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DESIGN OF SSSC BASED DAMPING CONTROLLER USING TLBO ALGORITHM

Kapil Parkh and Vinesh Agarwal
Department of Electrical Engineering, Sangam University, India

Abstract

The proposed study shows a coordinated serial synchronous static compensator (SSSC) design that has been introduced as a complement to soaking oscillations at low frequencies. The design and structure of SSSC-based control is based on the forward delay structure and includes gate turn of thyristor (GTO) as a control device. This controller is implemented in a single machine Infinity Bus Power System (SMIB) based on the Philips Heffron model to reduce low frequency oscillations. To adjust the parameters of the damping controller, the optimized learning-learning algorithm (TLBO) is used under various conditions such as reference voltage adjustment and parameter variation. The problem statement is formulated as an objective function using the absolute integral time error (ITAE). In addition, the given model has also been changed to MATLAB and changes in the reference voltage configuration and variation of system parameters have been tested. Later, these results were compared with different controllers and different objective functions to verify their soundness and system efficiency.

Keywords:

Power System, Philips Heffron model, Single Machine Infinite Bus System, Flexible AC Transmission System, Reference Voltage Setting, Parameter Variations

1. INTRODUCTION

Today, the energy requirement is increasing at a faster rate than production. Therefore, it is overloaded compared to its previous position. To solve this problem, there is a need to establish new generating units, which is not possible at the same rate due to the rate of energy consumption and other environmental restrictions. The solution to this problem may be to connect one area of the power system to another to cope with the increased load demand. But the operation of the power system in interconnections generally leads to the introduction of oscillations at low frequencies. The range of these oscillations varies from 0.2 to 3.0 Hz. Furthermore, a system is required to operate within its stability limits. An observation is that these systems are interconnected using weak link lines, making them more susceptible to oscillations, which can lead to loss of synchronism. Therefore, a system needs to be well damped to overcome these problems [1].

In the direction of finding current solutions, we have seen steady but rapid progress in power electronics. A great example is the Flexible AC Transmission System (FACTS) device. This family of devices has the ability to control the flow of energy through the lines and can, therefore, provide well soaking systems using it, as they are very fast and responsive [2].

It can be divided into two different categories depending on the equipment used. With a thyristor and a gate true closed (GTO) with thyristor. Among these, many members such as Synchronous Series Static Compensator (SSSC) have versatile features. This can eliminate the oscillations mentioned above; therefore, it can improve the stability of the system, moreover, regulating the flow of energy on the lines [3]. In addition, it refers to capacitive behavior or inductive behavior depending on the position on the line. It provides compensation to the lines by injecting controlled voltages in series. In general, it is a very sensitive and fast device [4].

Currently, the focus here is on the small signal stability of the electrical system for which we employed in the Phillips – Heffron linear model. This model is sufficient to conduct the proposed study. This given model is being introduced with low frequency oscillations that were then damp using a soaking controller that typically uses a lead delay structure. In keeping with the previous discussion, the damping controller employed has a main delay structure and is based on SSSC. But adjusting its parameters is quite difficult. Traditionally, it is time consuming and has a slow convergence rate [5]. This type of practice has highlighted development-based optimization techniques. These can be considered evolutionary techniques, as it corresponds to the behavior of nature [6]. Examples are genetic algorithm [7], particle swarm optimization [8], bacteria discovery optimization [9] etc.

In studying recent research, we came to know a new type of technique for solving optimization problem, which has gained popularity due to its many positive points. It is an optimization algorithm based on teacher learning (TLBO) [10]. TLBO is a new type of optimization algorithm for more optimal problem operation, which has been previously, solved using other techniques. It is a simple concept that consist of two parts, one is the master phase and the other is the learning phase [11].

Therefore, in a given low-frequency oscillation soaking study, the TLBO is used as an optimization technique to optimize the parameters of the SSSC-based damping controller. This problem is based on the time domain objective of integral multiplication by velocity deviation error. Furthermore, after the simulation is executed and the results obtained, a comparison is made with the optimized GSA controller to show the effectiveness of the displayed controller. The system performed tests and verified with various controllers (LEED-LAG, PID, PI) and various target functions (IAE, ITAE, ITSE).

The purpose of this research is to propose quick decisions, construction, high precision and advanced high performance Model for charging solar intelligent hybrid micro grid Balance and balance everything to maximize resource utilization Aide micro grids for smooth, sustained strength Supply which is the main objective of the project For the achievement of purpose, we aim to use in-depth learning for short-term forecast energy loads And the production of micro grid energy using historical data. The concept of the model is that, based on the forecast; If a micro grid is going to produce insufficient energy, and then it is moved by one or more connected neighbors Micro network Power, in a balanced way so that each and every micro grids. It can be run without any problem. If coincidentally produced micro grids and transport power will not be sufficient for load balancing Then the diesel generator will start first automatically Detachment of charge to avoid detachment.

