size, number of generations, size of e1ites, etc. the transition rate. Similarly, PSO uses inertial weight as well as social and cognitive parameters. The proper setting of the algorithm-specific parameters is a very important factor that affects the performance of the algorithms mentioned above. Incorrect1y tuning a1gorithm-specific parameters increases computational effort or resu1ts in an optimal local so1ution. Therefore, Rao et a1. (2011, 2012a, b), Rao and Savsani (2012), Rao and Pate1 (2012) recently launched the TLBO (Teaching-learning Optimization) algorithm, requiring only the common control parameters and non specific control parameter algorithms. Other scalable algorithms require the control of common control parameters and the control of the algorithm-specific parameters. The load of the tuning control parameters is comparatively lower in the TLBO algorithm. Thus, the TLBO algorithm is simple, efficient and requires relatively less computing effort. Therefore, TLBO was used in this work to test the unrestricted and limited multi-object test functions, and the results were compared to other optimization algorithms. TLBO algorithm, a teacher based on the performance impact of learners in the class, is an algorithm that is based on the teaching and learning proposed by Rao [1]. This algorithm, and interacting, describing the two basic modes of learning (i) by teachers (known as a teacher step) and (ii) other learners (known as a learner's level) Describe. This optimization algorithm is considered the group of learner is considered as the population will be provided different topics for the learners, to different design variables of the optimization problem considered, "goodness of adaptation" learning outcomes optimization problem value .. The best solution for the entire population is a teacher. The design variable is actually a parameter that relates to the objective function of the given optimization problem, and the optimal solution is the best value of the objective function. The work of TLBO is divided into two parts, "teacher level" and "learner level". The TLBO algorithm has already been tested with several limited and unrestricted benchmark functions and is superior to other advanced optimization techniques[2]

A. Algorithm of TLBO

Below is the steps describing TLBO algorithm.

1) The population (no. of students) size is started in the class N, no. of generation G corresponds to no. of units in distribution system D and limits of design variables. (U_L upper and L_L lower).

   Optimization problem: Minimize *f*(x), such that $L_L \le x \le U_L$

   f(x)= objective function x= vector for design variables

2) Generate a random population according to the number of students in the class (*N*)and number of subjects offered (*D*). This population is mathematically expressed as

$$V = \begin{bmatrix} x_{1,1} & x_{1,2} & \cdots\cdots & x_{1,D} \\ x_{2,1} & x_{2,2} & \cdots\cdots & x_{2,D} \\ \cdots\cdots & \cdots\cdots & \cdots\cdots & \cdots . \\ x_{N,1} & x_{N,2} & \cdots\cdots & x_{N,D} \end{bmatrix} \qquad (2)$$

$x_{i,j}$= initial grade of j^{th} subject of the i^{th} iteration.

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3) Evaluate the average grade of each subject offered in the class. The average grade of the j^{th} subject at generation g is given by

$$M^g = mean\ (x_{1,j}, x_{2,j}, \dots \dots, x_{i,j}) \quad (3)$$

4) Based on the objective value sort the population from best to worst. The best solution (teacher) is

$$X_{teacher} = x \qquad for\ \ f(x) = min \quad (4)$$

5) Changing grade point of every control variables of every individual student. These are,

$$x^g_{new(i)} = x^g_i + rand * (X^g_{teacher} - T_F M^g) \quad (5)$$

$$x^g_{new(i)} = x^g_i + r_1 * (X^g_{teacher} - round[1 + r_2]M^g) \quad (6)$$

r_1, r_2 are random numbers between [0, 1].

V. RESULT AND DISCUSSIONS

The Sim power system tool boxes are used for analysis and develop the power system model. This is a very useful tool for modeling and simulation. This tool contains power library. Several blocks are available in library such as generators, different types of machines, power electronic converter, excitation system, different drives, transformers, transmission lines etc.

A. MATLAB Model of SMIB System with SSSC Controller

Fig.4 shows MATLAB model of SMIB system with SSSC controller. This paper is carried on a modified Heffron-Phillips model of a single machine infinite bus (SMIB) system integrated with SSSC. In the following a TLBO for SSSC is well-designed to enhance the transient stability of the power system. In order to evaluate the performance of the proposed TLBO in damping low frequency oscillations (LFO), the SMIB power system is subjected to a disturbance such as changes in electromechanical power. Digital simulations are performed in the MATLAB/Simulink environment to provide comprehensive understanding of the issue. Simulation studies validate the effective performance of the developed TLBO in damping electromechanical oscillations in comparison without SSSC.

