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Application of Flower Pollination Algorithm for Optimally Tuning Zeigler Nichols Parameters for PID Controller to Enhance Transient Stability through SVC

Subhashree Choudhury, Prakriti Rout, Anshuman Satpathy, Tara Prasanna Dash

Abstract*: With the evolution of electrical networks, the complexity and non linearity of modern power systems has enhanced exponentially. In order to reduce these potentially harmful oscillations, power system stabilizers (PSS) are introduced in generators of modern power systems. The PSS brings the system back to a stable and balanced state and re-establishes the pre-fault performance of the system after removal of disturbance and restoration of line. However utilization of PSS in certain cases of increased transmission line loading and other significant faults is not very effective and is rather time consuming. These days to acquire better control and quality of power, FACTS devices are being commonly used in large power systems. When SVC, a versatile FACTS device is used simultaneously with PSS, there is not only improvement in power transfer capability and controllability but also a distinct enhancement in power system stability. In order to increase the performance of the conventional PID controller of the PSS, it is tuned with a very simple and quick tuning method called Zeigler Nichols (ZN) which provides very fast elimination to disturbances in power system. However the conventional and ZN based PID controllers are confined only to linear control of power system. To further enhance the dynamic tuning process in order to obtain much faster and better transient as well as dynamic stability, a very adaptable and robust nature inspired technique of Flower Pollination Algorithm (FPA) is used to tune the ZN based PID controller. To realise the system transient stability for the conventional and proposed method, root locus and total harmonic distortion techniques have been adopted. The results ultimately reveal the efficacy and productiveness of FP based ZN- PID in successfully damping out inter area oscillations thus reducing the harmonics and improving overall stability in power systems as compared to other tuning methods.

Index Terms*: Zeigler Nichols (ZN), Flower Pollination Algorithm (FPA), Static Var Compensator (SVC), Flexible AC Transmission System (FACTS), Power System Stabilizer (PSS), Fast Fourier Transform (FFT), Total Harmonic Distortion (THD), transient, stability, Proportional Integral Derivative (PID).

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I. INTRODUCTION

Nowadays the average demand of electricity is increasing dramatically even though there are constraints on transmission line expansion, thus resulting in increased complicacy of modern power systems. In such complex power systems small disturbances are very likely to occur.

Also there are increased chances of unevenness between the power demanded and the power actually available at a particular time, leading to small electromechanical oscillations in power systems. These oscillations often have very small frequencies within the range of (0.2-3) Hz [1]. These oscillations not only reduce the smooth operation, power transfer capability and security of power system but also enhance the risk of instability. It causes the power system parameters to swing uncontrollably thus reducing operational consistency. The term 'stability' in power systems refer to the ability of the system to come back to their original operating state after being subjected to disturbances under certain constraints [2]. To combat the multi-faceted problems mentioned above, modern power system generators are equipped with PSS that are used as feedback controllers to enhance flexibility for effectively damping out power system oscillations [3]. However, for electricity transmission over long distances and increased loading conditions, only use of PSS for mitigation of power system oscillation is sometimes not enough. For better utilization and reliability of existing transmission lines, improved power flow, reduction of sub synchronous resonance and most importantly enhanced system stability performance FACTS devices are being widely used in power systems [4]. Thus if FACTS devices are used jointly with PSS, it improves the compensation of reactive power, power transfer capability and provides enhancement in the transient and dynamic stability to a greater extent. It also effectively brings back the consistency in power system variables leading to greater power system performance [5]. Out of the many FACTS devices used in power system, SVC stands out distinctly because of its unique features. SVC is one of the most extensively used shunt compensator that provides greater precision, simplicity and spontaneous response to transient and dynamic instability as compared to classical shunt compensators [6].

It effectively reduces the power system losses, suppresses the power system swings and allows greater usage of existing transmission system networks to their thermal loading capacity as compared to other FACTS devices. From several studies on PSS and FACTS control, it is known that without proper tuning and optimization the conventional PID of the PSS will not respond effectively to certain disturbances. Thus the conventional PID of the PSS is first tuned with a simple yet productive ZN tuning method The ZN technique is a self-tuning technique that is relatively easy, simple to use and is utilized primarily to provide the PID loops the best disturbance reduction performance [7]. However, it makes the loops oscillatory and give large overshoots. Moreover the conventional PID and ZN tuned PID controllers are linear controllers that cannot respond appropriately to non linearities in power system. Hence for optimal placement of FACTS devices for greater operational performance and effective response to non linear systems, the PID controller is tuned dynamically using the versatile FPA technique [8]. FPA is a nature inspired meta heuristic robust technique which is based on the appealing flower pollination process of the plants to carry out reproduction. It shows flexibility in solving wide range of complex optimal problems. This technique of optimization is quite simple to implement and demonstrates fast convergence to optimum designs thus leading to much greater stability and operational efficiency [9].

For the verification and validation of the effectiveness of the FPA along with ZN, the system is subjected to two types of external disturbances; (i) introduction of heavy load and (ii) sudden change in reactive power. Furthermore for better stability analysis two methods are adopted: 1) Root locus technique to find the location and variation of the poles of the closed loop system and 2) FFT analysis for determining the THD of phase voltage of the transmission line It helps in examining the amount of harmonics present in the system and its effective elimination to improve stability [10].

The rest part of this paper is structured as follows: In Section II the detailed description about the components used in power system is given. Section III discusses about the control structure and the different tuning methods that have been used to tune PID in order to effectively obtain an optimal solution. Section IV contains the MATLAB/ Simulink model. In section V the stability enhancement by the proposed controller is verified through 1) root locus analysis and 2) calculation of total harmonic distortion. Finally in Section VI the conclusion from the entire paper is discussed.

II. POWER SYSTEM MODELLING

A simple one line diagram of a two synchronous machine system is demonstrated in Fig.1. It mainly comprises of two synchronous machine M1 and M2, having the same turbine and governor specifications, in addition to this, an external excitation system equipped with Automatic Voltage Regulator (AVR) and a PSS are also present. Furthermore, the system consists of busbars, transformers, a purely resistive load having a power rating of 5000 MW and most importantly SVC connected in parallel to load. The two machine system is subjected to some typical disturbances to study the effectiveness of the coordinated use of PSS and SVC as well as the proposed controller in the power system.