In this article, we will first discuss deep learning and its properties in section 2. Section 3 shows the study of second literature on different research papers. Section 4 discuss different types of methods and formulas and it is used in our research work and other standards. Problem creation in section 5 and the proposed model is discussed. In section 6 shows the experimental results and discussion followed that conclusion and future scope are discussed in section 7.

2. SINGLE MACHINE INFINITE-BUS (SMIB) POWER SYSTEM WITH SSSC

The system shown in Fig.1 below is investigated. The system has two signals as input to the SSSC. The first input signal is the VSC (M) amplitude modulation ratio. It is based on pulse width modulation (PWM). The second is the phase of injection voltage (OF). It is square with the main current, highlighting the disadvantages present in the inverter. Therefore, by varying the applied voltage amplitude, level compensation can be obtained. Therefore, SSSC is used with a sponge to improve the stability of the system [12].

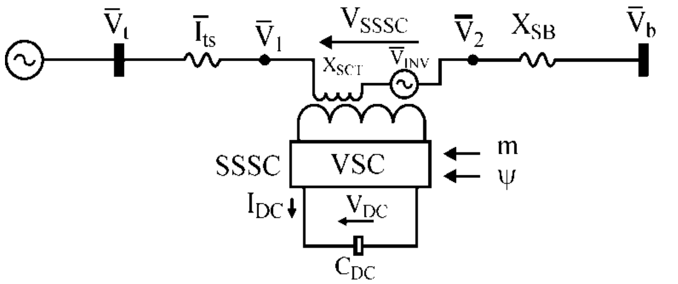

Fig.1. SMIB System with SSSC [5]

Originally it is a VSC built with semiconductor devices. It is implemented in series transmission line for impedance compensation. This generates AC voltage that can be regulated and then injected in series, where it is connected in quadratic with the line current. Therefore, it can control the flow of energy on the line presenting a capacitive or inductive reaction.

3. LITERATURE REVIEW

In a literature survey we found that many authors are working on small signal stability analysis and SMIB systems with SSSC based controllers. Controller parameters have been optimized using various optimization techniques. This probe controls the SSSC controller parameters optimized with TLBO and GSA algorithms.

In [1], power systems define various aspects of stability and discuss SMIB systems with modeling is discussed. Hingorani et al. [2] defining various FACTS controllers and their performance analysis with power supply. Khadanga et al. [3] presented an efficient approach to design an SSSC-based complementary controller for damping low frequency oscillations. Its lead retiring structure is used. Its parameters have been adapted with GSA. To improve the robustness of the proposed controllers, simulations are performed on a power system with SMBS. Song et al. [4] presented FACTS controller and various applications of FACTS in power system. Sawyer et al. [5] defined various stability classifications and implementations with power systems with different problems and its modeling.

Khadanga et al. [6] to improve the robustness of the proposed controller simulation in a power system consisting of SMIB with SSSC is presented. The simulated results are evaluated against traditional methods and comparison shows that the proposed approach is more accurate and robust.

Panda et al. [7] defined SSSC controller and optimized it using a bacteria feeding algorithm. Mahapatra et al. [8] used the DSS controller and the SSSC controller used for a hybrid firefly algorithm and a pattern search technique, used to adapt the parameters and different simulation results to different failure situations.

Panda et al. [9] defines the SSSC controller that is used for the damping controller and the simulation results define the performance with different failure conditions. Rao et al. [10] defined performance of TLBO algorithms and practical application of TLBOs in various fields. Sven et al. [11] explained the UN mastered classification GA to use in a previously known optimal solution set dimmed structured SSSC based stabilizer. Design goals are considered to achieve maximum benefit at minimum cost to select the best compromise solution.

Lei et al. [12] explained the performance of the FACTS controller and its performance and the SSSC controller is to reduce wet oscillation very quickly. Rao et al. [13] defined TLBO algorithm is implemented in the power system and various applications of the TLBO are implemented in the power system. TLBO is a recent algorithm and shows better results than other algorithms.

The review by different author developed Phillips Haffron model of SMIB system but when controller parameters tuning with TLBO algorithm system shows best result compare than previous result and settling of system improves. Ultimately the stability of system is improves is main objectives.

4. PROPOSED APPROACH

4.1 CONTROLLER BASED ON SSSC

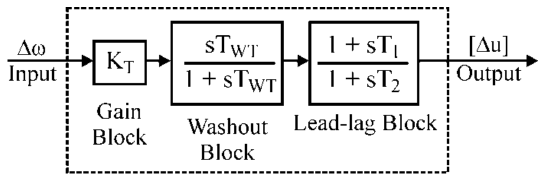

Fig.2. Structure of Lead-Lag Controller

As shown in the Fig.2 SSSC design is based on lead lag structure. There are three blocks mentioned in it. The third block performs phase compensation operation because a phase delay exists between the input signal present and the received signal at the output. The middle block, as its name suggests, serves to pass an input signal while passing an unwanted signal. High pass filters are used for this. The input speed change for the controller is ($\Delta\omega$) while the output is control vector (Δu) [13].

