

**DESIGN OF ROBUST PSS IN MULTIMACHINE POWER
SYSTEMS USING DRAGONFLY ALGORITHM AND
JELLYFISH SEARCH ALGORITHM**

by

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**BACHELOR OF SCIENCE IN ELECTRICAL AND ELECTRONIC
ENGINEERING**



Department of Electrical and Electronic Engineering
INTERNATIONAL ISLAMIC UNIVERSITY CHITTAGONG

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A thesis
submitted as partial fulfilment of the requirement for the degree of

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CERTIFICATE OF APPROVAL

The thesis/project entitled as “**Design of Robust PSS in Multimachine Power Systems using Dragonfly Algorithm and Jellyfish Search Algorithm**” submitted by **Md. Samiul Azam**, bearing Matric ID. **ET-171009** and **Mohammad Saiful Islam**, bearing Matric ID. **ET-171039** of session **Spring 2017**, to the Department of Electrical and Electronic Engineering, International Islamic University Chittagong, has been accepted as satisfactory in partial fulfilment of the requirements for the degree of Bachelor of Science in Engineering and approved for the examination held on **16th April, 2022**.

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DECLARATION

It is hereby declared that this work has been done by us and no portion of the work contained in this thesis/project has been submitted elsewhere for the award of any degree or diploma.

Md. Samiul Azam

Mohammad Saiful Islam

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Authors

ABSTRACT

In interconnected power system networks, due to the weak tie lines between the generators, low frequency oscillations (LFO) are introduced into the system. LFOs have been a serious concern for engineers for decades, as they cause the system to be unstable by reducing the damping torque if LFOs are not damped out rapidly. This thesis represents two new methods of modeling robust power system stabilizers (PSS) for multimachine networks using the dragonfly algorithm (DA) and jellyfish search algorithm (JSA). The proposed methods dampens LFOs by modifying the key parameters of traditional lead-leg type power system stabilizers (CPSS) using the DA and JSA optimization methods. For both models, maximizing the minimum damping ratio is considered as the objective function. These models are evaluated on a two-area four-machine network and an IEEE-39 bus network that are subject to a 3- ϕ fault. For the same networks, the results are compared to backtracking search algorithm (BSA) and particle swarm optimization (PSO). Comparative study shows that the DA and JSA based models gives better system damping performance compared to BSA and PSO-optimized methods, which demonstrates that the proposed models are reliable and robust.

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LIST OF ABBREVIATIONS

PSS	Power System Stabilizer
PSO	Particle swarm Optimization
LFO	Low Frequency Oscillation
DA	Dragonfly Algorithm
JSA	Jelly Fish Search Algorithm
CPSS	Conventional Power System Stabilizer
MMPS	Multi-machine Power System
SMIB	Single machine infinite bus
BSA	Backtracking Search Algorithm
FLC	Fuzzy Logic Controller
AVR	Automatic Voltage Regulators
GWO	Gray wolf optimizer
FACTS	Flexible AC Transmission System

CHAPTER 1

INTRODUCTION

1.1 Introduction

The power system is a network that includes the transmission, distribution and generation of electricity. The power system is nonlinear. Their parameters and configurations change with time. Increased power in modern power systems causes long transmission lines to be overloaded beyond their typical capacity. The interconnected power system is continuously increasing due to the increasing electric power demand in the current decades. In such systems, heavy power is transferred to the load, and the power system operates closer to the limits of transient and dynamic stability. Low frequency oscillations (LFO) are introduced with the advancement of power network, through weak tie lines between generators. LFOs are generator load angle oscillations at frequency range between 0.1 -3Hz [1]. These LFOs can grow significantly with time if they are not damped out quickly, resulting in severe system outages [2], [3]. The electrical network may face LFO problems due to arbitrarily fluctuating load conditions or system turbulences. Aside from the periodic minor interruptions, the renewable energy sources integration into both distribution and generation side causes a constant imbalance between load and generation, resulting in LFOs. To increase the power system's stability, the oscillations must be decreased significantly.

In recent years, PSS is being extensively used to increase the damping of power system networks. A PSS is an electrical component that enhances system stability, the principal role of the PSS is to generate electric torque by applying an electric signal to the excitation system of synchronous generators. When the torque is applied to the rotor, the speed of the rotor changes, and all external power oscillations are stopped as a result [4]–[7]. PSS is also said to be more cost-effective and more straightforward to install than other controllers.

1.2 Background

In the 1950s to 1960s, continuously acting automatic voltage regulators (AVR) had widely been used for voltage regulations in many power plants. Although it maintained a constant voltage level to the load, it could not make the “fine adjustments” required to

control oscillation in the speed. As a result, the AVR could not damp the low-frequency oscillation for extended periods. Because of AVR's limitation, the quantity of power transmitted on the system was limited. The Power System Stabilizer (PSS) was integrated into synchronous generators to allow fine-tuning power oscillations, also known as low-frequency oscillations (LFO). PSS is used with the excitation mechanism of the synchronous generator to provide an extra control signal to improve system damping [3], [8]–[10]. If the network contains renewable energy sources, low-frequency oscillation can also occur. A modified AVR and PSS design is proposed in this article [11] to improve these types of systems' damping.

Recently, several modern control theory-based PSS models have been designed, including intelligent control, variable structure control, optimal control, and adaptive control [12]–[14]. Regardless of modern control techniques, the conventional lead-leg PSS structure is still most popularly used by power system utilities due to its simplicity [15]–[17]. The parameters of a conventional PSS can significantly impact the power system's dynamic stability [17]. PSS performance can be significantly improved by choosing the correct parameter values.

PSS can be built in a sequential manner using conventional techniques, with one electromechanical mode being considered at a time [18]. Nevertheless, the stabilizer for one electromechanical mood may cause instability in other moods. That is why sequential techniques are avoided [19]. A gradient-based design is proposed in this paper [20]. However, gradient techniques can become stuck in one of the local optimal, causing them to fail.

Traditional systems are developed and operated in areas where they exhibit linear conduct, despite the power system network being characterized by high nonlinearity. The linear model is used to design conventional PSS [21]. When the nonlinearity is substantial, and the linear model is unstable, the major disturbance results in a significant shift in the operating point [21], [22]. Consequently, it is essential to consider the impact of nonlinearity. Jiang demonstrated in [23] how to develop a nonlinear PSS utilizing synergetic control theory, and Fusco et al. demonstrated in [24] how to develop a nonlinear PSS and excitation controller utilizing nonlinear control.

The power system industry continues to employ the traditional PSS structure despite the possibility of new control methods with various structural configurations [16].

Recently, intelligent strategies for modifying PSS parameters have gained popularity and have been more extensively utilized than classic fixed gain PSS systems. Various optimization meta-heuristics techniques, such as artificial bee colony [25], differential evolution [26], particle swarm optimization [27]–[30], tabu search algorithm [31], simulated annealing [22], In order to tune the parameters of PSS for both MMPS network and SMIB network, a non-dominated sorting genetic algorithm [27] is used.

1.3 Motivation

LFOs can make a system unstable if they are not damped out quickly. That's why PSS is used to provide extra damping to the excitation system of the generators. To find the optimal parameters setting for best performance of PSS is a challenge for engineers. Many metaheuristics technique has been used to tune the parameters of PSS. Two recently developed metaheuristic optimizations are Dragonfly Algorithm and Jellyfish search algorithm. Seyedali Mirjalili suggested the Dragonfly Algorithm (DA) [19], a novel swarm intelligence optimization technique in its present form. It is a new unreasonable intelligent meta-heuristic Optimization algorithm inspired by a natural, artificial Dragonfly's dynamic and static unreasonable behavior. The usefulness and superiority of this technique have been demonstrated compared to various well-known main meta-heuristic strategies accessible in the literature. To compare the performance of the DA from various perspectives, three functional test functions with different characteristics were chosen: unimodal, multi-modal and composite functions [32]–[35]. This algorithm is successfully implemented in many optimization problems, such as Wind power forecasting [36], Applied science survey [37], Feature selection [38], Optimal DG placement [39], and so on.

Artificial jellyfish search algorithm (JSA) [40] is a novel bio-inspired swarm-based metaheuristic optimization method inspired by jellyfish foraging in the sea, which was developed by Jui-Sheng Chou and Dinh-Nhat Truong. JSA has three valuable features: (1) It is simple to apply; (2) It is simple to code; and (3) It only has two internal parameters. The JSA method is validated using 25 large-size (CEC2005) and 50 small-size mathematical benchmarking functions of varying dimensions. The test results

demonstrate that JSA can achieve the optimum value in fewer iterations than other optimization methods in its class. The JSA shows comparatively better results in mathematical benchmark testing than the GA, PSO, DE, ABC, GSA, FA, TLBO, SOS, TSA, and WOA algorithms [40]. This novel optimization technique is successfully implemented in different optimization problems such as distribution systems automation [41], optimal power flow [42], PEMFCs' model uncertain parameters [43], parameter estimation of single-phase transformer [44] and so on.

DA and JSA are successfully implemented in solving different optimization problems, but they are not used yet to optimize the parameters of PSS in multimachine networks. So, in this thesis DA and JSA are implemented to optimize the parameters of PSS in multi-machine networks.

1.4 Objective: The objectives of this thesis are given below:

- To optimize the parameters of PSS in multimachine networks to enhance power system stability
- To implement DA and JSA algorithm in power system stability enhancement problem
- To compare the performance of DA and JSA with conventional PSS (CPSS), PSO and BSA-tuned PSS in optimizing the PSS parameters

1.5 Thesis Outline:

Organization of the thesis includes six chapters:

- **Chapter 1 (Introduction):** It includes Introduction, Background, Objective and Thesis outline
- **Chapter 2 (Literature Review):** It includes Literature review. Here, previous works on power system stability is discussed with advantage and disadvantage
- **Chapter 3 (Problem Formulation):** It includes Problem Formulation. CPSS structure, control parameters and objective function are discussed in this section
- **Chapter 4 (Methodology):** It includes Methodology, where details on Dragonfly algorithm and Jellyfish search algorithm is discussed with flowchart.
- **Chapter 5 (Results and Discussion):** It includes simulation results & discussion. In this section, two area four machine network and IEEE-39 bus

network details are given and comparative results of CPSS, PSO, BSA, DA and JSA-optimized PSS are discussed

- **Chapter 6 (Conclusion):** It contains concluding thoughts, discussions, limitations and future scope

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction:

This chapter discusses the previous research works on power system stability enhancement. The contributions and limitations of those works are also discussed. Literature review on PSS, FACTS devices and optimization algorithms are discussed in **section 2.2**, **section 2.3** and **section 2.4** respectively.