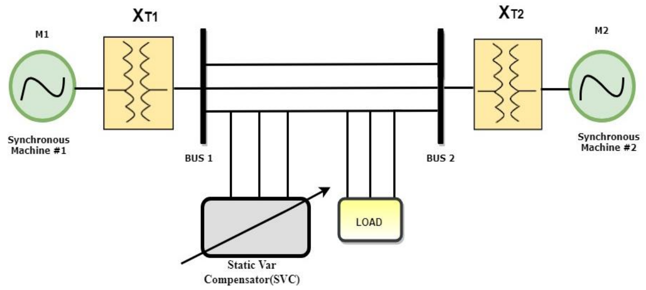

Fig. 1. One line diagram of system under study

A. POWER SYSTEM STABILIZER

The generation of low frequency oscillations is a quite common incident in large complex power systems. These electromechanical oscillations often cause the power system variables like voltage, current and power to swing continuously reducing the operational consistency of the two machine system [11]. In worse cases it can even cause collapsing of entire systems leading to blackouts [12]. As a result there is huge wastage of money and consumers have to pay a heavy price. To avoid such incidents nowadays modern power systems are equipped with PSS. It is primarily a controlling device present in generator's excitation system, as a feedback to produce a damping torque which keeps altering with the change in speed of rotor of the generator, for mitigation of electromechanical oscillations [13]. It thus plays a vital role in improving the stability and thus bringing constancy in power system parameters.

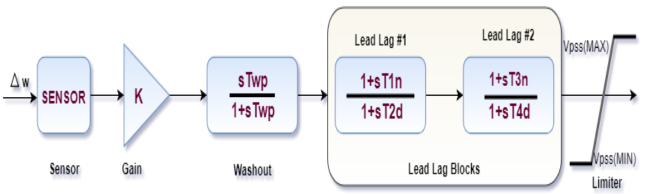

Fig. 2. Generic model of lead-lag PSS

Fig.2 depicts the generic model of lead lag PSS where Twp is the washout filter time constant. T1n, T2d, T3n and T4d are the time constants of the lead-lag blocks phase lag compensation. It mainly comprises of: 1) a sensor block- which acts as a low pass filter that allows only smaller magnitude frequencies to pass; 2) washout block: a high pass filter that makes the PSS to respond to transient instabilities and resist changes in dc offsets; 3)lead lag block: to provide adequate amount of phase lead to compensate phase lag between generator torque and exciter input; 4) a gain K which is proportional to damping provided by PSS and 5) limiter that limits the terminal voltage fluctuations during transient fault conditions.

B. *STATIC VAR COMPENSATOR (SVC)*

The extensive use of FACTS devices in power system has not only helped increasingly in improving the system operation and security but has also led to remarkable reduction in cost.

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SVC is one such versatile and flexible shunt connected FACTS device that has an edge over other FACTS devices because of its striking features. It is a fast acting device that effectively controls the temporary and steady state over voltages, has greater power transfer capability and reduces line losses [14]. In AC power systems SVC improves power system characteristics like steady state, stability limits, regulate voltage and damp power system swings. SVC basically has a fixed shunt capacitor and a controlled reactor, that are connected in parallel and function in two main modes i.e. capacitive and inductive respectively [15]. The one line diagram of SVC model is illustrated in Fig. 3. These two components can be classified as follows: 1) Thyristor controlled reactor (TCR) and 2) Thyristor- switched capacitor (TSC).

TCR and TSC are both made up of a reactor and capacitor respectively which are controlled individually by two thyristors connected in parallel and in reverse order [16]. In a TCR, a thyristor valve which is bidirectional in nature is connected in series with a fixed reactor. To operate TCR in a continuous manner it is controlled with a proper firing angle input. Similarly, a TSC is also made up of a thyristor valve which is bidirectional in nature, connected in series with a capacitor bank and a current limiting damping reactor. TSC is controlled without the control of firing angle which leads to a step change in reactance. SVCs provide very fast response to a small change in system voltage as a benefit over simple mechanical compensation schemes [17].

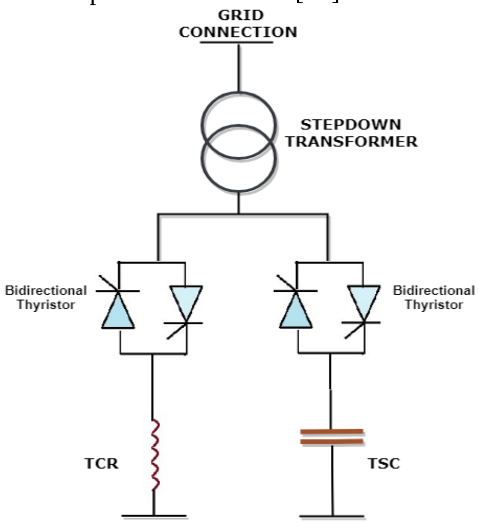

Fig. 3. One line diagram of SVC model

III. CONTROL STRATEGIES OF THE POWER SYSTEM

A. *CONVENTIONAL PID*

PID controller plays a vital role in the closed loop control of almost all industrial processes. PID primarily is named after proportional (P), integral (I) and derivative (D) terms. A PID controller is utilized as a feedback that flexibly keeps calculating an error value e(t) repeatedly by finding the difference between the measured variables and desired set point and applies an error rectification based on proportional integral and derivative terms [18]. Finally the three main parameters are used to generate a control signal with reduced error. The P, I and D parameters can be mathematically formulated as below in [18]:

$$u = kpe(t) + ki\int_0^t e(t)dt + kd\frac{d}{dt}e(t) \tag{1}$$

Where kp, ki, kd are non negative values and denoted as the coefficients for the proportional, integral and derivative terms representation.

- The reduction of rise time is due to kp (proportionality).
- The steady state error is reduced with the use of ki (integral).
- The settling time and peak overshoot is minimized using kd (differentiation).

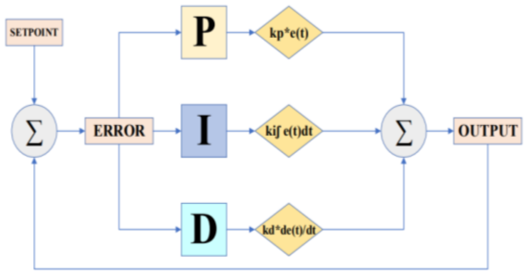

Fig. 4. Block diagram of conventional PID controller

Although PID controller is quite reliable, yet the initial speculation of PID parameters is quite time consuming and it cannot respond to nonlinearities [18]. Hence some versatile tuning methods need to be utilized to effectively tune PID controller for best results.

B. *ZEIGLER NICHOLS METHOD*

Zeigler Nichols (ZN) is one of the very fast and simplest PID tuning techniques that played a huge role in serving the base for development of further PID feedback controller technologies [19]. Increased performance, cost effectiveness and simplicity of the ZN method makes it better as compared to other heuristic methods of tuning [20]. The basic steps of PID tuning using ZN are as follows:

Basic steps of ZN tuning method:

Step 1. In this process the derivative (D) and integral (I) are set to zero.