4.2 OBJECTIVE FUNCTION

Here, J is the objective function formulated using the absolute integral time error for velocity deviation. It is shown as.

$$J = \int_{0}^{t_{sim}} t\left|e(t)\right|dt \tag{1}$$

where

e is the error signal (Δu)

t_{sim} is the simulation time range.

The objective function should be minimized for better system response in terms of disposal of time and overshoot. The problem is the parameter limitations of the SSSC driver on the lock.

Minimize J Subject to

$$K_T^{\min} \le K_1 \le K_T^{\max} \tag{2}$$

$$T_1^{\min} \le T_1 \le K_1^{\max} \tag{3}$$

$$T_2^{\min} \le T_2 \le K_2^{\max} \tag{4}$$

4.3 THE LINEARIZED EQUATIONS

When designing an electromechanical damping stabilizer, a linear incremental model around an operating point is commonly used. The Philips Heffron power system model is obtained around a fixed operating point. This is done by linearizing the system equations and they are initially nonlinear. The Fig.3 shows the modified model of the SMIB system. In this modified model the various scalar constant K_1 to K_9 and other K_{pu}, K_{qu}, K_{vu} and K_{cu} is define as row vector.

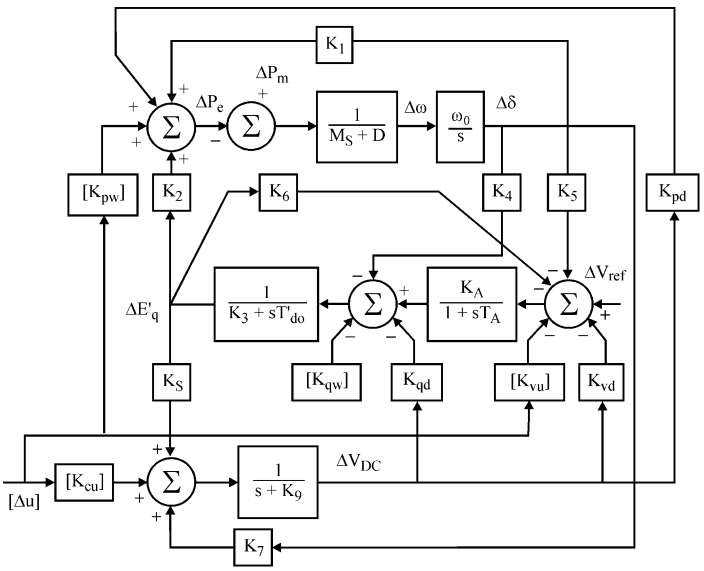

Fig.3. Modified Phillips Heffron Model of SMIB System

$$\Delta\dot{\omega} = \frac{\Delta P_m - \Delta P_e - D\Delta\omega}{M} \tag{5}$$

$$\Delta\delta = \omega_0 \Delta\omega \tag{6}$$

$$\Delta E_q = \frac{-\Delta E_q - \Delta E_{fd}}{T_{do}^{'}} \tag{7}$$

$$\Delta\dot{E}_{fd} = \frac{-1}{T_A}\Delta E_{fd} + \frac{K_A}{T_A}\left(\Delta V_{ref} - \Delta V_t + V_s\right) \tag{8}$$

$$\begin{aligned}\Delta\dot{V}_{dc} &= K_7\Delta\delta + K_8\Delta E_q' + K_9\Delta V_{dc} + K_{cm}\Delta m_E \\ &+ K_{c\delta m}\Delta\psi + K_{cb}\Delta m_B \Delta\psi\end{aligned} \tag{9}$$

where

$$\Delta P_c = K_1\Delta\delta + K_2\Delta E_q' + K_{pm}\Delta m + K_{p\delta m}\Delta\psi + K_{pb}\Delta m_B + K_{pd}\Delta V_{dc}$$

$$\Delta E_q = K_3\Delta E_q' + K_4\Delta\delta + K_{qm}\Delta m + K_{q\delta m}\Delta\psi + K_{qd}\Delta V_{dc}$$

$$\Delta V_t = K_5\Delta\delta + K_6\Delta E_q' + K_{vd}\Delta m + K_{v\delta c}\Delta\delta_E + K_{vdm}\Delta\psi + K_{vd}\Delta V_{dc}$$