2.2 Literature review on PSS:

A.E. Leona, J.M. Mauricio, J.A. Solsona have presented a nonlinear observer-based excitation controller design in this paper [45]. The controller only needs sensing currents and rotor speed, load angle information is not needed. The weakness of this paper is, FACTS devices are not integrated. Ramesh Devarapalli. Biplab Bhattacharyya. Nikhil Kumar Sinha. Bishwajit Dey have proposed Amended GWO algorithms [46], Amended GWO is used to optimize traditional PSS. But it is not validated experimentally. Also no renewable sources are used. G. Shahgholian, A. Movahedi, and J. Faiz have coordinated TCSC and PSS in this research [47]. PSO Algorithm is used to tune the parameters of PSS and TCSC, which makes it a robust design. The limitations are no renewable sources are considered and tested on a single network. [48] in this research, H. Shayeghi, A. Safari, and H. A. Shayanfar have coordinated PSS and TCSC and two different algorithms are implemented to optimize the parameters i.e., Velocity update relaxation particle swarm optimization (VURPSO) and Genetic algorithm (GA). But, optimal placement of the controller is not discussed and no renewable sources are considered. Coordinated design of PSS and TCSC with Genetic algorithm optimization technique is designed by A. B. Khormizi and A. S. Nia [49]. Optimal placement of the controller also defined. The limitations are no FACTS devices are used and no online tuning has been used.

2.3 Literature review on FACTS device:

S.M. Abd Elazim and E.S. Ali have presented Bacteria foraging optimization algorithm-based SVC for damping power system oscillations [50]. In this paper, Wide range of loading conditions are considered. But it has been tested on a simple network

and no renewable energy source is considered. Mahiraj singh rawat and shelly vadhera have compared three different FACTS devices, and UPFC is found to be the most effective one [51]. But the problem of this paper is, no online tuning and no Algorithm has been used to tune the parameters. M.G. Hemeida, Hegazi Rezk, Mohamed M. Hamada have presented comparison of dynamic performances of STATCOM and SVC on a WF connected system [52]. This paper also uses Fuzzy logic controller (FLC. But in this paper, Optimal placement of the controller in the system has not been defined and the accuracy of these systems is compromised. T. T. Nguyen and R. Gianto have presented three different techniques using UPFC, SDC and PSS [53]. Neural network is used to tune the parameters. This paper discussed a new method for representing the power system configuration in terms of a reduced nodal impedance matrix. But these have been tested on a single two area four machine network and with more fine tuning the size of the neural network and its training can be greatly simplified and kept to be minimal. [54] in this research, A. Kazemi and M. V. Sohrforouzani have used SVC, TCSC and UPFC for power system stability improvement. Proposed controller uses a combination of a FLC and a PI controller. But No algorithm has been used and no online tuning of the parameters. In this research [55], SVCs, TCSCs, TCPSs, STATCOMs and UPFCs has been used. A systematic approach is presented to establish the dynamic model of a MMPS installed with multiple UPFCs, STATCOMs, SVCs, TCPSs and TCSCs. But, parameters aren't optimized using algorithm. A. Movahedi, A. H. Niasar, and G. B. Gharehpetian have presented SSSC, TCSC, STATCOM and PSS based design [56]. GA, GSA and AVURPSO are used to tune the parameters of the controllers. Wind and PV connected two area four machine network is considered in this research. Optimal placement of the controllers have not been defined.

2.4 Literature review on optimization algorithms:

Numerous algorithms are introduced to solve complicated optimization problems. One of the most well-known evolutionary algorithms is the genetic algorithm (GA) [57]. This algorithm was motivated by Charles Darwin's hypothesis of biological evolution. In reality, the survival of the fittest is the key process mimicked in GA. Fitter creatures have a better chance of surviving in nature. Particle Swarm Optimization is the most used swarm-based algorithm (PSO) [58]. The flocking behavior of birds in nature has inspired the PSO algorithm. Each particle is treated as a solution to a specific optimisation problem in this approach. The Grey Wolf Optimizer (GWO) [59] is

modeled after the biological leadership structure and foraging process of grey wolves. Four types of grey wolves are employed to replicate the hierarchical system: alpha, beta, delta, and omega. In addition, the optimization incorporates three key foraging procedures: searching prey, approaching prey, and killing prey. The Whale Optimization Algorithm (WOA) is presented in this paper [60]. To replicate the hunt for prey, surrounding prey, and bubble-net foraging behavior of humpback whales, this method incorporates three operators. In this paper [61], Dragonfly algorithm is proposed for single and multi-objective problem solving. It mimics the static and dynamic behaviors of dragonflies for swarm intelligence algorithms' exploration and exploitation characteristics. A new meta-heuristic algorithm is proposed in this paper called Jellyfish Search (JS) optimizer [40]. It is based on the food searching behaviors of Jellyfish in the ocean. Active and passive motion of Jellyfish is used to simulate exploration and exploitation.

CHAPTER 3

PROBLEM FORMULATION

3.1 Introduction:

In this chapter the details of FACTS device, mathematical modelling of synchronous generator, structure of the conventional PSS and optimization problem are discussed. A synchronous generator is a synchronous machine that transforms mechanical energy to alternating current electricity by electromagnetic induction. Conventional PSS is a lead-leg type one input and one output controller, which works on the linear region of power system. It can not adopt with the change in operating point beyond linear region.

3.2 Modeling of synchronous generator:

The synchronous generator is capable of converting the rotational energy of a primary mover into alternating current (AC) power at a predetermined voltage and frequency. The pace at which a synchronous motor rotates at a steady rate is referred to as the synchronous speed.

The synchronous generator is operated using Faraday's electromagnetic induction principles. Electromagnetic induction is the electromotive force induced in the armature coil as it rotates in a constant magnetic field. An EMF is created when the field spins while the conductor stays static. As a result, the relative movement between the conductors and the field causes the electromotive force in the conductor. The wave shape of the induced emf is commonly a sinusoidal curve. The rotor and stator are the rotating and stationary elements of a synchronous generator. They are the power-generating elements of the synchronous generator. The rotor has the field pole, whereas the stator has the armature conductor. The relative motion between the rotor and the stator causes the voltage between the conductor. The construction of a synchronous generator is shown in **Fig. 3.1**.

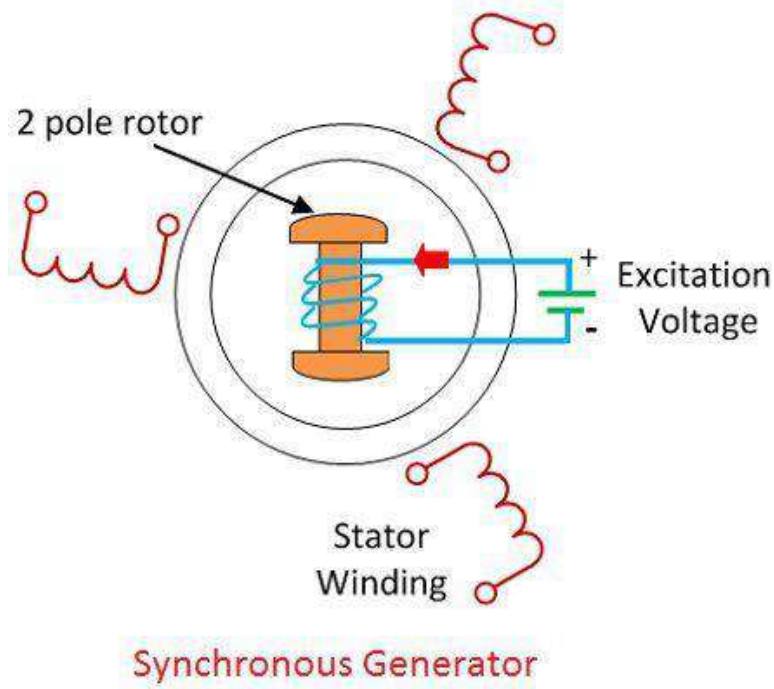


Fig. 3.1. Synchronous generator structure [62].

A fourth-order equation model can represent the n number of synchronous generators in a power system network [3], [8], [9]. Where any i^{th} generator on that network can be expressed mathematically by these equations:

$$\dot{\delta}_i = \omega_b(\omega_i - 1) \quad (1)$$

$$\dot{\omega}_i = \frac{1}{M}(P_{mi} - P_{ei} - P_{Di}) \quad (2)$$

$$\dot{e}_q = \frac{1}{T_{do}}[E_{fdi} - e_{qi} - (x_{di} - x'_{di})i_{di}] \quad (3)$$

$$\dot{E}_{fdi} = \frac{1}{T_{Ei}}[K_{Ei}(v_{tri} - v_{ti} + u_{PSSI}) - E_{fdi}] \quad (4)$$

The meaning of the symbols used in the given equations is mentioned in the Appendix section. These nonlinear differential equations from (1) - (4) can be linearized with some approximation [9].

3.3 FACTS devices:

Power consumption has risen dramatically in recent years, yet due to limited resources and environmental constraints, power generation and transmission have been severely restricted. Transient stability control is a key topic of research because it ensures the stable functioning of power systems in the case of substantial disruptions and failures. Controllers for flexible AC transmission systems (FACTS) have mostly been utilized to solve different power system steady state control difficulties. By regulating the series and shunt characteristics, FACTS devices may regulate the active and reactive power flows in a transmission line. FACTS controllers can control the network condition extremely quickly, and this capability may be used to increase the voltage stability, as well as the steady state and transient stabilities of a complex power system. This allows the current network to be used closer to its thermal loading capacity, minimizing the need to build new transmission lines. SVC, STATCOM, TCSC, SSSC, and UPFC are some of the most well-known FACTS devices.

3.3.1 Static Var Compensator (SVC):

SVC stands for static Var compensator and is linked to the power line in parallel. SVC functions as a generator/load, with its output modified to interchange capacitive or inductive current in order to sustain or manage certain power network parameters. The basic purpose is to rapidly regulate voltage at weak points in a network. **Fig. 3.2.** shows the basic structure of SVC.

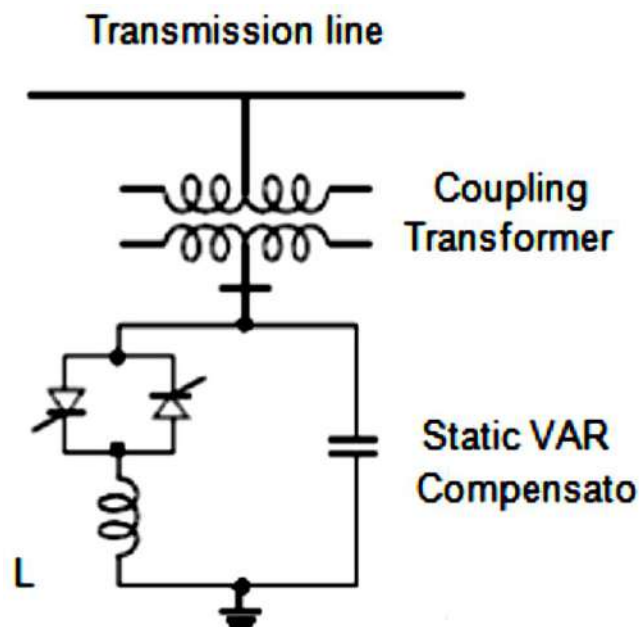


Fig. 3.2. Structure of SVC [63]

3.3.2 Thyristor Controlled Series Capacitor (TCSC):

The TCSC is a series type compensator that improves system stability while increasing power transmission. TCR is used in conjunction with series capacitor bank components in TCSC devices. The TCR and capacitor configuration allows the capacitive reactance to be easily adjusted over a large range and changed to a situation where the bi-directional thyristor pairs conduct continuously and inject suitable reactance into the line when commanded. **Fig. 3.3** shows the single line diagram of TCSC.