Step 2. In the next step the proportional gain is increased gradually till it reaches the ultimate gain 'Ku'.

Step 3. At this point it is assumed that the control loop is consistent and has stable oscillations.

Step 4. The oscillation period 'Tu' is for settling the P,I and D gains depending on the type of controller used.

At the point Ku the output of controller has very stable and constant swings.

The correction u(t) can be achieved from error e(t) using the below PID equation mentioned in Eq. 2

$$u(t) = Kp\ e(t) + \frac{1}{Ti}\int_0^t e(t)dt + Td\frac{de(t)}{dt} \tag{2}$$

For the PID tuning using Zeigler Nichols Kp, Ti and Td values are mentioned in the Appendix of Table 3.

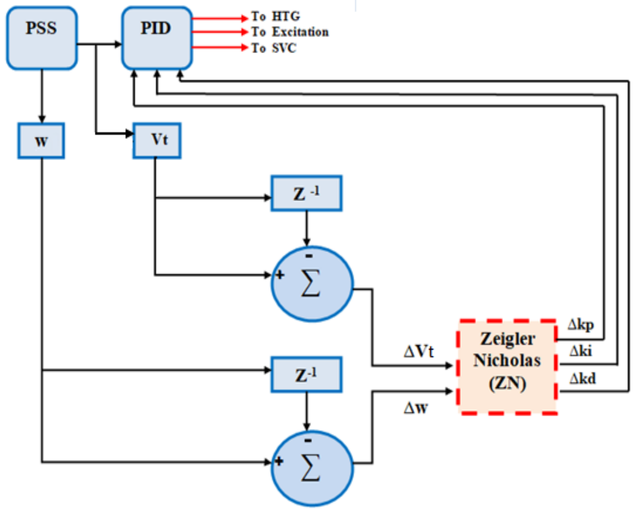

Fig. 5. Control Structure of ZN based PID

Fig. 5 illustrates the control structure of ZN based PID controller. The rotor angular speed w and the terminal voltage Vt are taken as input. The difference between the set points and actual value Δw and ΔVt are given to ZN based Controller. The controller then generates the tuned values of kp, ki and kd. Δkp, Δki and Δkd are fed to the PID controller.

However the ZN technique of controlling PID is linear in nature. It provides very little robustness to loops and is quite oscillating in nature [18]. As a result it leads to loop instability. To overcome the shortcomings of ZN based technique, the ZN based PID controller of the PSS needs to be further tuned dynamically with a versatile optimization technique. Optimization techniques play an important role in finding an optimal solution to a problem. The sole objective of these techniques is to either minimize cost and error or maximize profit or both for optimal design. There are many optimization techniques reported in the literature like Particle Swarm Algorithm (PSO) [2], Genetic Algorithm (GA) [4], Differential Evolution (DE) [3], Artificial Intelligence (AI) [7] etc. These can be either classical that are derived from complex mathematical calculations or heuristic that gives very accurate results in large problems. FPA is one such intelligent optimization technique which is developed by Xin-She-Yang in 2012. It has proved to be effective in wide range of optimization problems. This versatile technique is discussed below in details.

C. FLOWER POLLINATION ALGORITHM

Since time immemorial, nature has been motivating many researchers to solve enormous challenging problems by making use of many laudable meta heuristic optimization techniques. These techniques are inspired from some fascinating features of biological systems and are very efficient in determining optimal solutions of these multifaceted complex problems [22]. FPA is one such modern and versatile nature-inspired optimization technique which is based on the flower pollination process of plants. Modern botanists have discovered about 400,000 types of flowering plant species present in nature. For over 125 years there has been a tremendous improvement in the evolvability of these flowering species, in which flower plays the vital role. The main function of a flower is to reproduce through the process of pollination. Flower pollination typically deals with transfer of pollens from male part of a plant to female part of the same or different plant for successful reproduction [23]. This transfer is carried out by pollinators like birds, insects and other animals. Based on the type of pollinators there are typically two types of pollination.

1. *Biotic pollination*: This pollination is carried out by living pollinator agents like bats, birds, insects, honeybees, squirrels, rodents etc. for transfer of pollen grains from one flower to another. This type of pollination is responsible for over 80% of reproduction in flowering plants [24].
2. *Abiotic pollination*: This pollination makes use of nonliving methods like water, rain, wind etc for movement of pollen from male to female [24].

With the passage of time some pollinators have developed an interesting characteristic of maintaining flower constancy i.e. they visit only some specific flower species thus avoiding all other flowering species [25]. Flower constancy provides some notable evolutionary benefits which is mentioned below:

1. It enhances the probability of the movement of pollen gamets to the same or conspecific plants thus increasingly allowing the same flower species to reproduce.
2. The pollinators too are well acquainted and sure of the constant supply of nectar from these particular flowers thus requiring little memory and reducing the cost of exploring or learning. It ensures the guaranteed nectar intake and cuts down the investment cost.

Pollination can occur in two ways [25]:

1. *Self Pollination*: It means fertilization of a flower by transfer of pollen gamets from the same flower or a different flower of the same plant. The transfer often takes place through non living methods and thus is abiotic in nature.
2. *Cross Pollination:* It means fertilization of a flower by transfer of pollen gamets from a flower of another plant having similar specifications [26]. The transfer often takes place with the help of living pollinators and thus is biotic in nature.

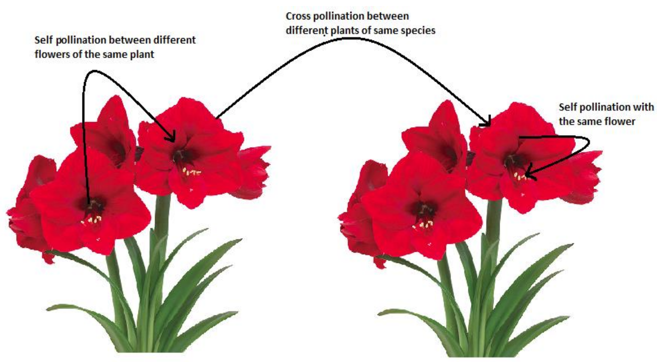

Fig.6. Process of cross pollination and self pollination in flowers

Fig.6 shows the process of cross and self pollination occurring in flowers. For the transfer of pollen from one flower to other pollinators like birds, honeybees etc.
often show L´evy flight behaviour for optimization of search efficiency [27].