Constants of the model depend on system parameters and the operating condition. Signal m is the modulating index of the inverter, and it is assumed to be the control signal of the SSSC. So that the magnitude of the series injected voltage can be controlled and the desired dynamic compensation of the reactive power will be achieved.

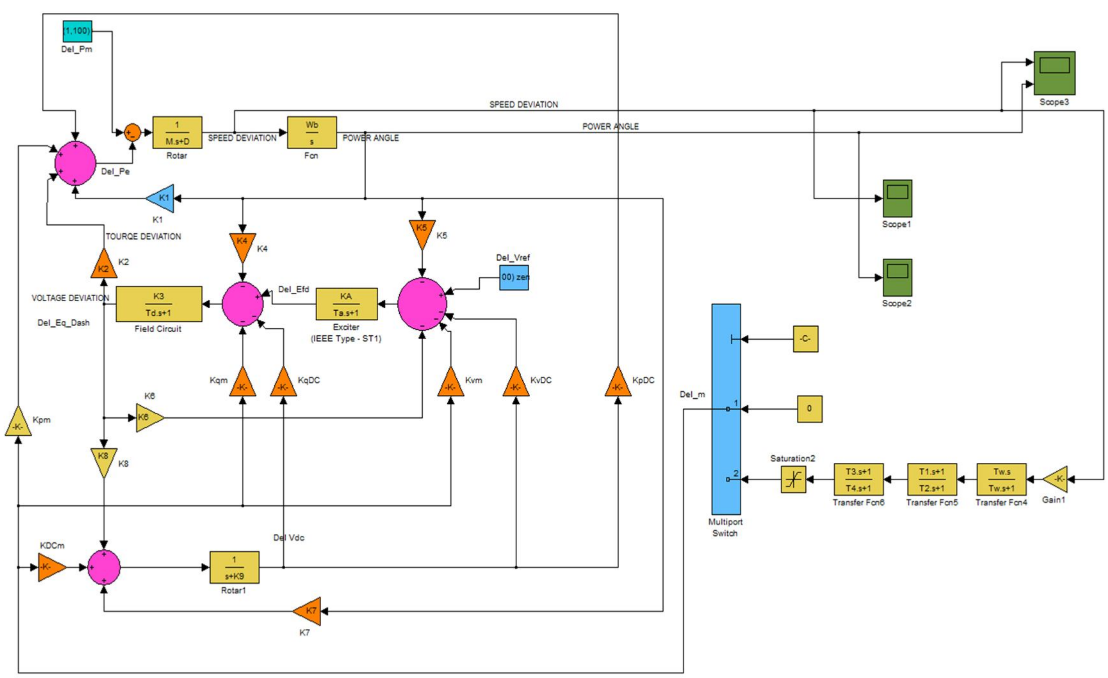

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Table 1: TLBO optimized SSSC controller parameters for SMIB

S.N.	System	TLBO Optimized SSSC Controller Parameters		
		K	T_1	T_3
1.	SMIB system	19.9239	1e-4	30.4572

The characteristic response of the objective utility is shown in Fig.5.

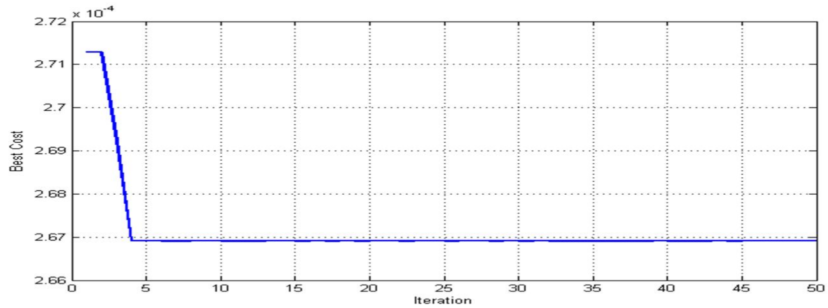

Fig.5 Convergence of fitness role for SMIB power system

B. Simulation Result for SMIB Power System

The performance of the power system was evaluated considering reference voltage setting & mechanical torque input. We tested at various conditions as 30%, 100% step increase. The various graphs the change in speed deviation & power angle deviation has been shown. Response with both no control and TLBO based optimal control are displayed