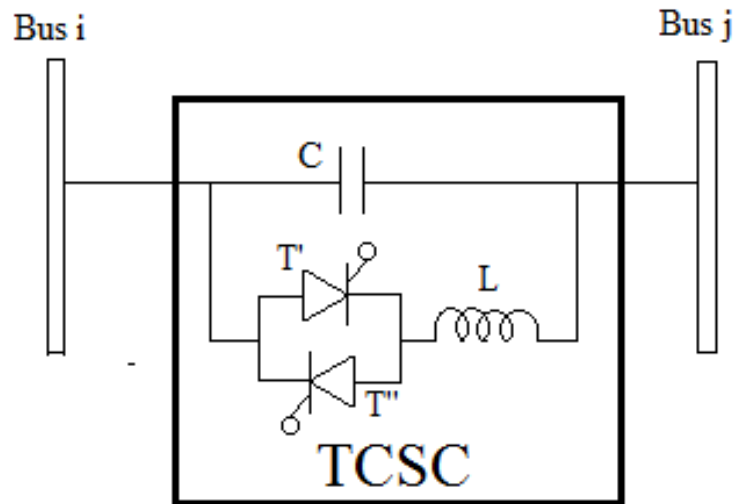


Fig. 3.3. Structure of TCSC [63]

3.3.3 Static Synchronous Series Compensator (SSSC)

A power system is linked in series with the SSSC. A voltage source converter is connected to a transmission network through a transformer in series. Because it can produce a nearly sinusoidal voltage in series with a power line with variable and adaptable magnitude and phase angle, it may be categorized as an asynchronous voltage source. The injected voltage is nearly parallel to the line current. Inverter losses are made up of a small percentage of the provided voltage that is in phase with the line current. The bulk of the injected voltage, which is polarized in the same direction as the line current, contributes an inductive or capacitive reactance to the power line as a result of its orientation. The electrical energy flow in the transmission line is influenced by varying reactance. A basic construction of SSSC is given in **Fig. 3.4**.

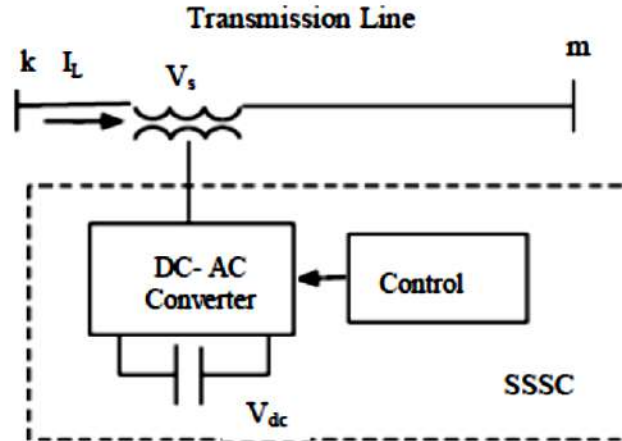


Fig. 3.4. Structure of SSSC [63]

3.3.4 Unified Power Flow Controller (UPFC):

The Unified Power Flow Controller (UPFC) is the most adaptable FACTS device, with the potential to improve steady state stability, dynamic stability, and transient stability. Figure 4 depicts the basic structure of a UPFC. The UPFC is made up of two ac/dc converters that can both provide and consume active and reactive power. A series transformer connects one of the two converters to the transmission line, while a shunt transformer connects the other to the line in parallel. The two converters' dc sides are linked by a single capacitor, that supplies dc voltage for converter functioning. Maintaining a consistent voltage all over the dc capacitor requires a power balance between the series and shunt converters. Because the UPFC's series branch injects a voltage with a changing amplitude and phase angle, it may exchange actual power with the power line, improving the line's power flow capability and transient stability limit. With the power system, the shunt converter exchanges a current with a regulated amplitude and power factor angle. The dc bus voltage is generally regulated at a desired value to balance the real power taken from or supplied into the power system by the series converter plus the losses. **Fig. 3.5** provides the general structure of UPFC

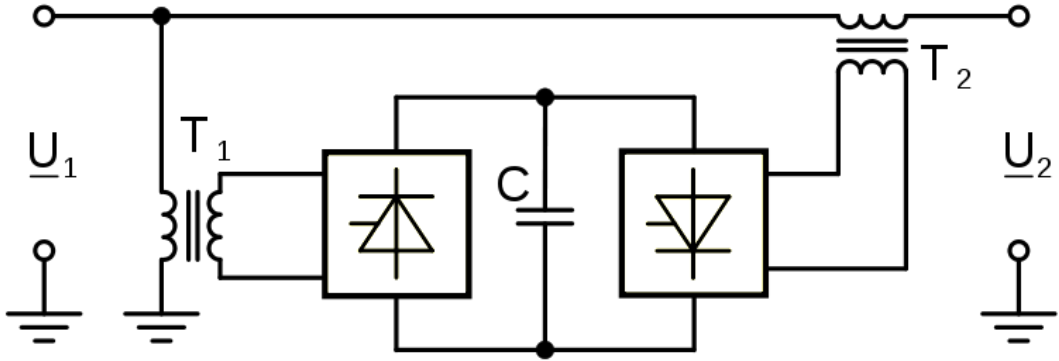


Fig. 3.5. Structure of UPFC [64]

3.4 Problem formulation:

A typically two-stage lead-lag CPSS is represented in Fig. 3.6, where the fluctuation in the generator angular frequency ($\Delta\omega_i$) is the input, and output signal is the control signal changes (U_{PSSi}). Washout/rest block is connected to disable PSSs in steady-state operation having time constant T_w , while limiter block regulates the size of the control signal. Two lead-leg phase compensators are connected between washout filter and limiter block with time constants T_1 , T_2 , T_3 and T_4 .

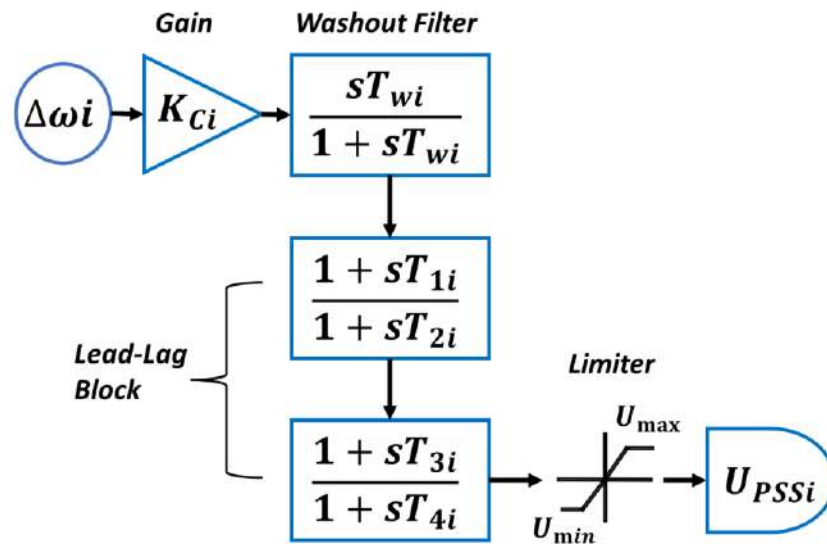


Fig. 3.6. Conventional PSS structure.

The challenge is to tune the PSS parameters such that the system damping ratio can be improved. Generators minimum damping ratio is taken as the objective function. The optimization problem is to maximize the objective function (J):

$$J = \max \{ \zeta_i, i=1,2,3,\dots,n \} \quad (5)$$

Here, ζ_i is the i^{th} machine's minimum damping ratio and n is the number of machines.

Maximization of J

$$K_{ci}^{min} \leq K_{ci} \leq K_{ci}^{max}$$

$$T_{1i}^{min} \leq T_{1i} \leq T_{1i}^{max}$$

$$T_{2i}^{min} \leq T_{2i} \leq T_{2i}^{max}$$

$$T_{3i}^{min} \leq T_{3i} \leq T_{3i}^{max}$$

$$T_{4i}^{min} \leq T_{4i} \leq T_{4i}^{max}$$

CHAPTER 4

METHODOLOGY

4.1 Introduction:

Dragonfly algorithm (DA) is developed by Mirjalali in 2016 and Jellyfish search algorithm (JSA) is developed by Dinh-Nhat Truong and Jui-Sheng Chou in 2021. The details of the Dragonfly and Jellyfish algorithm with flowchart are discussed in this chapter.

4.2 Dragonfly algorithm:

The Dragonfly(DA) algorithm was developed by Mirjalili and published in 2016 [61]. Dragonflies are small predatory flying bugs that predate on a variety of small insects, including mosquitoes, ants, bees, and butterflies [61], [65], [66]. There are about 3000 types of dragonflies, and they also have two life stages: nymph and adult [61], [67]. The dragonfly algorithm is inspired by dragonflies' natural swarming behaviors, which are dynamic (migratory) and static (feeding) [61], [68]. Rather, dragonflies form small groups and circle a specific area repeatedly in search of food and potential prey. The swarm behavior of dragonflies is modeled using five simple foundational concepts, as shown in the following table [37], [61], [68], [69]. Here, P denotes the current individual's position, P_j is the j^{th} surrounding individual's position, and M the total number of neighbours. The steps of DA is given below:

Step 1. This mathematical separation model demonstrates how humans utilize reliable collision avoidance to avoid clashing with other persons in the vicinity.

$$S_i = -\sum_{j=1}^M P - P_j \quad (6)$$

Step 2. Alignment indicates the individual's speed relative to other individuals in the vicinity of the same group. The alignment is represented as follows:

$$A_i = \frac{\sum_{j=1}^M v_j - v_i}{M} \quad (7)$$

Where v_j denotes the velocity of the j^{th} individual

Step 3. Cohesion is the tendency of individuals to move toward the center of a swarm's group. It is defined as follows:

$$C_i = \frac{\sum_{j=1}^M P_j - P}{M} \quad (8)$$

Step 4. The following equation models food source attraction(F):

$$F_i = F_p - P \quad (9)$$

Where, F_i represents the food source of the i^{th} individual and F_p is the position of the food source.