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It refers to the random walk i.e. jump or fly of a pollinator where the lengths of steps taken by them have a probability distribution often showing greater variance. The trait of maintaining flower constancy can be utilized as an incrementing step thus distinguishing between similar and different flowers. In a nutshell, all the traits mentioned above on flower constancy, pollination and pollinator behaviour are governed by some specific rules as mentioned below:

Step 1. Biotic and cross pollination are an inherent part of global pollination process where the pollinators showing L'evy flight characteristics.

Step 2. Abiotic and self pollination are an inherent part of local pollination process.

Step 3. Flower constancy plays an important role in enhancing reproduction probability and is proportional to the similarity of flowers involved.

Step 4. Global and local pollination is often controlled by a switch probability $p_r \in [0,1]$. Due to physical proximity and other factors such as wind, local pollination can have a significant fraction p_r in the overall pollination activities.

Although in the reality, every plant can have numerous flowers and each flower can release millions of pollens, taking simplicity into account it is assumed that each plant has only one flower and each flower can release only one pollen [28]. As a result there is no requirement of distinguishing a flower or a pollen gamet or the optimal solution to the problematical question. Thus we can use a single term solution 'yi' to refer to a single flower or a pollen.

3.3.1 Global Pollination Search Process:

As in global pollination the living biotic pollinators carry the pollen gamets large distances in order to ensure the optimal reproduction of the flowering plants and diversity, Rule 1 and Rule 3 of FPA can be mathematically represented as follows:

$$y_i^{t+1} = y_i^t + L(g* - y_i^t) \quad (3)$$

Where y_i^t represents the solution term or a pollen at iterating step t and g* is considered as the best solution as compared to all the other solutions of the present iteration. The term L is the size of a step and is used for determining the potency of the pollination. L is derived from the Levy distribution as follows:

$$L \sim \frac{\lambda\Gamma(\lambda)\sin(\frac{\pi\lambda}{2})}{\pi}\frac{1}{s^{1+\lambda'}} \; (s>>0) \quad (4)$$

Where $\Gamma(\lambda)$ is used to refer to the standardized gamma function λ is normally assumed to be 1.5. The distribution is only applicable for larger steps s>0.

3.3.2 Local Pollination Search Process:

As in local pollination only abiotic pollination agents are involved, the Rule 2 and Rule 3 representing the local pollination and flower constancy respectively can be mathematically formulated as follows:

$$y_i^{t+1} = y_i^t + \epsilon(y_j^t - y_k^t) \quad (5)$$

Where y_j^t and y_k^t represent the pollen gamets from flowers of different plant of similar species. The characteristics of maintaining flower constancy is imitated in this equation. If y_j^t and y_k^t belong to the identical species that can be picked from the similar population, the equation gets modified into a local random walk if we find € (a random vector) from a random distribution in [0,1]. The modified solution thus obtained will not be very far-off from existing solutions.

3.3.3 Switch Probability:

It is very important to consider the frequency and percentage of each pollination type. A switch probability p_r has been used in Rule 4 to imitate this essential feature wherein the value of p_r determines whether the alteration in solution either follows local or global pollination. Its suitable value is mentioned in the Appendix of the paper. For most applications is considered to get more effective results. Fig. 7 describes the overall concept of FPA through a flowchart representation.

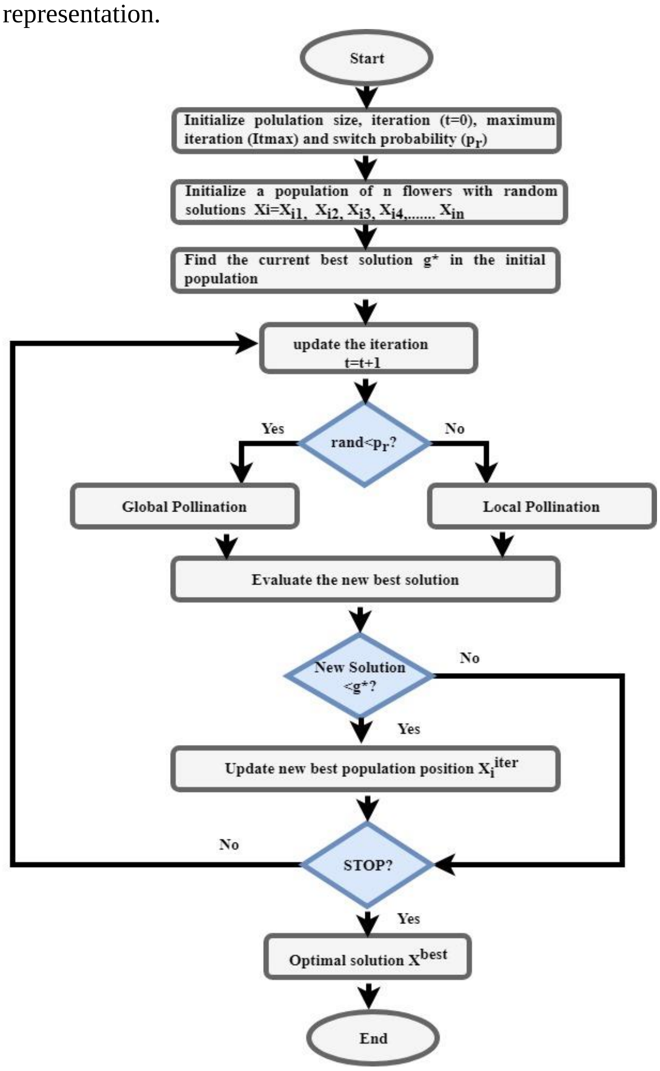

Fig.7. Flow chart of Flower Pollination Algorithm

D. *APPLICATION OF FPA-ZN IN TUNING OF PID CONTROL PARAMETERS OF PSS*

In order to achieve better flexibility, operational superiority and to obtain most favourable solutions for complex problems tuning techniques like FP and ZN have been used. These techniques are often used either for minimization or maximization purposes.

The PID controller of the PSS is first tuned with ZN technique and then the ZN based PID controller is further tuned dynamically using the FP Algorithm.