$K_{pu}, K_{qu}, K_{vu}, K_{cu}$ are row vectors defined as:

$$K_{pu} = [K_{pm} \cdots K_{p\delta m}]$$

$$K_{qu} = [K_{qm} \cdots K_{q\delta m}]$$

$$K_{vu} = [K_{vm} \cdots K_{v\delta m}]$$

$$K_{cu} = [K_{cm} \cdots K_{c\delta m}]$$

The vector u is defined as:

$$u = [\Delta m \cdots \Delta\Psi]^T$$

where Δm is the change in modulation index and $\Delta\Psi$ is the change in phase angle

5. SSSC CONTROLLER - TLBO ALGORITHM

This technique is similar to that given in [10] [13]. It is based on the learning environment in the classroom where teachers and students (learners) are and it works in two stages. As there are two different types of people in the class, the first stage is named teacher and the second stage is named apprentice. Students, teachers, participant outcomes and classroom subjects correspond to the population, the best solution, the appropriate value of the optimization algorithm, and the designed variable. Here, the teacher is considered to be the best solution, as students first learn only from them. A brief description of the steps is given below.

5.1 TEACHER PHASE

In this phase, the teacher teaches the student. Basically, students move as close to the teacher as possible, because this is the best solution. In other words, the teacher increases the average result for the class. Let, i is the iteration, m is the total subjects (design variables), n is the total learners, Population size is the k varying from 1 to n and $M_{j,i}$ is the learners mean result in any subject (j varying from 1 to m)

In a given population, all subjects are taken into account and the results are obtained. The best result of them is taken as k_{best}, where, k_{best} is the best student, assigned the best overall result, namely, iteration from X_{total}-$k_{best,i}$. But in a class, the teacher is one with all the knowledge and the other members (trainees) in the class impart knowledge to him, therefore, the teacher is the best student.

$$Difference\_mean_{j,k,i} = r_i\left(X_{j,kbest,i} - T_F M_{j,i}\right) \tag{10}$$

where, $X_{j,kbest,i}$ is the best learner result for j, TF is the teaching factor (1 or 2) (not a parameter in TLBO) and r_i is the random number [0,1].