Step 5. A mathematical model of enemy distraction is:

$$E_i = E_p + P \quad (10)$$

Using this formula, E_i represents the enemy's location, and E_p represents the enemy's position.

It is possible to update the positions of artificial dragonflies in their search space by taking the step vector ΔP , and the position vector P into consideration. The vector P resembles the PSO algorithm's velocity vector. It is given as follows:

$$\Delta P_i^{t+1} = (sS_i + aA_i + cC_i + fF_i + eE_i) + \omega \Delta P_i^t \quad (11)$$

Where s denotes the weight of separation, S_i denotes the i^{th} individual's separation, while a denotes the alignment weight. A_i represents the i^{th} individual's alignment, c is cohesion weight, C_i is the cohesion of the i^{th} individual, f denotes the food factor, F_i is the food source of the i^{th} individual, e indicates the enemy factor, E_i represents the enemy position of the i^{th} individual, w is the inertia weight, and t is the iteration number. Then, the position of the i^{th} dragonfly at $t+1$ is updated as follows:

$$P_i^{t+1} = P_i^t + \Delta P_i^{t+1} \quad (12)$$

The exploration is accomplished using high alignment weights and low consolidation weights; however, the operation is accomplished using low alignment and high cohesion weights [37]. The convergence rate DA may be adjusted adaptively by adjusting the weights s , a , c , f , e and w .

When there are no adjacent solutions, a random walk (Levy flight) is included to enhance the exploration, randomness, and exploitation of the artificial dragonflies. As a result, the i^{th} dragonfly's position at iteration $t+1$ is modified as follows:

$$P_i^{t+1} = P_i^t + Levy(d) \times P_i^t \quad (13)$$

Where, d denotes the dimension of the positions of the vectors. The levy flight is calculated as follows:

$$\text{Levy}(d) = 0.01 \times \frac{r1 \times \sigma}{|r2|^{\frac{1}{\beta}}} \quad (14)$$

Where $r1$ and $r2$ are random vectors distributed evenly in the range $[0,1]$, is a constant, and indicates the gamma function, the following equation is calculated:

$$\sigma = \left(\frac{\tau(1+\beta) \times \sin(\frac{\pi\beta}{2})}{\tau \times 2(\frac{\beta-1}{2}) \times \beta \times (\frac{1+\beta}{2})} \right)^{\frac{1}{\beta}} \quad (15)$$

$$\tau(a) = \int_0^{\infty} (t^{a-1} e^{-t}) dt \quad (16)$$

When a is an integer, we have:

$$\tau(a) = (a-1)! \quad (17)$$

The flow chart of DA is given in **Fig. 4.1**

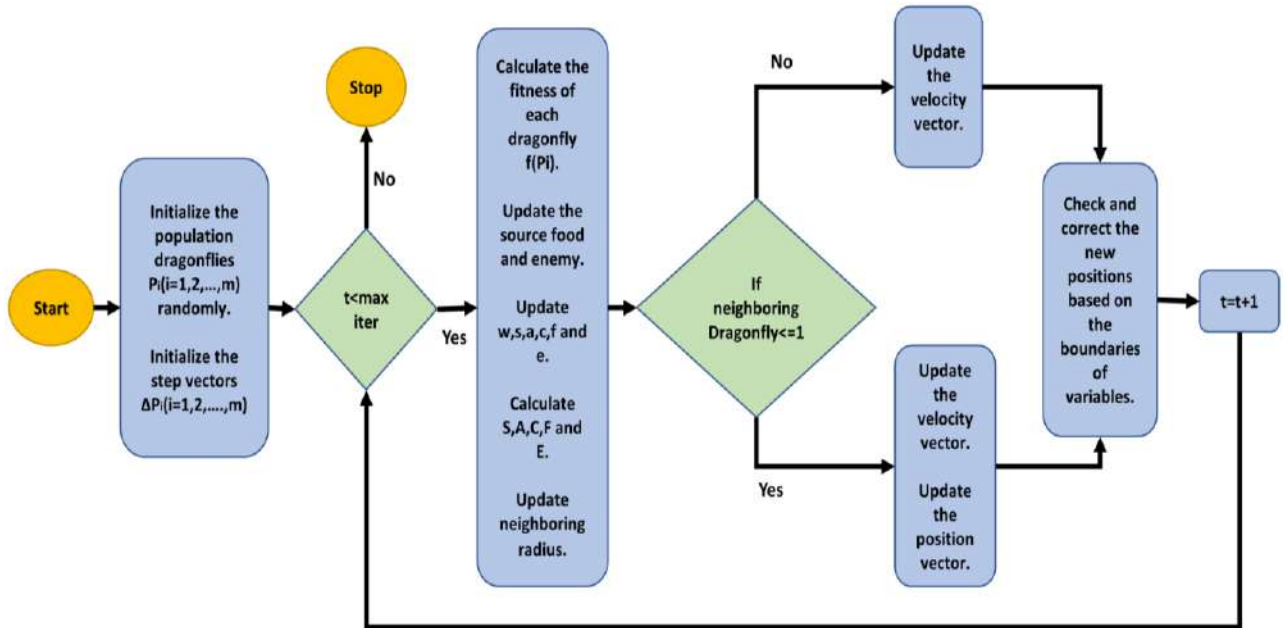


Fig. 4.1. Flow Chart of DA

4.3 Jellyfish search algorithm:

Jellyfish's food searching behaviour is taken as inspiration for the JSA. It is a relatively new algorithm developed in 2021 by Dinh-Nhat Truong and Jui-Sheng Chou [40]. The

flowchart of JSA is shown in **Fig. 4.2**. Three strategies guide the implementation of the JSA:

- Depending on their “Time control mechanism,” Jellyfish may migrate with the sea waves or within the swarm.
- Jellyfish search for areas with a greater supply of food than their present position.
- The position and its objective function affect the amount of food found.

A jellyfish bloom is created by the Jellyfishes’ rapid active and passive motions inside the swarm, and Food availability differs in jellyfish-visited areas. Comparing food sizes may help to determine optimal places, i.e., the FF’s best value.

The population is first initialized using the Logistic chaotic map described in Eq. (18) [70], and the ocean current is constructed using Eq. (19). As recommended in [40], the value of n is considered 4.0.

$$X_{i+1} = \eta X_i(1 - X_i), \quad 0 \leq X_0 \leq 1 \quad (18)$$

$$X_i(t + 1) = X_i(t) + rand(0,1) \times (X^* - \beta \times rand(0,1) \times \mu) \quad (19)$$

The movements of Jellyfish in a swarm are governed by passive and active motions. Jellyfish move about their locations in passive motion and update their positions according to Eq. (20), and the active motion is defined using the formula shown in Eq. (21).

$$X_i(t + 1) = X_i(t) + \gamma \times rand(0,1) \times (U_b - L_b) \quad (20)$$

$$X_i(t + 1) = X_i(t) + rand(0,1) \times \overrightarrow{Direction} \quad (21)$$

For active motion, the direction of each Jellyfish is always towards the best foodstuff. The direction is represented by Eq. (22)

$$\overrightarrow{Direction} = \begin{cases} X_j(t) - X_i(t) & \text{if } f(X_i) \geq f(X_j) \\ X_i(t) - X_j(t) & \text{if } f(X_i) < f(X_j) \end{cases} \quad (22)$$

The transition between passive and active motion in ocean currents is governed by the time control variable $C(t)$. It is given by Eq. (23):

$$c(t) = \left[\left(1 - \frac{t}{Max_{iter}}\right) \times (2 \times rand(0,1) - 1) \right] \quad (23)$$

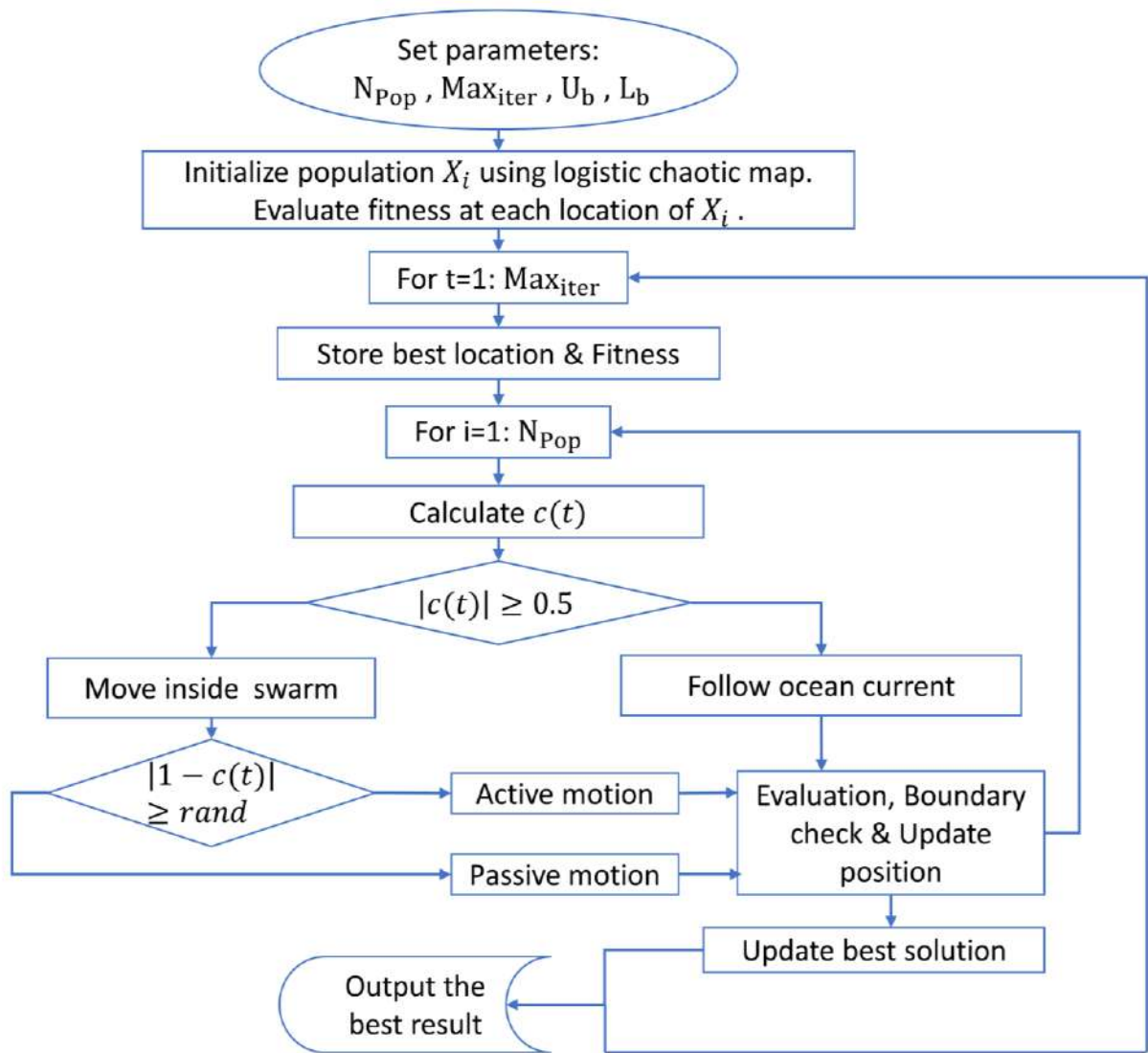


Fig. 4.2. Flow Chart of JSA

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 Introduction:

In this chapter, descriptions of the two test networks are given. Test network-1 is the Kundur's two area four machine network and test network-2 is IEEE-39 bus network. Matlab simulation is carried out for both network, after applying three-phase into the systems. Matlab 2017a is used for this thesis. Simulation results for two different algorithms is compared with conventional PSS, PSO and BSA-tuned PSS.