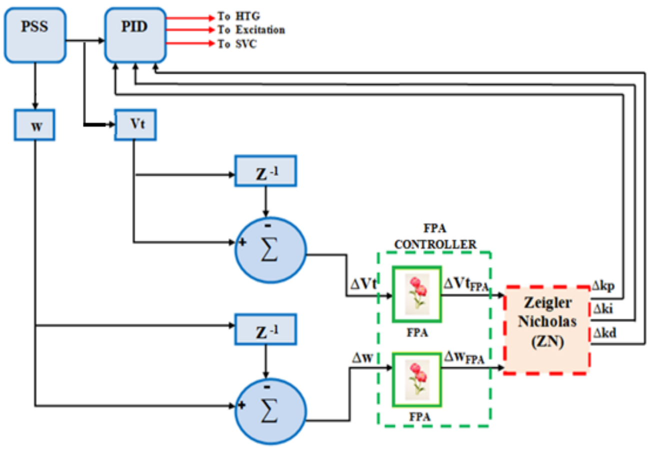

Fig. 8. Control Structure of FPA optimized ZN based PID

The main objective in this paper is to tune PID controller for minimization of error. Fig, 8 illustrates the control structure of FPA optimized ZN tuned PID controller. Two objective functions are considered (i) Angular speed deviation of rotor (Δw). (ii) Change in terminal voltage of two machine system (ΔVt). For these objective functions a powerful control measure named ITAE (Integral Time Absolute Error) is used error reduction, ITAE integrates the product of time and absolute error over time. ITAE control measure for tuning criterion of PID is used because of its ability in producing systems which settle quite quickly as compared to other methods. In case of ITAE, the closed loop response is very less oscillatory in nature [29]

The general form of ITAE is given below:

$$ITAE_1 = \int_0^t (e_{t1}(t))^2\, dt \quad (6)$$

Where $e_{t1}(t)$=Δw= w(k) – w(k-1) (7)

$$ITAE_2 = \int_0^t (e_{t2}(t))^2\, dt \quad (8)$$

Where $e_{t2}(t)$=ΔVt= Vt(k) – Vt(k-1) (9)

Δw and ΔVt are considered as the errors to be minimised. In other words it is the degree of the variation of controlled variable from set point.Here w(k) and Vt(k) are the speed and terminal voltage deviation in present iteration respectively and w(k-1) and Vt(k-1) are the speed deviation and terminal voltage in last iteration respectively. Using the above two control measures effective optimal values of kp, ki and kd are determined as follows:

$$\Delta kp = kp(k) - kp(k-1) \quad (10)$$

$$\Delta ki = ki(k) - ki(k-1) \quad (11)$$

$$\Delta kd = kd(k) - kd(k-1) \quad (12)$$

IV. MATLAB SIMULATION MODEL AND RESULT ANALYSIS

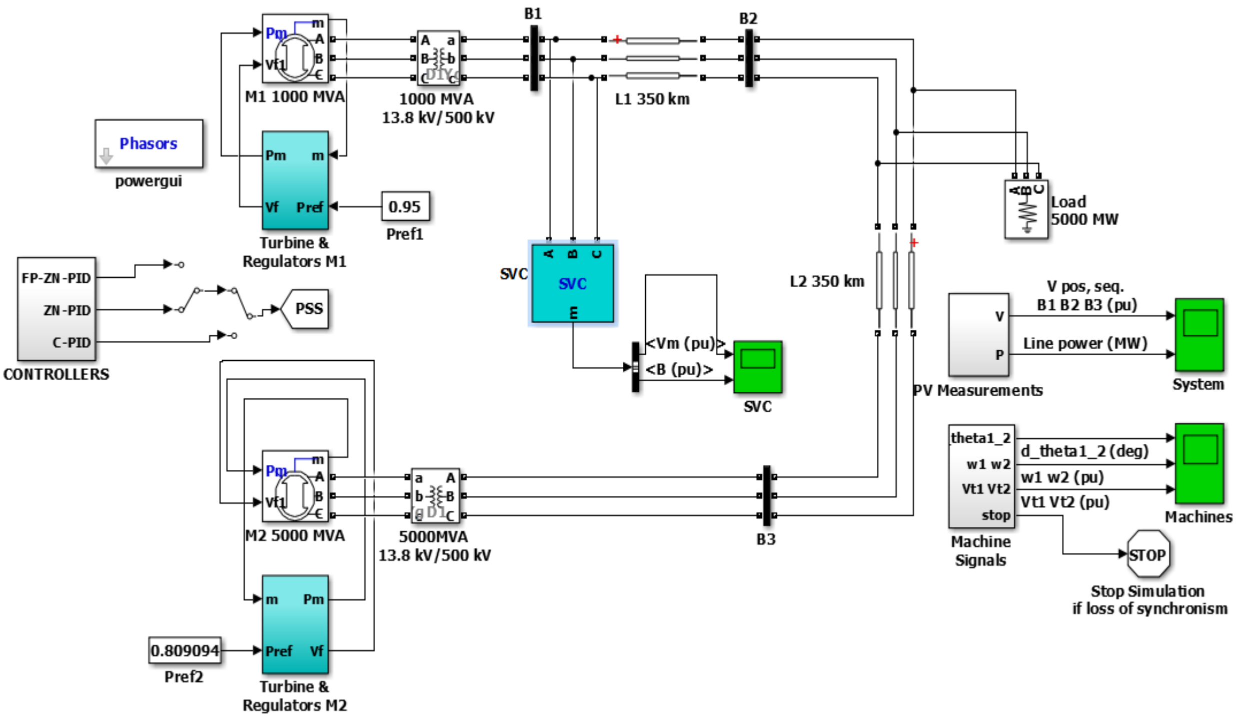

Fig. 9. Model of two machine power system with SVC in MATLAB/Simulink environment

Fig.9 demonstrates the MATLAB/Simulink model of a two machine system with the combined use of PSS and SVC along with the conventional and proposed controller (FPA, ZN-PID and PID). The specifications of the components used in Fig.10 of two machine system are mentioned in the Appendix. In order to verify and validate the effective functioning of the various tuning techniques, the system is subjected to 3 kinds of external disturbances. These includes:

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1. Introduction of a heavy load by changing the resistive load from 5000 MW to 7000MW.
2. Sudden change in reactive power from 0 vars to 5e+009 vars.

The performance of power system variables of the dynamic FP based ZN-PID controller is compared and contrasted with only ZN based PID controller and conventional PID. The corresponding values of the proposed and conventional control techniques being compared in terms of various types of fault and in term of control parameters (like rise time, settling time and peak overshoot) are given in Table 1 and Table 2 respectively.