1) *30% Step Increase in Reference Voltage Setting in SMIB without & with TLBO Tuned SSSC Controller:* The fig. 6 to 7 shows both the responses when SSSC is not used and when it is used with TLBO. The various response shows as speed, power angle deviations. From these responses, it is known that uncontrolled response is poorly damped and controlled response settle down quickly as both conditions

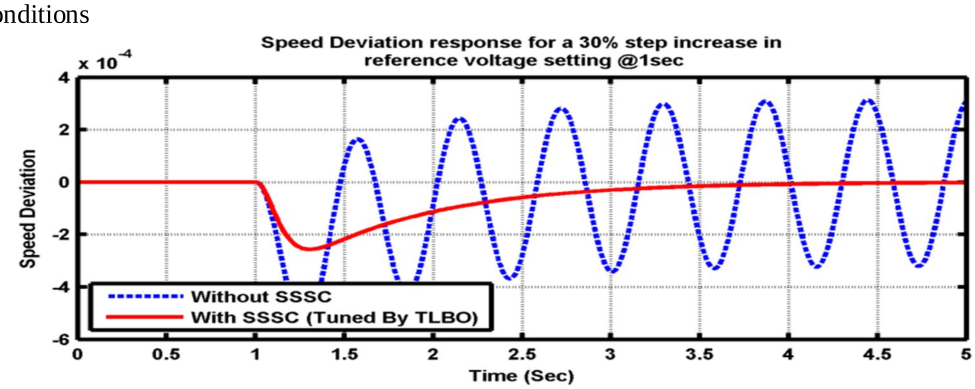

Fig.6: Speed deviation in SMIB system in reference voltage setting

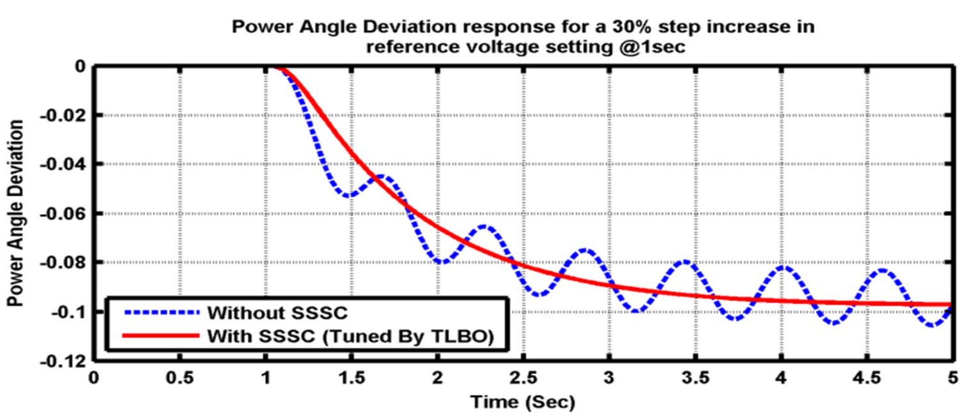

Fig.7: Power angle deviation in SMIB system in reference voltage setting

2) *30% Step Increase in Mechanical Torque input in SMIB without & with TLBO Tuned SSSC Controller:* The fig.8 to 9 shows both the responses when SSSC is not used and when it is used with TLBO. From these responses, it is known we got better response when we tuned SSSC by TLBO algorithm.