5.2 Simulation results and discussion:

A MATLAB-based simulation of the linear model of an IEEE-39 bus ten-machine system and a two-area four-machine system is used to test the efficiency of the DA and JSA in MMPS networks. The DA and JSA-optimized PSS simulation results are compared against other PSS based on PSO, BSA, and conventional/without PSS, where all the parameter values remain the same for all algorithms. For each generator, the problem dimension is 5, the size of the population is 100, and the maximum iteration is 1000. T_w is set to 10s in the reset block. K_{ci} , T_{1i} , T_{3i} are optimized using DA and JSA in this paper. K_{ci} limit is set as [0.0 to 50.0], and T_{1i} , T_{2i} , T_{3i} and T_{4i} limits are set as [0.01 to 1.00].

5.2.1 *Network-1: Two area four machine network*

The test network-1 is represented in **Fig. 5.1**. Reference [3] provides more information about the network data. It consists of eleven buses and two regions, which are linked by a weakened link between buses 7 and 9. At buses 7 and 9, a total of two loads are applied to the system. Buses 7 and 9 are additionally equipped with two shunt capacitors. The main frequency of the system is 60 Hz. Two comparable regions are linked by a weak connection in this system. Each section has two generators, each with a 20 kV and a 900 MVA rating.

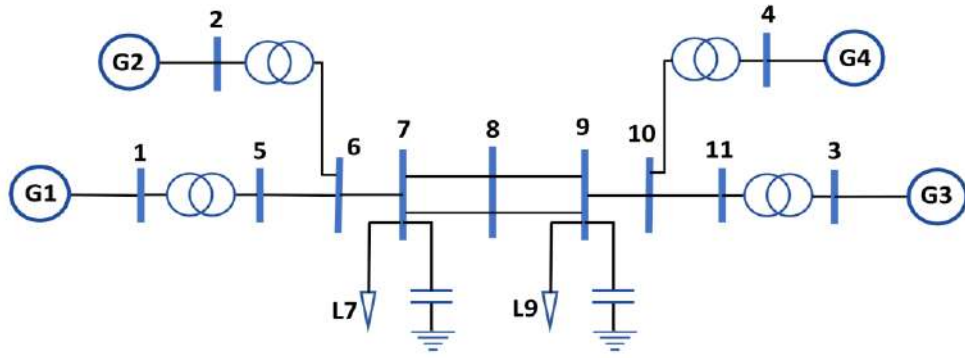


Fig. 5.1. Two area four machine network

For a particular base case [3], the DA and JSA technique is used to carry out the optimization process for three parameters K_{ci} , T_{1i} and T_{3i} . T_{2i} and T_{4i} values are set to 0.0500. This MMPS network is tested with different optimization techniques, and the damping ratios are given in [71]. The optimized parameter values are shown in **Table I**. **Fig. 5.2** illustrates the objective function variations with respect to the iteration numbers for the DA and JSA-tuned PSS. JSA and DA provide minimum damping ratio (MDR) of 0.7376 and 0.487 respectively. It shows JSA algorithm provides better convergence results than DA algorithm for the same objective function. Bus 7 is subjected to a 3- ϕ fault for 0.1s which begins at 0.5s. The whole process is simulated for 5 seconds. **Fig. 5.3** demonstrates angular frequency variations for four machines, where the oscillations are damped using the conventional PSS. It shows CPSS can not stabilize the system within 5s. **Fig. 5.4** and **Fig. 5.5** illustrates the angular frequency for four generators using JSA and DA-tuned PSS respectively, both techniques stabilize the angular frequency within 2.5s.