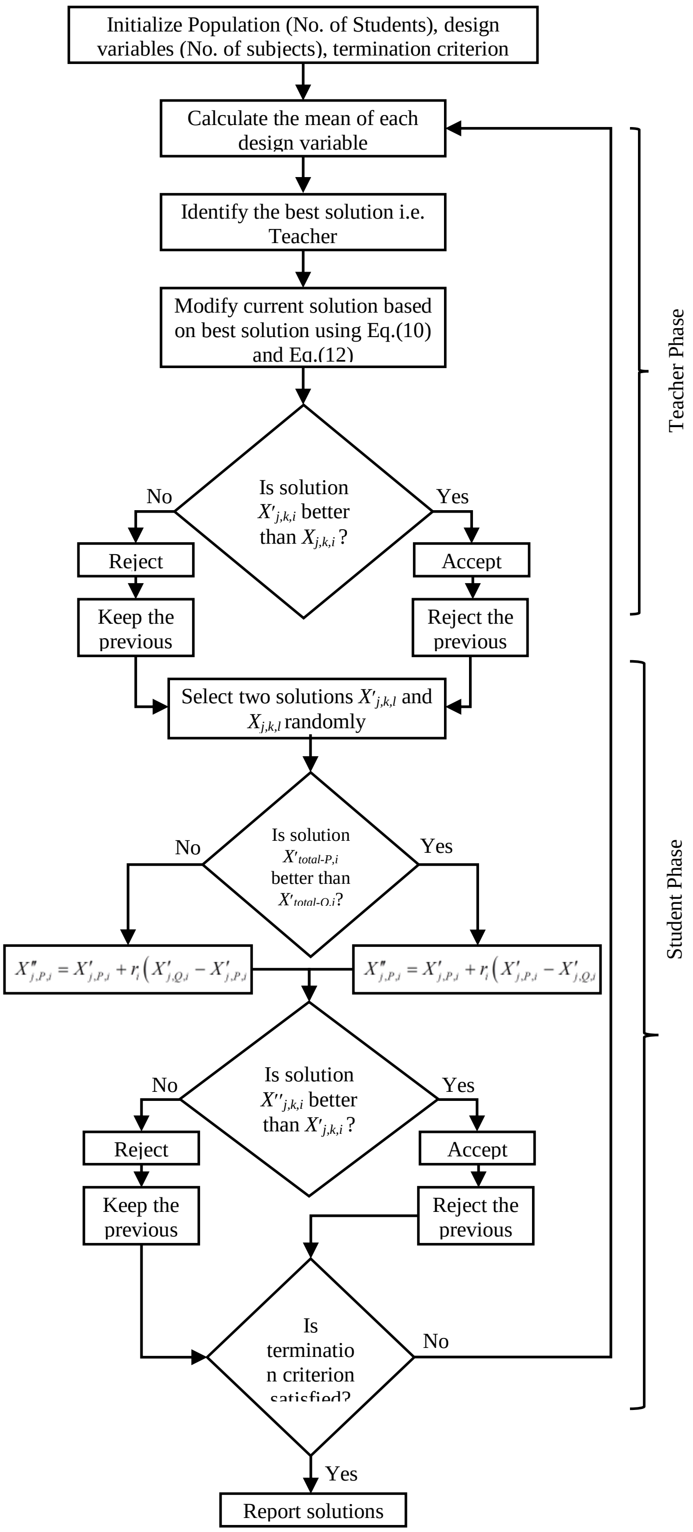

Fig.4. Flow Chart of TLBO Algorithm [14]

Equal probability decides TF which is, shown as,

$$T_F = round\left[1 + rand\left(0,1\right)\left\{2-1\right\}\right] \quad (11)$$

TF is randomized by Eq.(10). It does not initially exist for the algorithm. For the algorithm to work properly, it must be within 1-2. Based on the difference of the mean *j*, *k*, *i*, the current phase is updated to the master phase

$$X'_{j,k,i} = X_{j,k,i} + Difference\_mean_{j,k,i} \quad (12)$$

where, $X'_{j,k,i}$ is the updated value of $X_{j,k,i}$ that gets is acknowledged if it improves function value [14].

5.2 LEARNER PHASE

This is the second part of the algorithm in which students develop their knowledge and interact with each other. There is communication between different students present in the class, which ultimately results in an increase in their knowledge group. This can only happen when one student knows more than the other. For the population of *N*, it is learning. It is explained below.

We selected learners *P* and *Q*:

$$X''_{j,P,i} = X'_{j,P,i} + r_i\left(X'_{j,P,i} - X'_{j,Q,i}\right), if\ X'_{total-P,i} \le X'_{total-Q,i} \quad (13)$$

$$X''_{j,P,i} = X'_{j,P,i} + r_i\left(X'_{j,Q,i} - X'_{j,P,i}\right), if\ X'_{total-Q,i} \le X'_{total-P,i} \quad (14)$$

where, $X''_{j,P,i}$ is approved when better value

It is inspired by the classroom environment where the teacher teaches the students to increase their knowledge. Therefore, it is a population-based technique and requires population size and generation number as control parameters. The flow chart of the TLBO algorithm is shown in Fig.4. The steps of flow chart is defined in Fig.5.

Algorithm 1: Pseudo-Code of TLBO Algorithm

Input: Initialize *N* (number of learners) and *D* (number of dimensions)

Output: The teacher *XTeacher*

Step 1: Begin

Step 2: Initialize learners and evaluate them;

Step 3: Let the best learner as *XTeacher* and calculate the mean

Step 4: While (stopping condition is not met);

- a. For all learners % Teaching phase
  - i. *TF* = round(1 + rand(0,1));
  - ii. Update all learners according to Eq.(2);
- b. End for

Step 5: Evaluated the new learners;

Step 6: Accept each new learner if it is better than the old one;

Step 7: For all learners % Learning phase

- a. Randomly select another learner which is dill rent from it;
- b. Update the learners according to Eq.(3).

Step 8: End for

Step 9: Accept each new learner if it is better than the old one;

Step 10: Update the teacher and the mean;

Step 11: End while

Fig.5. Various Steps of TLBO Algorithm

6. EXPERIMENTAL RESULT AND DISCUSSION

In the results section we analyze the modified Philips Hafron model of the SMIB system with SSSC. The system was tested with a variety of disturbances, such as setting reference voltages, parameter variations, various controllers, and target functions. Various types of plotted graphs such as speed, power angle, electric power angle deviation without controller and GSA with TSBO technique. That proposed system of SMIB system built by TLBO technology.

6.1 CASE-1: 5% INCREASE IN REFERENCE VOLTAGE SETTING

Initially, SSSC has no controller for soaking. Then, SSSC controllers connected with GSA and TLBO were used for these cases, with time speed, electric angle and electric power deviation shown in Fig.6 - Fig.9. It is observed from these reactions that the uncontrolled reaction is poorly damped and the controlled reaction stabilizes quickly. The TLBO tuned SSSC shows better response than the GSA tuned SSSC. The Fig.6 shows the best cost vs. iteration graph. The TLBO differentiated SSSC parameters and the different algorithm separating the time response time is shown in Table.1 and Table.2.