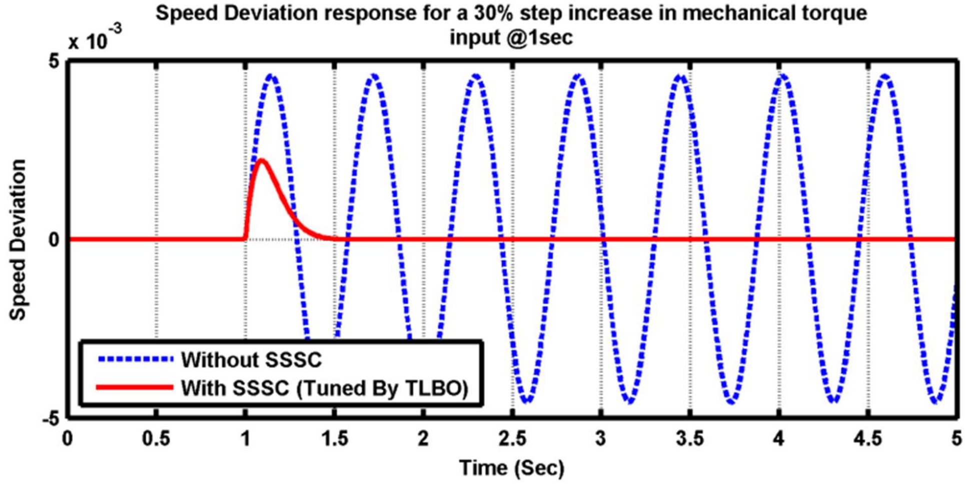

Fig.8: Speed deviation in SMIB System in mechanical torque Input

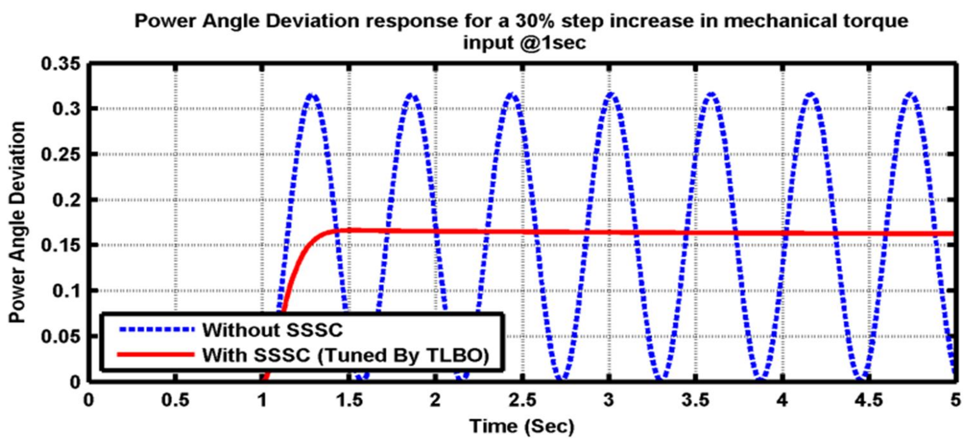

Fig. 9: Power angle deviation in SMIB system in mechanical torque input

3) *100% Step Increase in Reference Voltage Setting in SMIB without & with TLBO Tuned SSSC Controller:* Fig.10 to 11 shows speed deviation and power angle deviation at reference voltage setting in without and with SSS controller, but when parameter tuned with TLBO we get superior response.