Case1. Introduction of Heavy Load

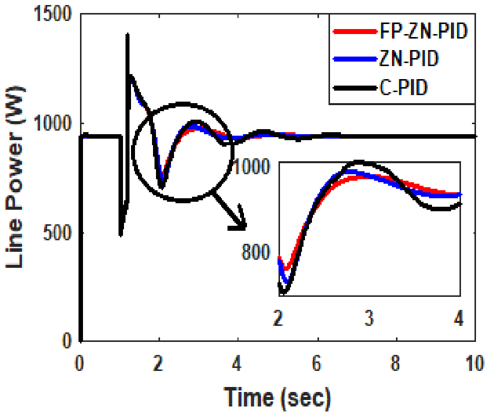

Fig. 10. Line Power of the two machine system

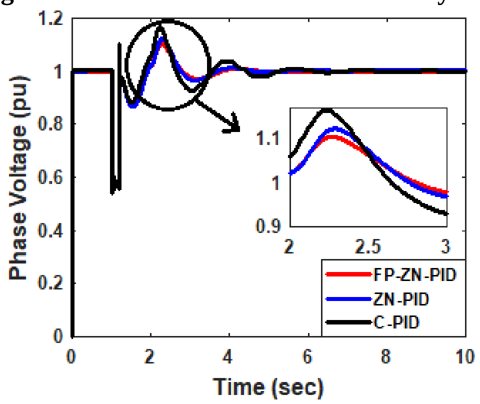

Fig. 11. Phase Voltage of the two machine system

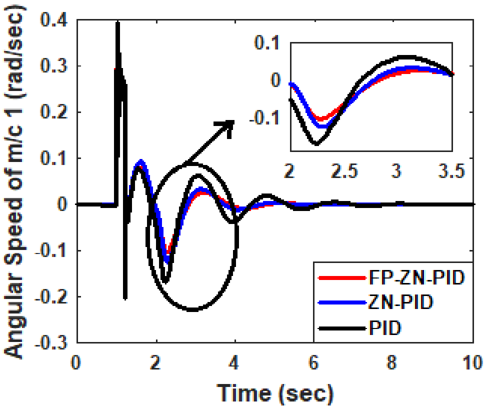

Fig. 12. Angular Speed of machine 1(M1)

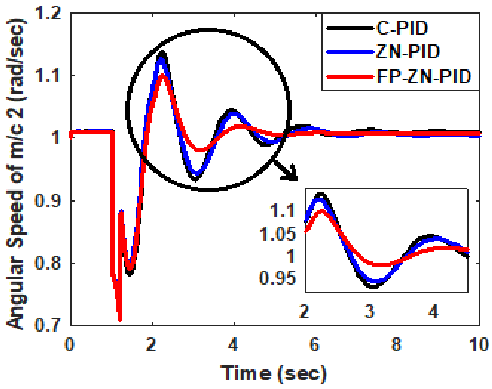

Fig. 13. Angular Speed of machine 2(M2)

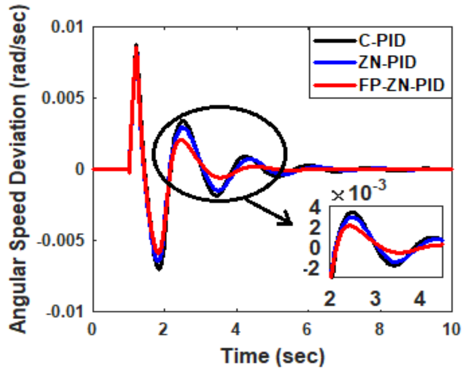

Fig. 14. Angular Speed deviation of M1 and M2

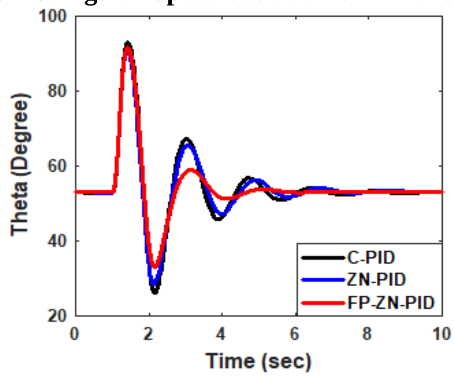

Fig. 15. Rotor Angle of two machine system

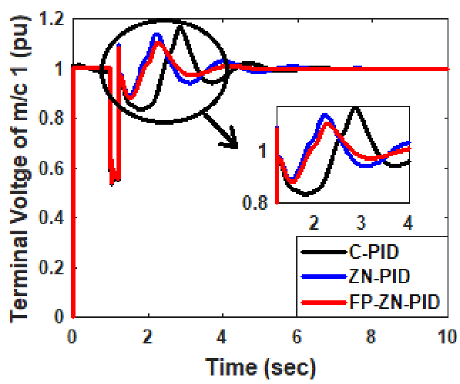

Fig. 16. Terminal Voltage of machine 1(M1)

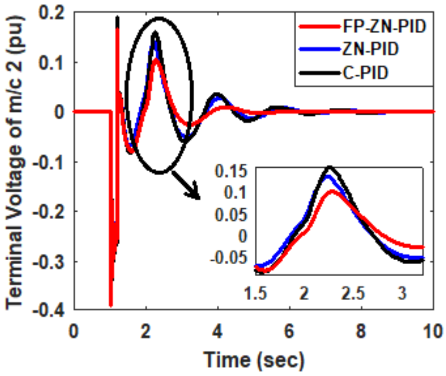

Fig. 17. Terminal Voltage of machine 2(M2)

Fig. 10 - Fig. 17 depict the performance of power system variables in presence of (i). Conventional PID; (ii). ZN based PID; (iii). FP based ZN-PID when subjected to a heavy load that requires large amount of power at the load end of the system. Fig. 10 and Fig. 11 show the line power and the phase voltage performance of two machine system. Fig. 12 and Fig. 13 present the angular speed of rotor of machine 1 and machine 2 respectively. Similarly Fig. 14 depicts the angular speed deviation of machine 1 and machine 2. Fig. 15 represents the rotor angle performance in case of this particular fault. Fig. 16 and Fig. 17 show the terminal voltage of machine 1 and machine 2 respectively. From all the results obtained, it can be seen and concluded that the ZN based PID controller yields better results than the conventional PID controller when led to introduction of a heavy load, However, the ZN based PID controller when further tuned optimally through FPA technique, it outperforms even the ZN based PID controller with less peak overshoot, relatively greater settling time and improved system transient stability.