Table.1. TLBO Tuned SSSC Parameters

TLBO Tuned SSSC Parameters		
K	T_1	T_2
68.6674	0.2980	0.2658

Table.2. Settling time at 5% increase in reference voltage setting

Types of Deviation	Without SSSC Settling Time	With GSA SSSC (Settling Time in s)	With TLBO SSSC (Settling Time in s)
Speed Deviation	Highly Oscillatory	2.1274	1.4984
Power Angle Deviation	Highly Oscillatory	2.0165	1.4373
Electrical Power Deviation	Highly Oscillatory	1.748056	1.5417

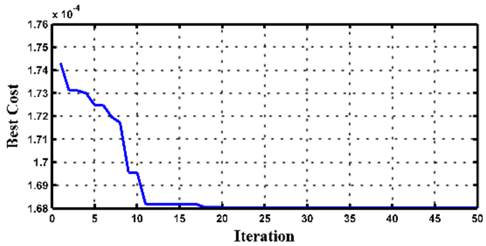

Fig.6. Best cost vs. Iteration Graph of TLBO

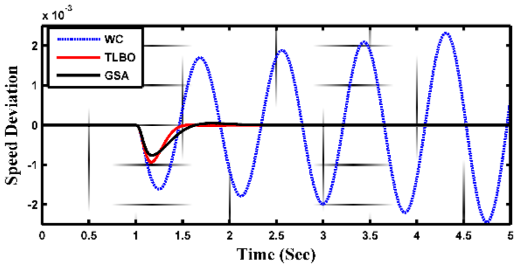

Fig.7. Speed deviation response for a 5% step increase in reference voltage setting

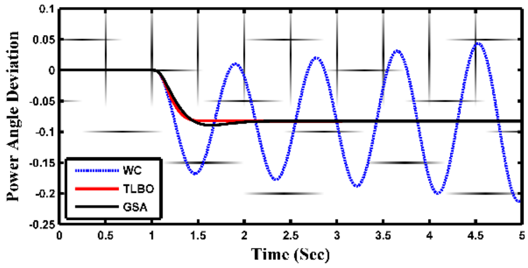

Fig.8. Power Angle Deviation Response for a 5% Step Increase in Reference Voltage Setting

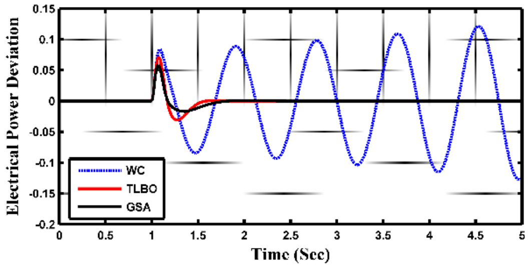

Fig.9. Electrical Power Deviation Response for a 5% Step Increase in Reference Voltage

6.2 CASE-2: PARAMETER VARIATIONS AT 5% INCREASE IN REFERENCE VOLTAGE SETTING

The Fig.10 to Fig.12 show the various responses and the system is tested in 25% increment/open axis direct axis time continuity and machine inertia with parameter variation without SSSC controller, with GSA and with TLBO algorithm. Results from previous simulations have concluded that the TLBO algorithm presents a higher response to the SSSSC controller than the GSA algorithm. The Table.3 shows the comparison table of different controllers with their installation time

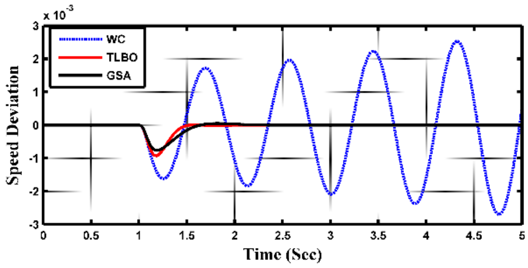

Fig.10. Speed Deviation for a 25% Increase in Open Circuit Direct Axis Transient Time Constant

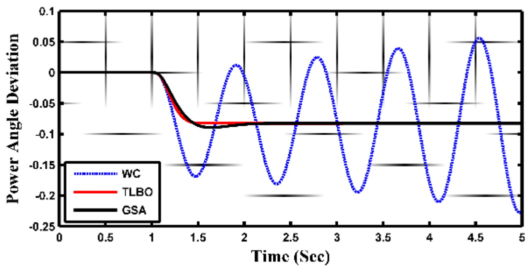

Fig.11. Power Angle Deviation for a 25% Increase in Machine Inertia Constant

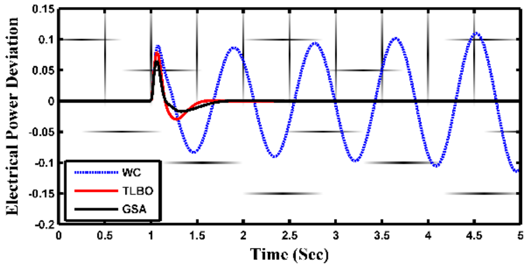

Fig.12. Electrical power deviation response for a 25% decrease in open circuit direct axis transient time constant

Table.3. 25% up/down in open circuit direct axis transient time constant and machine inertia constant with settling time