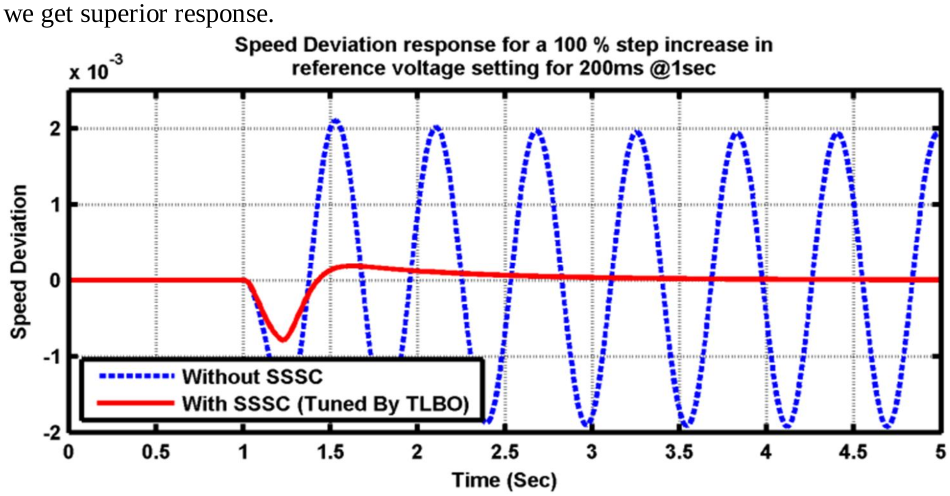

Fig. 10: Speed deviation in SMIB system in reference voltage setting

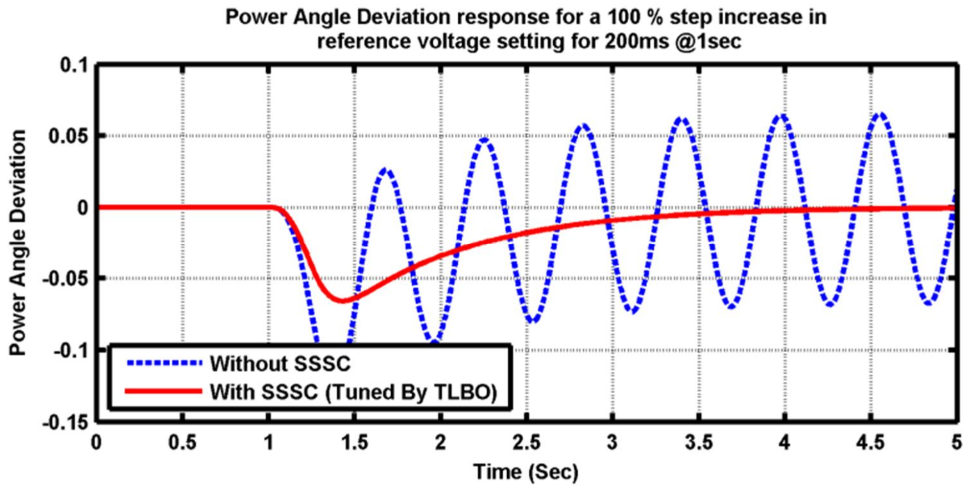

Fig. 11: Power angle deviation in SMIB system in reference voltage setting

4) *100% Step Increase in Mechanical Torque input in SMIB without & with TLBO Tuned SSSC Controller:* Fig.12 to 13 shows speed deviation and power angle deviation at mechanical torque input without and with SSS controller, but when SSSC parameter tuned with TLBO system fast settle and improve stability.