Case 2. Sudden increase in Reactive Power

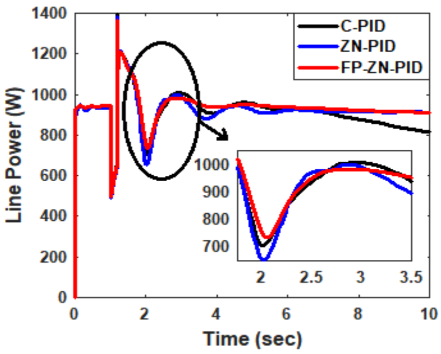

Fig. 18. Line Power of the two machine system

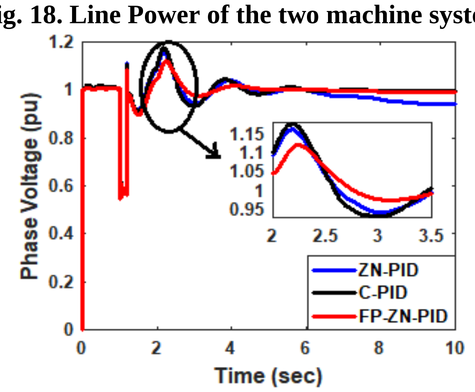

Fig. 19. Phase Voltage of the two machine system

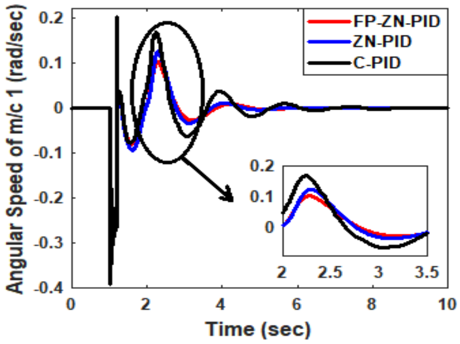

Fig. 20. Angular Speed of machine 1(M1)

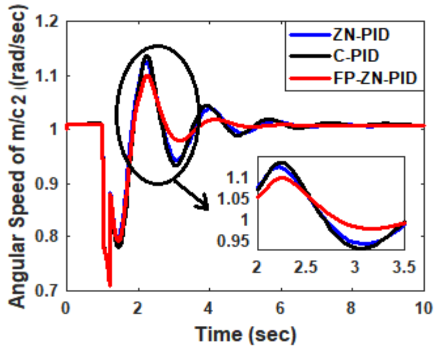

Fig. 21. Angular Speed of machine 2(M2)

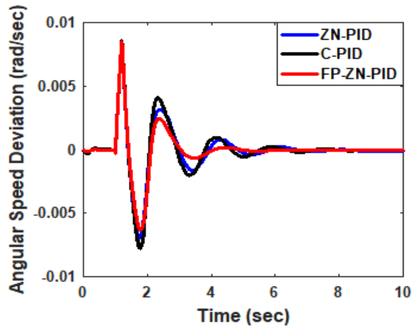

Fig. 22. Angular Speed deviation of M1 and M2

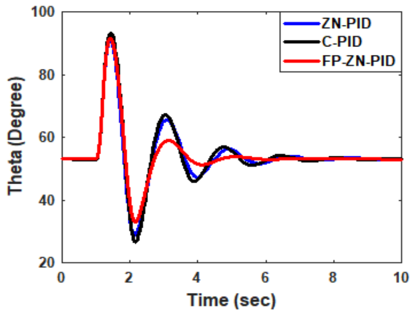

Fig. 23. Rotor Angle of two machine system

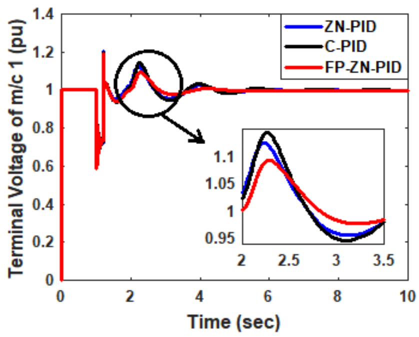

Fig. 24. Terminal Voltage of machine 1(M1)

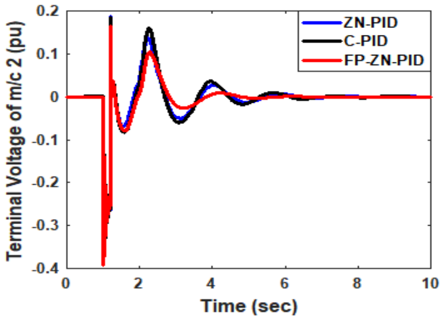

Fig. 25. Terminal Voltage of machine 2(M2)

Fig.18 - Fig.25 represent the performance of power system variables in presence of conventional PID, ZN based PID and FP based ZN-PID controller when the reactive power of the two machine system is suddenly increased. Fig. 18 and Fig. 19 portray the line power and phase voltage performance of the two machine system. Fig. 20 and Fig. 21 present the angular speed of rotor of machine 1 and machine 2 respectively. Similarly Fig. 22 depicts the angular speed deviation of machine 1 and machine 2. Fig. 23 shows the rotor angle of two machine system. Fig. 24 and Fig. 25 depict the terminal voltage of the machine 1 and machine 2 respectively. It can be concluded from the above results that the FPA based ZN-PID surpasses the ZN-PID and conventional PID in terms of enhanced dynamic stability, robustness, better rise time, peak time and settling time.

Table 1. A direct comparison of PID parameters between conventional PID, ZN tuned PID and FP based ZN-PID controller for different type of faults.

Sl.no	FAULTS	PID			ZN-PID			FP-ZN-PID		
		kp	*ki*	*kd*	*kp*	*ki*	*kd*	*kp*	*ki*	*kd*
1	HEAVY LOAD	3.21	3.75	2.98	2.74	2.88	2.64	1.9	1.56	1.78
2	REACTIVE POWER	2.25	2.56	2.67	1.82	1.67	1.88	1.025	1.012	1.56

Table 2.A contrast between conventional PID, ZN tuned PID and FPA optimized ZN-PID for different parameters in power system

Sl. No.	POWER SYSTEM PARAME-TERS	PID			ZNPID			FP-ZN PID		
		PEAK TIME	*RISE TIME*	*SETTLING TIME*	*PEAK TIME*	*RISE TIME*	*SETTLING TIME*	*PEAK TIME*	*RISE TIME*	*SETTLING TIME*
1	*Vt1*	7.7621	4.2576	126.599	3.6799	1.8156	122.599	1.9988	0.9694	102.55
2	*Vt2*	6.3731	3.2656	124.77	3.9299	1.9299	125.699	1.9799	1.0299	112.55
3	*w1*	8.9	5.67	132.37	4.02	1.56	126.78	1.77	0.86	99.99
4	*w2*	8.1289	4.72	130.11	2.76	1.44	120.77	1.85	0.97	107.66
5	*w1-w2*	6.26	3.12	125.67	2.19	1.24	115.67	1.56	0.82	86.56
6	*Theta*	6.6731	3.2656	124.77	3.9299	1.9299	125.699	1.9799	1.0299	112.55
7	*Line power*	5.96	3.25	140.65	2.12	1.67	112.23	1.26	0.869	101.11
8	*Line Voltage*	8.92	5.56	160.64	4.56	1.29	150.26	2.639	0.826	116.26