Types of Deviation	Speed Deviation	Power Angle Deviation	Electrical Power Deviation
Without SSSC	Highly Oscillatory	Highly Oscillatory	Highly Oscillatory
With GSA SSSC	2.1308s	2.0133s	1.7374s
With TLBO SSSC	1.4963s	1.4394s	1.5463s

6.3 CASE-3: DIFFERENT DAMPING CONTROLLER

The Fig.16-Fig.18 show different reactions from different soaking controllers such as TLBO-PI, TLBO-PID and TLBO lead-lag. Finally, the TLBO forward-delay structure shows better response than the TLBO-PI and TLBO-PID controller. Therefore when the system uses the TLBO-lead-lag structure it improves the response and stability of the system. The Table.4 and Table.5 define the comparison with various controller adjustment parameters and their installation time. The Fig.13-Fig.15 show the best cost vs. iteration graphs of the various controllers.

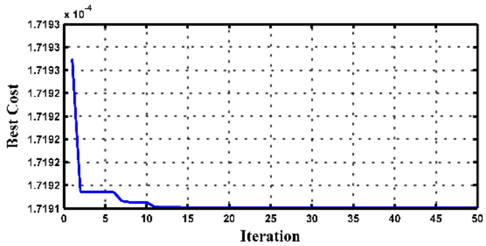

Fig.13. Best cost vs. Iteration Graph of TLBO-PI

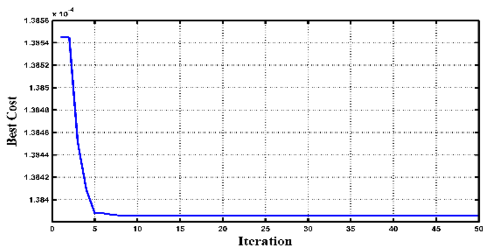

Fig.14. Best cost vs. Iteration Graph of TLBO-PID

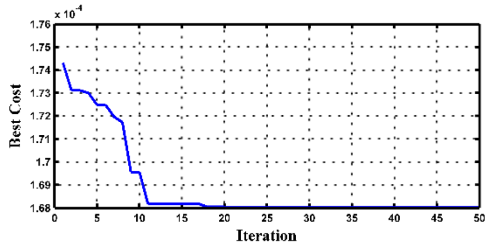

Fig.15. Best cost vs. Iteration Graph of TLBO Lead-Lag

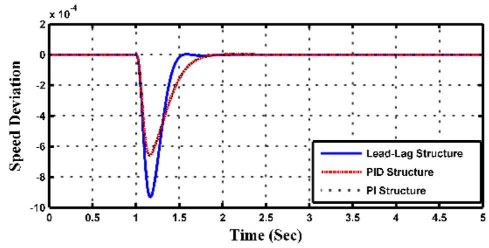

Fig.16. Speed Deviation at Different Damping Controller

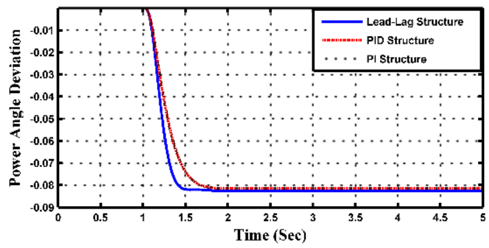

Fig.17. Power Angle Deviation at Different Damping Controller

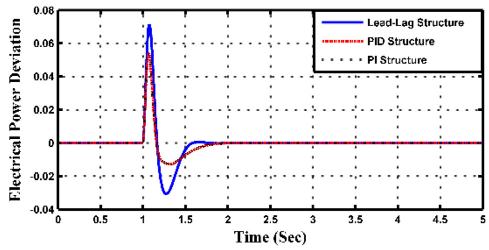

Fig.18. Electrical Power Deviation at Different Damping Controller

Table.4. TLBO Tuned Different Controller Parameters

TLBO-PI			TLBO-PID			TLBO-Lead-Lag		
K_P	K_I	-	K_P	K_I	K_D	K	T_1	T_2
96.6631	0.1		96.6631	0.1	$1e^{-4}$	72.8677	$1.0001e^{-4}$	0.0417

Table.5. Settling Time at Different Controller

Types of Deviation	Settling Time (s)		
	TLBO-PI	TLBO-PID	TLBO-Lead-Lag
Speed Deviation	1.79777	1.7964	1.4984
Power Angle Deviation	1.6689	1.6674	1.4373
Electrical Power Deviation	1.7918	1.7914	1.5417

6.4 CASE-4: DIFFERENT OBJECTIVE FUNCTION

The Fig.22-Fig.24 show different responses for different objective functions such as integral full error (IAE), square error multiplied by integral time (ITSE) and absolute error by integral time (ITAE). In conclusion, TLBO-ITAE shows better response than other objective functions. The Table.6 and Table.7 depict the fitness values, SSSC adjustment parameters and the establishment time of various objective functions. The Fig.19 – Fig.21 represent the best-cost vs. iteration graphs of various objective functions.