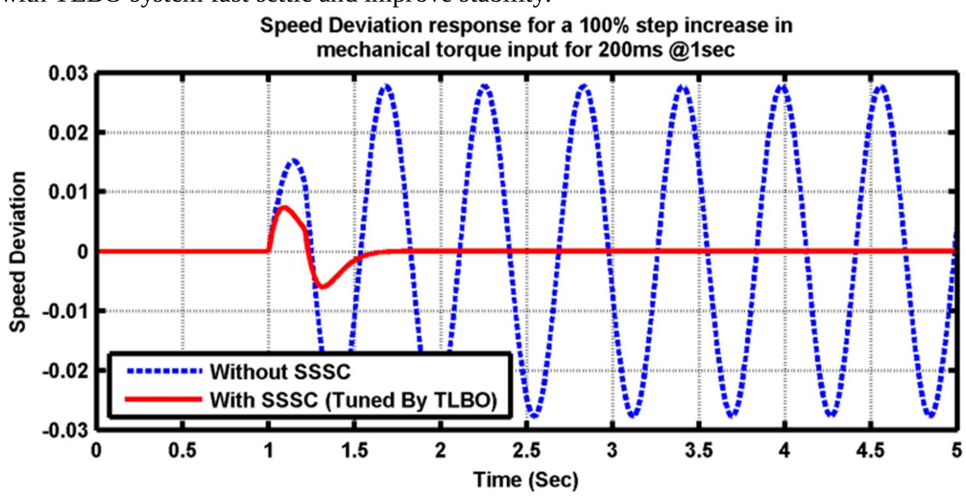

Fig. 12: Speed deviation in SMIB system in mechanical torque input

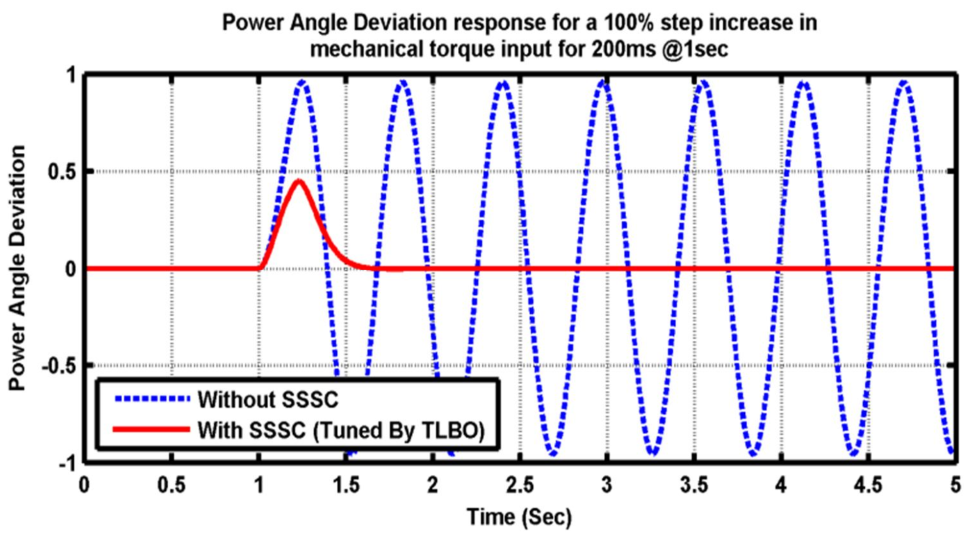

Fig. 13: Power angle deviation in SMIB system in mechanical torque input

5) *Parameter Variations at 30% Step increase Mechanical Torque input:* Fig.14 to 15 shows speed deviation and power angle deviation at mechanical torque input without and with SSS controller, at 25% increase and 25% decrease machine inertia constant. The system stability improve when we use TLBO tuned SSSC controller.