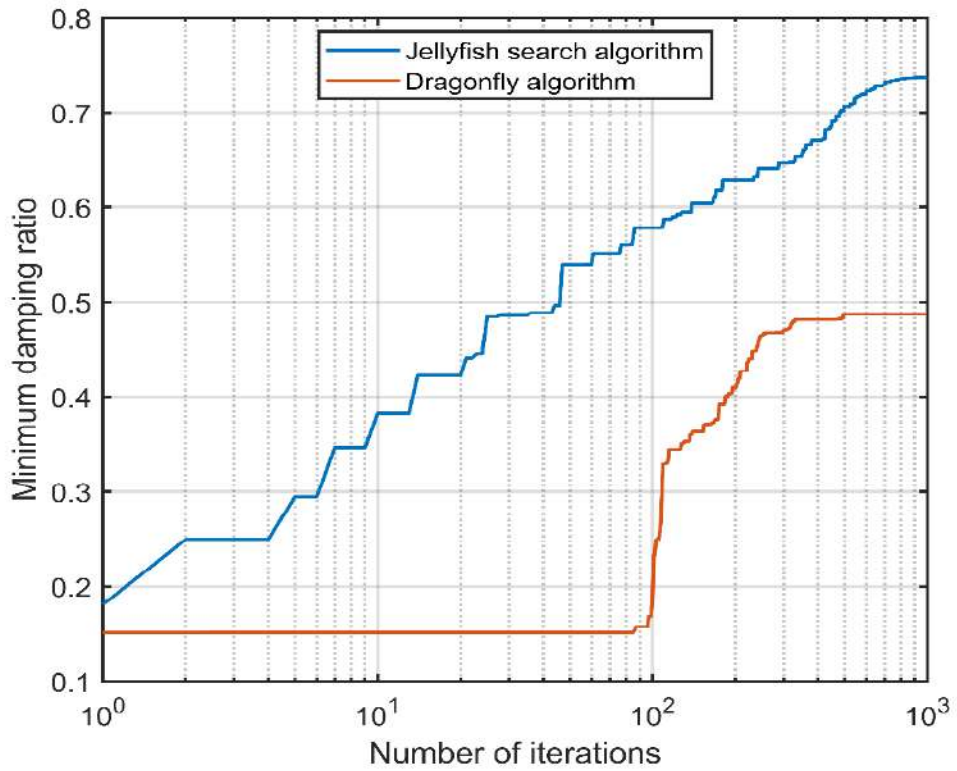


Fig. 5.2. Objective function variations for JSA and DA

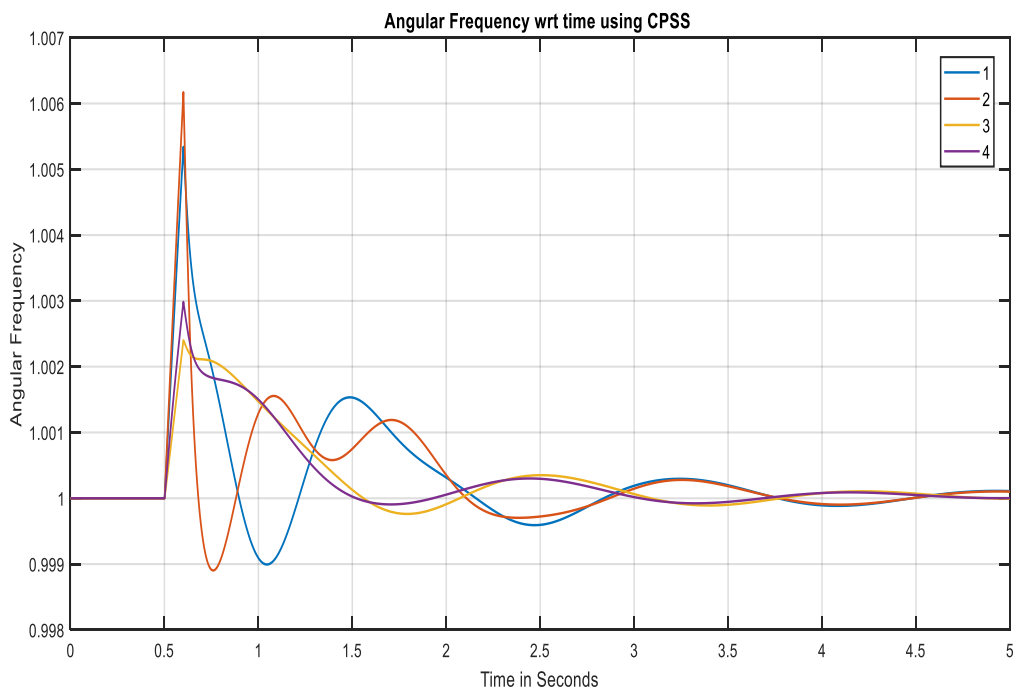


Fig. 5.3. Angular frequency for four generators with CPSS

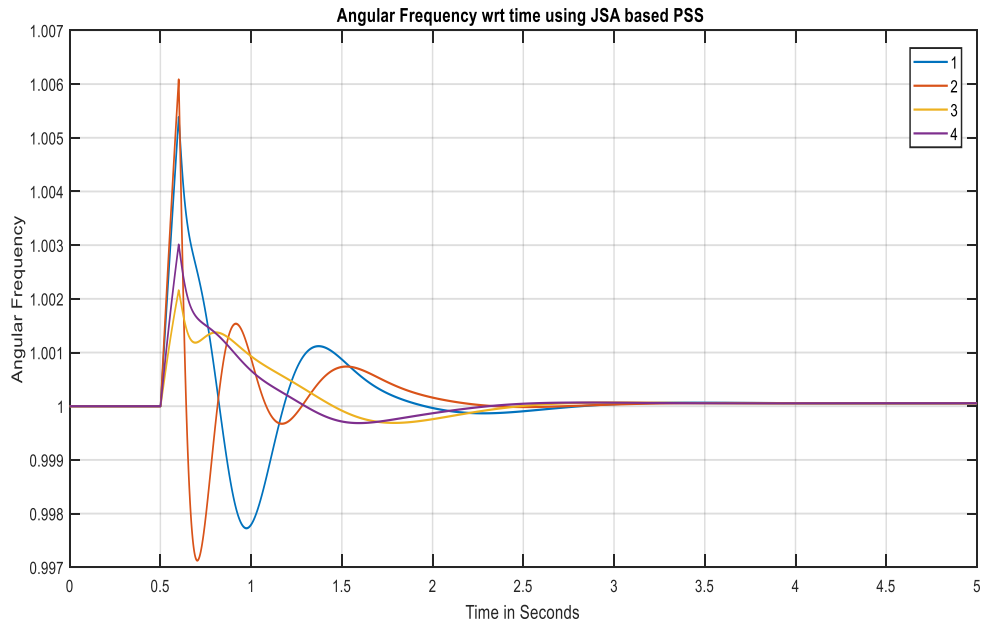


Fig. 5.4. Angular frequency for four generators with JSA-tuned PSS

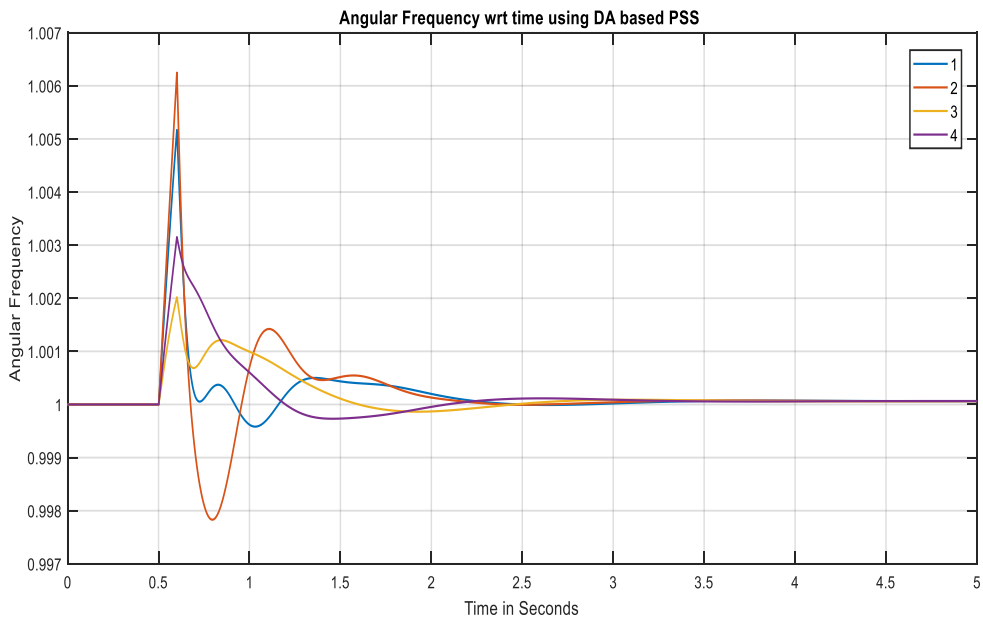


Fig. 5.5. Angular frequency for four generators with DA-tuned PSS

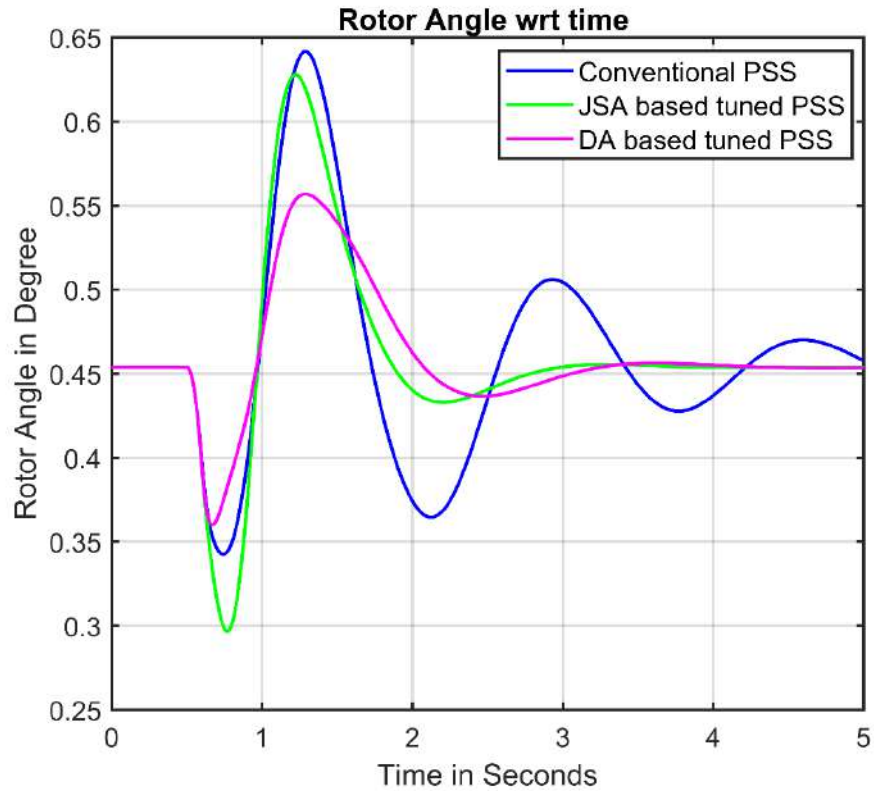


Fig. 5.6. Rotor angle of G_3

Fig. 5.6 shows the variations in G_3 rotor angle for the same fault, which demonstrates that the DA and JSA-based PSS can stabilize oscillations much faster than CPSS. Control signal G_3 is shown in **Fig. 5.7** also shows stable performance. The DA and JSA technique have a substantially shorter settling time than CPSS. Other generators show similar performance.

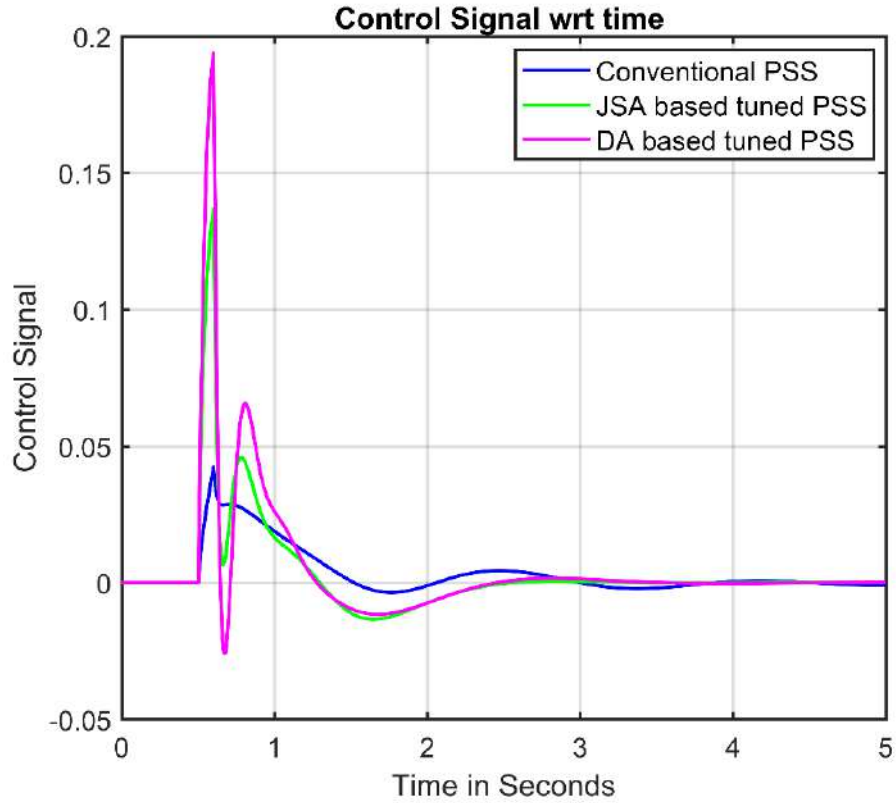


Fig. 5.7. Control signal of G_3

Table 5.1. Optimized parameters values for different algorithms in network-1

Gen No.	JSA-tuned PSS			DA-tuned PSS		
	K_c	T_1	T_3	K_c	T_1	T_3
G_1	18.8305	0.0209	0.0250	38.4974	0.1791	0.0308
G_2	42.9914	0.0594	0.0796	23.6960	0.0113	0.0713
G_3	30.7775	0.0906	0.1241	38.9520	0.2479	0.0444
G_4	19.4093	0.0594	0.0860	12.1425	0.0112	0.1682

5.2.2 Test network-2: IEEE-39 bus network

The IEEE 39 bus system is well known as New-England Power System [8]. The system consists of 36 transmission lines, 39 buses, 10 generators, 19 loads and 12 tap-changing transformers. Generator 1 represents the aggregation of a large number of generators. **Fig. 5.8** shows the single line diagram of IEEE-39 bus system. For a particular base case [8], the DA and JSA-based technique is used to tune the PSS parameters. **Table 5.2** illustrates the optimized parameters for DA and JSA-tuned techniques. **Fig. 5.9** depicts objective function variations for DA and JSA, where JSA and DA provides

MDR of 0.1949 and 0.1626 respectively. JSA shows better convergence result compared to DA.

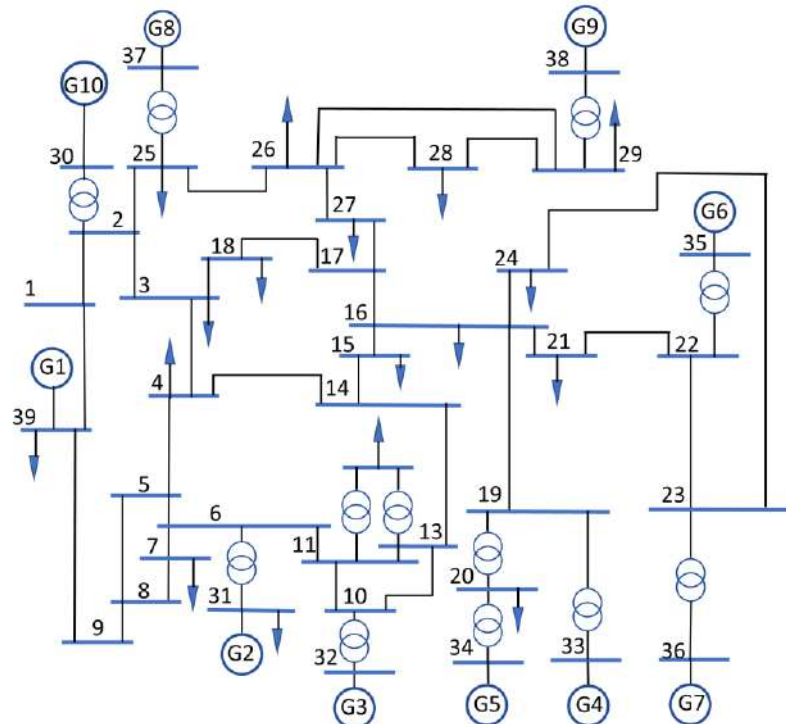


Fig. 5.8. IEEE-39 bus network.