Objective function is defined as

$$IAE = \int_0^{t_{sim}} |e(t)|dt \; ; \; ITSE = \int_0^{t_{sim}} te^2(t)dt \; ; \; ITAE = \int_0^{t_{sim}} t|e(t)|dt \quad (15)$$

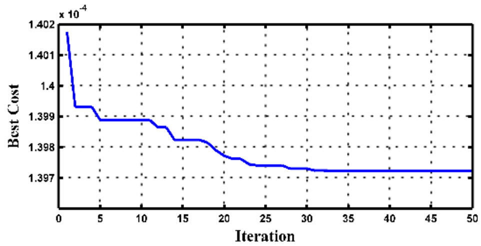

Fig.19. Best cost vs. Iteration Graph of IAE Objective Function

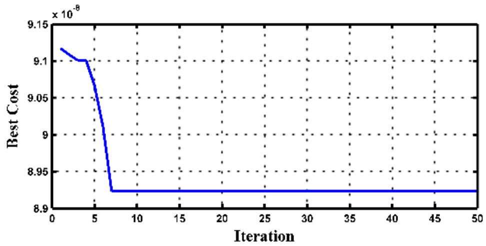

Fig.20. Best cost vs. Iteration Graph of ITSE Objective Function

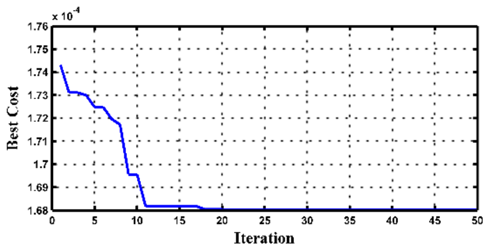

Fig.21. Best cost vs. Iteration Graph of ITAE Objective Function

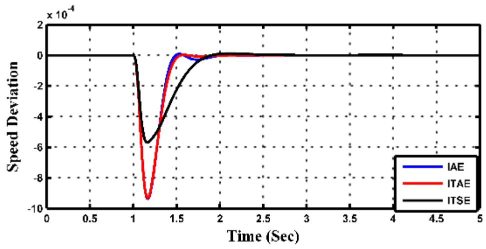

Fig.22. Speed Deviation at Different Objective Function

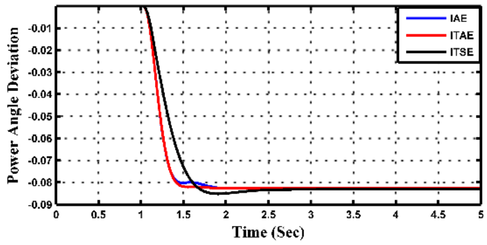

Fig.23. Power Angle Deviation at Different Objective Function

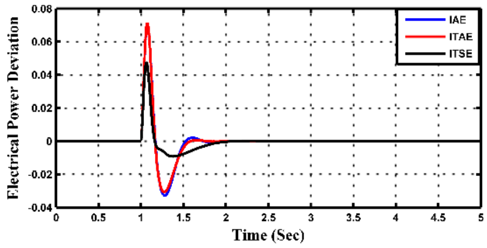

Fig.24. Electrical Power Deviation at Different Objective Function

Table.6. Fitness Value and Parameters of Different objectives Function

Types of Objective Function	Fitness Value	TLBO Tuned SSSC Parameters		
		K	***T*₁**	***T*₂**
TLBO-IAE	1.3972e-4	76.0363	0.064	0.0560
TLBO-ITSE	8.9233e-8	100	0.1	0.0679
TLBO-ITAE	1.6802e-4	72.8677	1.0001e-4	0.0417

Table.7. Different Objectives Function with their Settling Time

Types of Deviation	Settling Time (s)		
	TLBO-IAE	**TLBO-ITSE**	**TLBO-ITAE**
Speed Deviation	1.8459	1.8491	1.4984
Power Angle Deviation	2.1018	1.7191	1.4373
Electrical Power Deviation	1.9130	1.6612	1.5417

7. CONCLUSION AND FUTURE SCOPE

From all previous graphs and results obtained, it has been verified that the proposed scheme showed better responses. This has been confirmed by examining four different cases of the Philips Hafron power system model based on the TLS SSSC driver. It has shown oscillating damping response faster than GSA based systems. Furthermore, in terms of parameter variation, it is superior to the latter schemes. TLBO cable: The delay controller used for a given purpose has worked well compared to the TLBO-PI and TLBO-PID controller. Finally, the objective function TLBO-ITAE response is better than the other two objective functions.

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