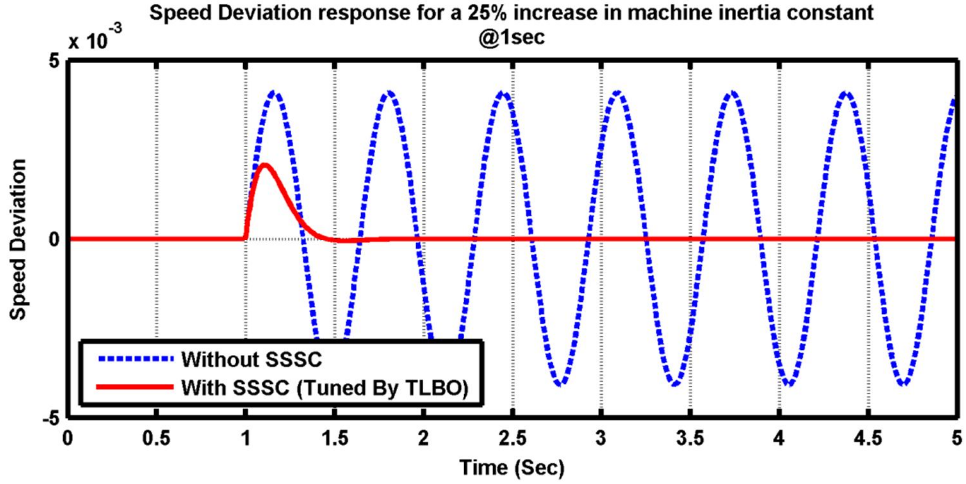

Fig. 14: Speed deviation in SMIB system in mechanical torque input

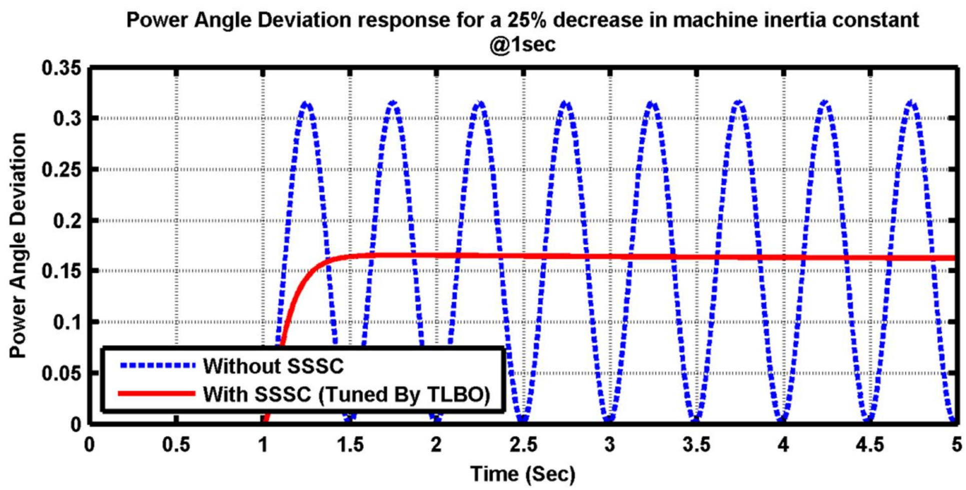

Fig. 15: Power angle deviation in SMIB system in mechanical torque input

6) *Parameter Variations at 30% Step increase Reference Voltage Setting:* Fig.16 to 17 shows speed deviation and power angle deviation at reference voltage setting without and with SSS controller, at 25% increase and 25% decrease machine inertia constant. The system stability improve when we use TLBO tuned SSSC controller.

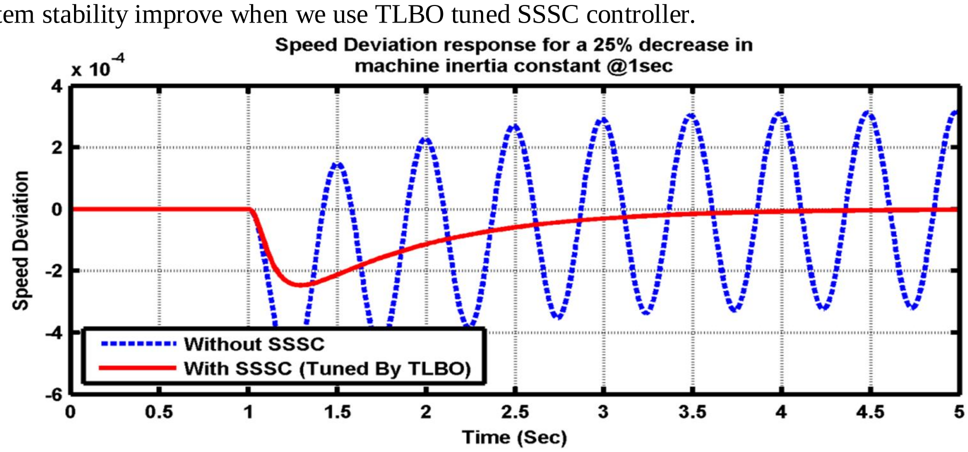

Fig. 16: Speed deviation in SMIB system in reference voltage setting

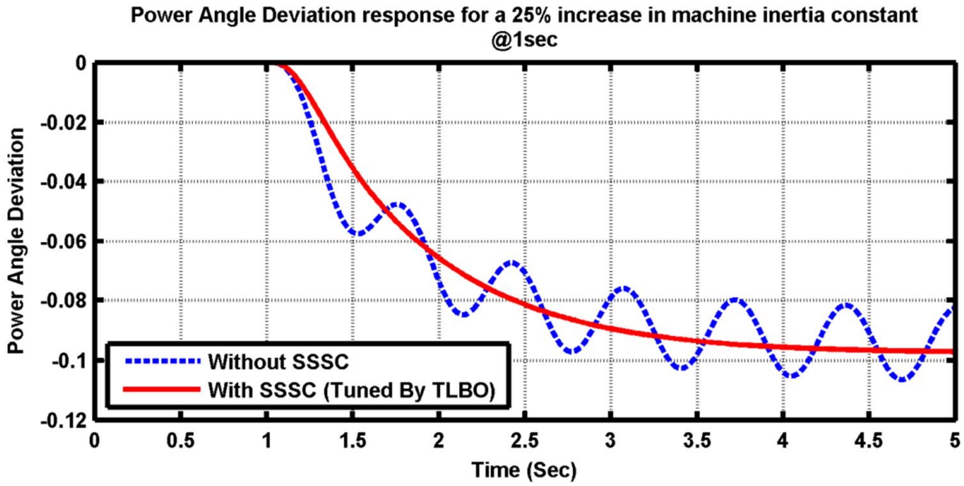

Fig. 17: Power angle deviation in SMIB system in reference voltage setting

VI. CONCLUSIONS

In this paper, A Phillips-Haffron model based SMIB system has been developed with the integration of TLBO based SSSC controller and then was analyzed in MATLAB/Simulink. The conditions under which the system is analyzed are different reference voltage settings and mechanical torque input observing the settling time after deviations in speed, power angle. Under any conditions, the system without SSSC as controller for damping underperforms as the damping is really poor. With the inclusion of TLBO based SSSC controller for damping system performances improves.