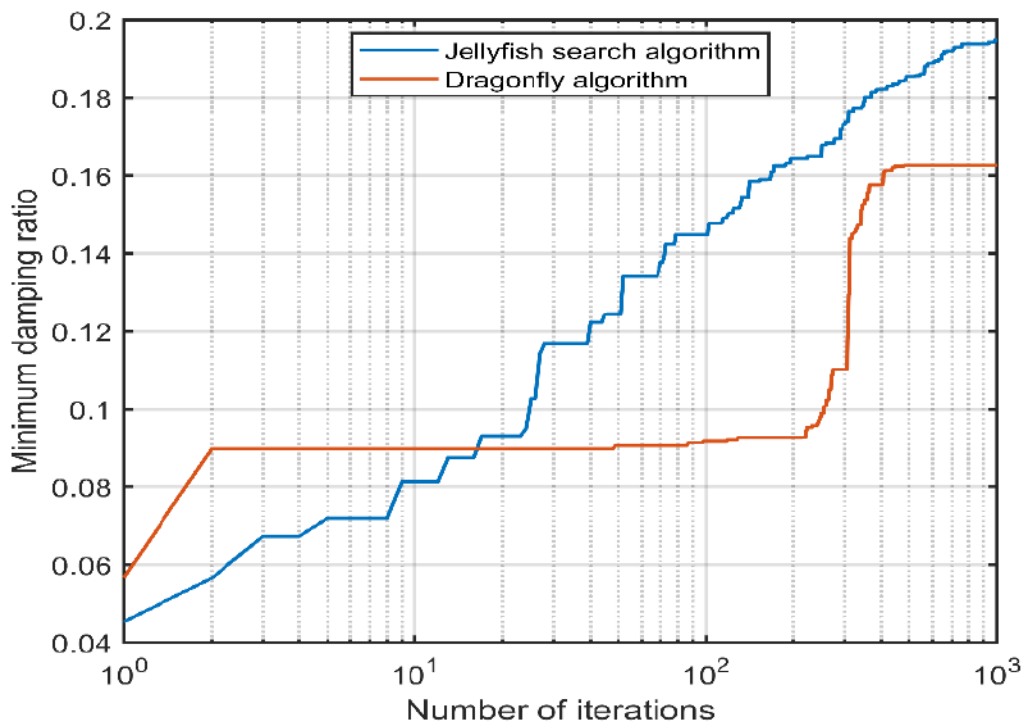


Fig. 5.9. Objective function variations for DA and JSA

Bus 29 is exposed to a three-phase fault that starts at 0.5s, and lasts for 0.1s. The fault is simulated for 5s. **Fig. 5.10** demonstrates angular frequency variations for ten machines, where the oscillations are dampened using the conventional PSS. It shows CPSS can not stabilize the system within 5s, rather it destabilizes the system. **Fig. 5.11** and **Fig. 5.12** illustrates the angular frequency for ten generators using JSA and DA-tuned PSS respectively, both techniques stabilize the angular frequency within 2.5s and 2.7s respectively.

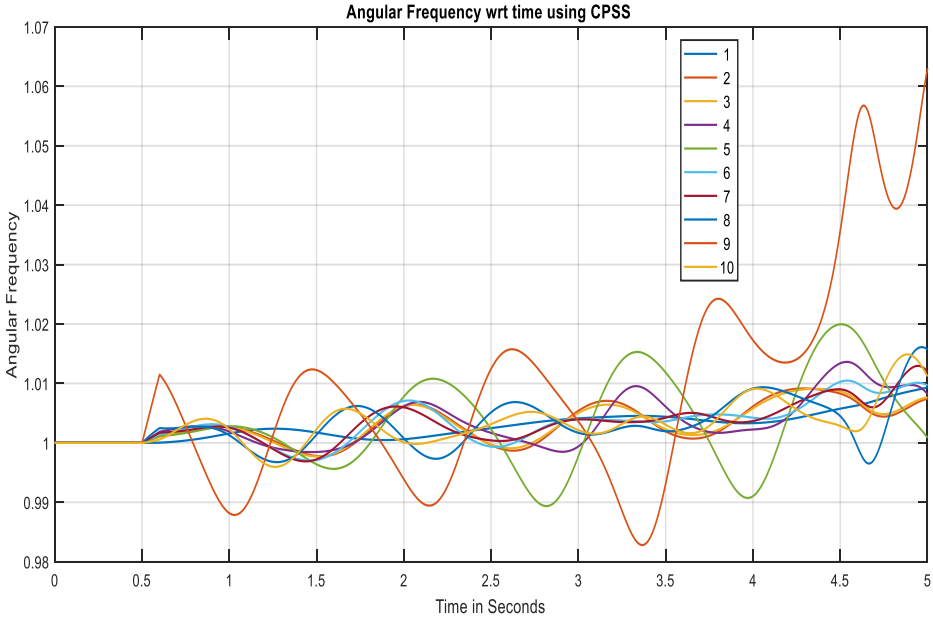


Fig. 5.10. Angular frequency for ten generators with CPSS

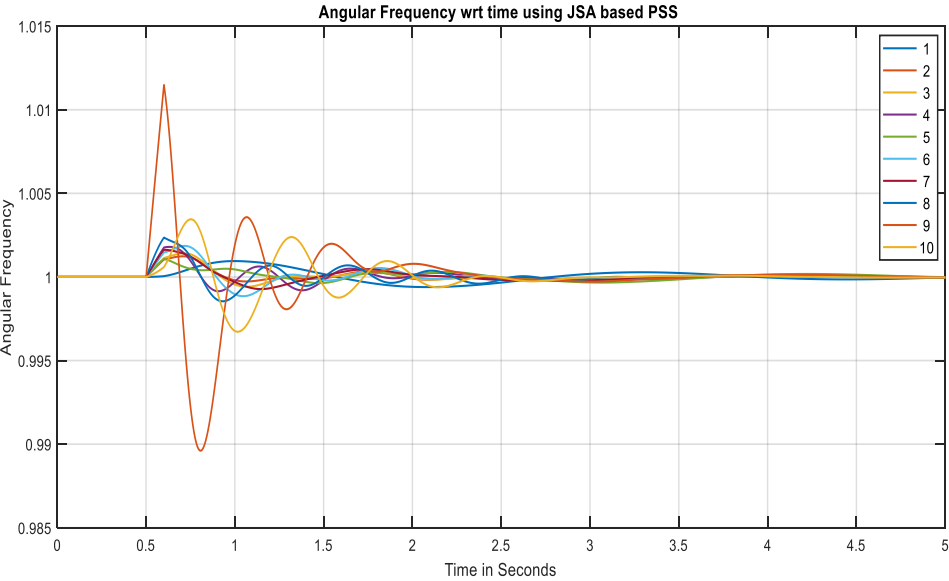


Fig. 5.11. Angular frequency of ten generators with JSA-tuned PSS.

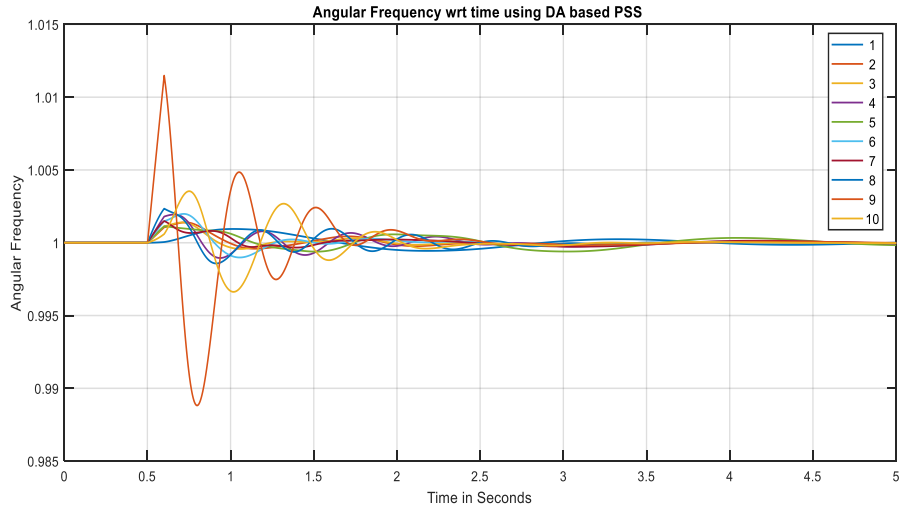


Fig. 5.12. Angular frequency of ten generators with DA-tuned PSS.

Fig. 5.13 shows the variations in G_5 's rotor angle for the same fault, which demonstrates that the DA and JSA-based PSS can stabilize oscillations much faster than CPSS. Control signal G_3 is shown in **Fig. 5.14** also shows stable performance. The DA and JSA technique has a substantially shorter settling time than CPSS. Other generators show similar performance. This indicates that the JSA-based PSS design is more compatible and robust.