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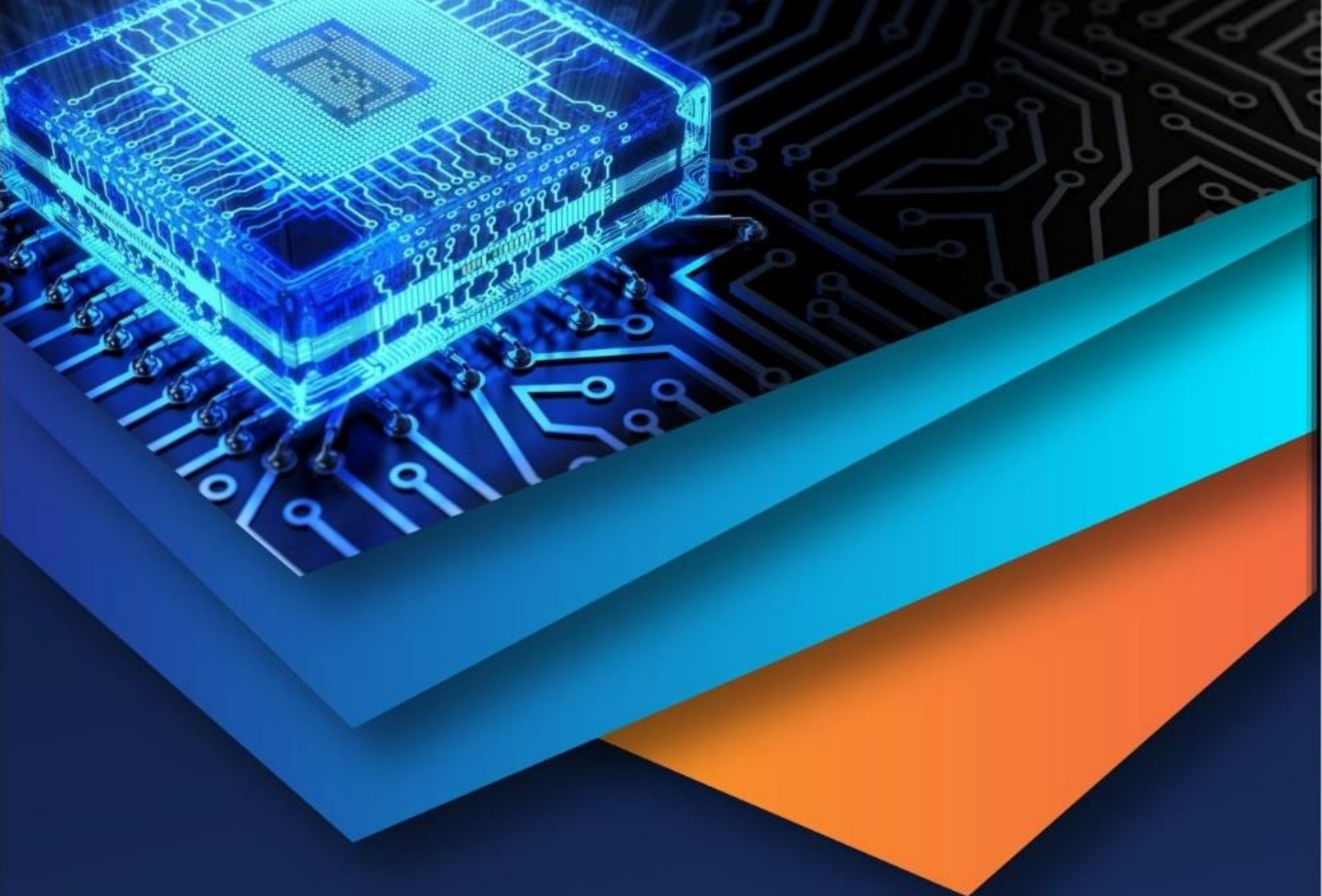

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