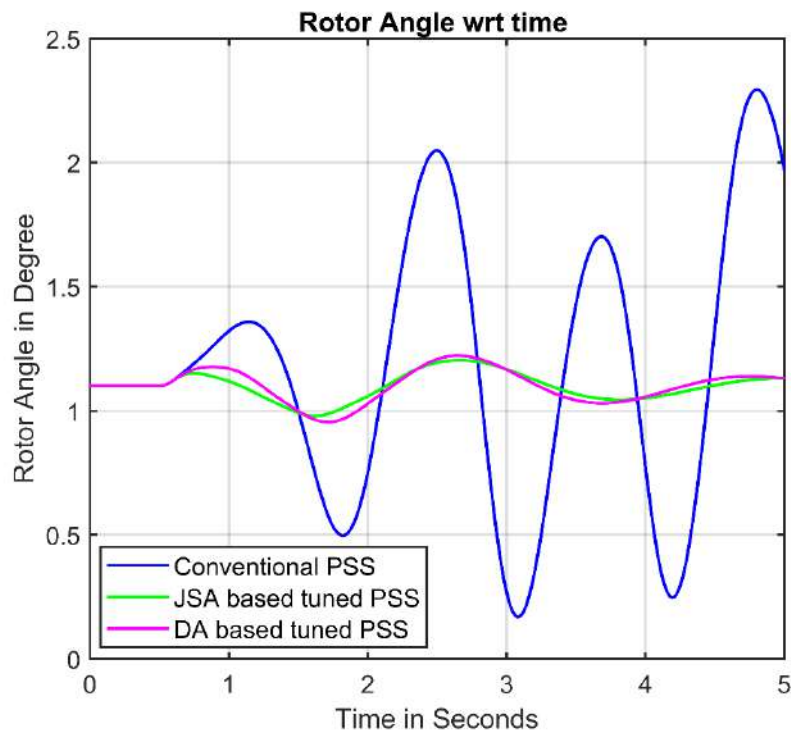


Fig. 5.13. Rotor angle of G_5

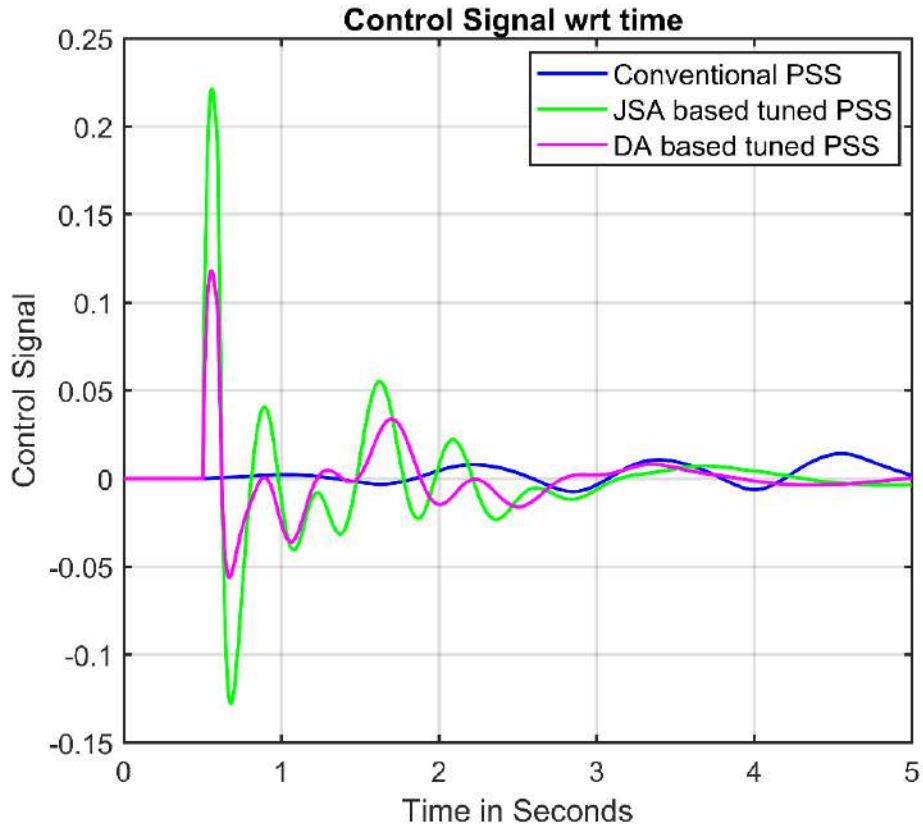


Fig. 5.14. Control signal of G_5

Table 5.2. Optimized parameters values for different algorithm in network-2

Gen No.	DA-tuned PSS			JSA-tuned PSS		
	K_c	T_1	T_3	K_c	T_1	T_3
G₁	0	0	0	0	0	0
G₂	11.2296	1.0000	0.9717	36.2517	0.6845	0.7004
G₃	43.1849	1.0000	0.4377	42.9155	0.6991	0.5929
G₄	50.0000	0.7781	0.4761	44.9636	0.6921	0.9241
G₅	2.8657	0.4166	1.0000	17.5877	0.2540	0.4606
G₆	16.7740	1.0000	1.0000	37.1972	0.7953	0.7464
G₇	12.6743	0.8262	0.0846	14.9012	0.2394	0.1075
G₈	41.1955	1.0000	0.7979	33.1334	0.9423	0.9506
G₉	44.1348	0.3101	0.1312	25.3069	0.5592	0.1156
G₁₀	40.7769	1.0000	0.9417	49.3066	0.9866	0.9524

5.3 Comparative study:

The comparison among the results found using different optimization algorithms for Network-1 (Two area four machine network) is shown in **Fig. 5.15**. The MDR for conventional, BSA, PSO, DA and JSA-tuned PSS are shown in **Fig. 5.15**. It shows JSA-tuned PSS provides 4.7 times, 2.3 times and 1.5 times larger damping ratio than conventional, PSO and BSA-tuned PSS respectively. On the other hand, DA-based PSS provides 3.1 times and 1.5 times larger damping ratio than CPSS and PSO-based PSS respectively.

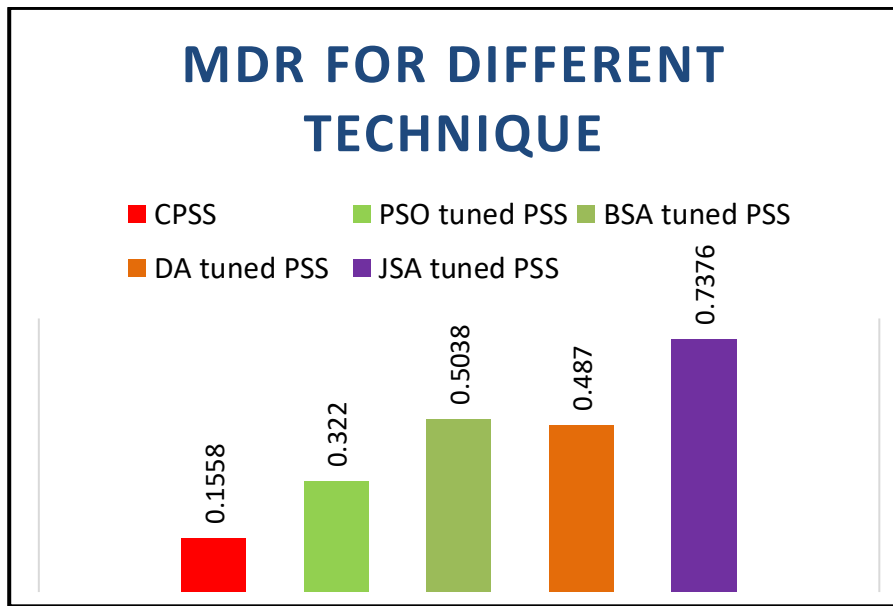


Fig. 5.15. MDR for different optimization techniques for network-1

Fig. 5.16 provides the comparison of results found for different optimization algorithms in network-2 (IEEE-39 bus network). The MDR for CPSS, BSA, PSO, DA and JSA-tuned PSS are shown in **Fig. 5.16** [72]. For the same system configuration, the JSA-based technique provides 7.4 times and 6.3 times larger minimum damping ratio compared to PSO and BSA-optimized techniques respectively. On the other hand, the MDR of the DA-based technique is 5.2 times and 6.2 times larger than BSA and PSO-based techniques respectively.

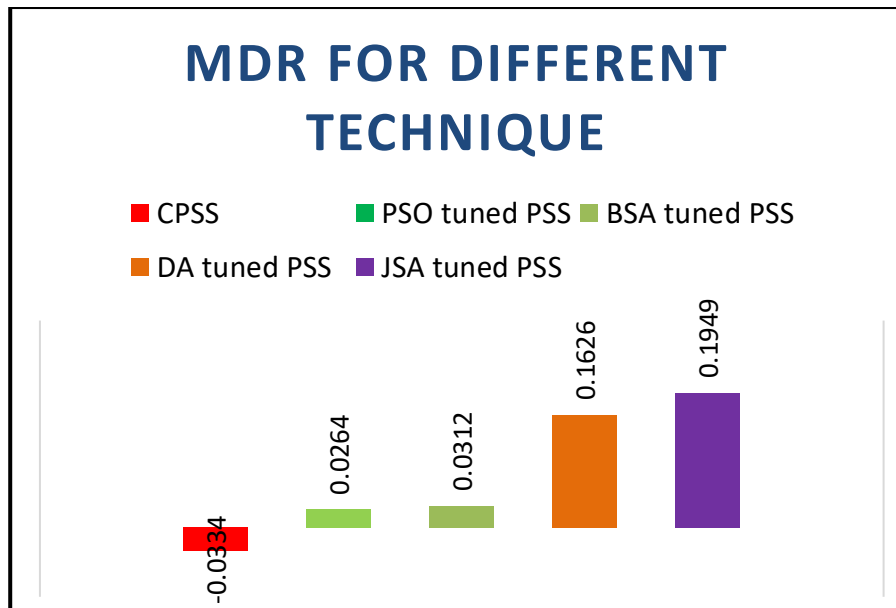


Fig. 5.16. MDR for different optimization techniques for network-2

CHAPTER 6

CONCLUSION

6.1 Introduction:

In this chapter, overall contribution of this thesis is discussed. Future scope and limitations are also mentioned.

6.2 Conclusion:

Various types of disturbances constantly impair the stability of electric power systems by creating LFOs. PSSs are integrated with synchronous generators to enhance the stability of the system. This thesis proposes a new PSS design method for the multimachine power system (MMPS) network based on two new optimization algorithms called artificial jellyfish search algorithm (JSA) and dragonfly algorithm (DA). The suggested methods are tested on two multimachine power systems models with different system configurations. For both cases, the technique's robustness is demonstrated by its convergence independent of the initial guess. Time-domain simulations of angular frequency, rotor angle, and control signal show that DA and JSA-tuned PSS can stabilize the system much faster than conventional PSS. Furthermore, for the identical system design, the damping ratio study of two MMPS networks shows that the DA and JSA-based method provides better damping ratio than the PSO and BSA-optimized techniques. Also, the DA and JSA-based technique require the fewest objective function evaluations to achieve convergence. After introducing 3- ϕ faults, the suggested PSS designs significantly improve system stability, as shown by time-domain simulations. The limitation of this thesis are, no renewable energy source is considered in the multimachine networks. Also, there is no real time optimization of the PSS, it works on the pre-defined values. In future to improve the model FACTS devices can be integrated.

APPENDIX NOMENCLATURE

$K_1 - K_6$ = Fourth order model constants
 T'_{do} = Time constant of the open circuit field
 T_1, T_2, T_3, T_4 = Time constants for CPSS
 K_C = Gain of the CPSS
 T_E = Time constant for the excitation system
 K_E = Gain in the excitation system
 T_w = Constant washout block time
 v_{tr}, v_t = Reference and terminal voltages
 v_q, v_d = Voltages of the quadrature and direct axes
 i_q, i_d = Currents of the quadrature and direct axes
 x'_q, x'_d = Transient reactance of the quadrature and direct axes
 x_q, x_d = Reactance of the quadrature and direct axes
 ω_0 = Base angular frequency; M = System inertia coefficient
 ∇E_{fd} = Field excitation
 e'_q = Internal voltage of the generator
 δ, ω = Rotor angle, Angular frequency
 P_D = Damping Coefficient; u_{PSS} = Control input
 P_e, P_m = Output electrical power and input mechanical power

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