V. STABILITY ANALYSIS

A. ROOT LOCUS TECHNIQUE

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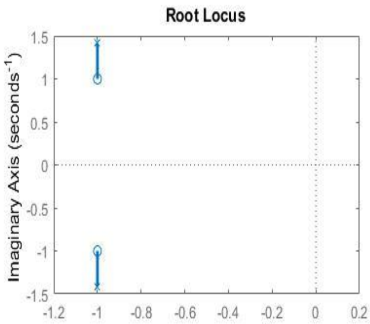

Fig.26. Root Locus of Conventional PID

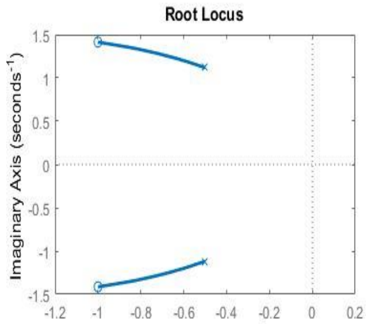

Fig. 27. Root Locus of ZN tuned PID

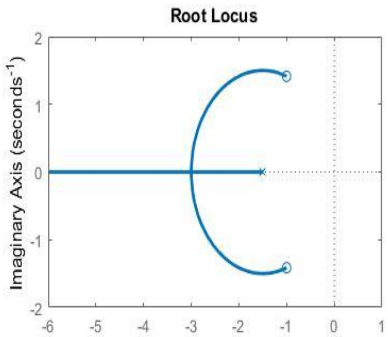

Fig. 28. Root Locus of FPA tuned ZN-PID

The poles and zeros play an important role in determining the system stability. The root locus is a very powerful technique used in many classical control system problems for stability analysis [30]. It is used to determine the location of poles and roots in the s-plane in order to determine the stability performance of the overall system and analysis of error. In a closed loop LTI system it can easily determine a system is stable or unstable depending on the position of its poles and can also predict different types of oscillations present.

The characteristic equation of the Root Locus Technique is mentioned below.

$$1 + G(s)H(s) = 0 \qquad (10)$$

Where G(s) is the forward path gain and H(s) is the feedback gain. Fig. 26, Fig. 27 and Fig. 28 demonstrate the root-locus of conventional PID, ZN- based PID and FP based ZN-PID. In all these plots it is found that the poles lie as complex conjugate pair on the LHS of the s-plane and are therefore stable. However the conventional PID illustrated in Fig.26 is confined to a very small stable region. The ZN based PID shown in Fig.27 covers a much broader stable region as compared to conventional PID. The FPA optimised ZN based PID depicted in Fig.28 covers the widest region of optimal stability as compared to ZN based PID and conventional PID.

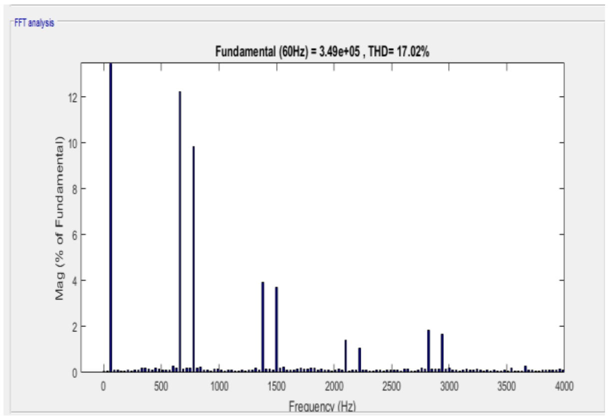

Fig.29. FFT analysis in case of conventional PID

B. FFT ANALYSIS AND DETERMINATION OF THD

The stability analysis of the system is determined through FFT analysis by calculation of THD in the presence of harmonics in the system that creates losses and increase instability. Fig. 29, Fig. 30 and Fig. 31 represent the FFT analysis through the THD calculation for the transmission line phase voltage in cases of only conventional PID, ZN tuned PID and FPA based ZN-PID respectively. FFT analysis plays a significant role in conversion of an input signal from original domain to frequency domain for determination of harmonics [31]. The total harmonic distortion is 17.02%, in case of only PID, whereas it is 1.81% in case of ZN based PID. However it is further reduced to a greater extent i.e. 1.21% in case of FPA based ZN-PID which is well within the IEEE-519 limits.

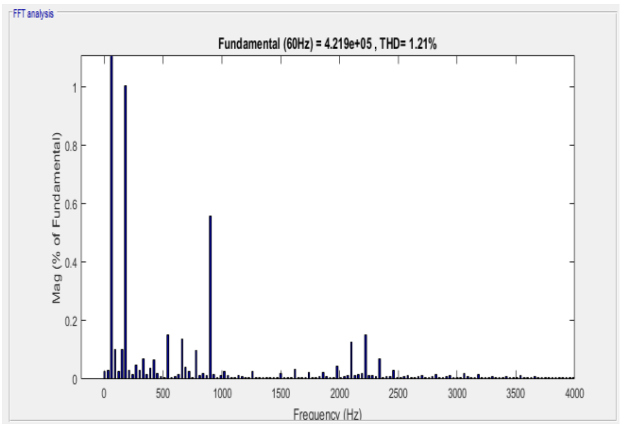

Fig.30. FFT analysis for ZN based PID controller

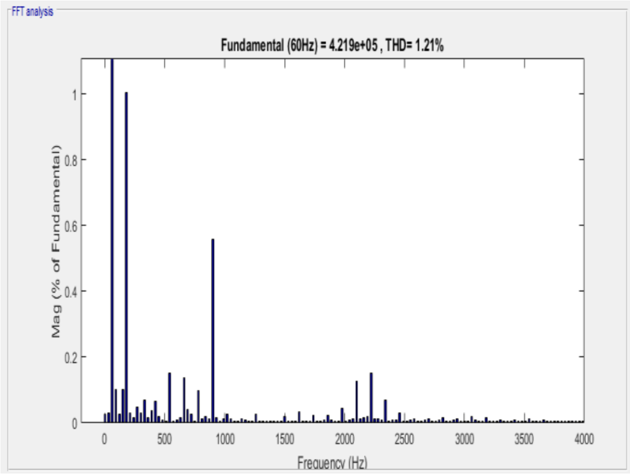

Fig.31. FFT analysis for FPA based ZN PID controller

VI. CONCLUSION

In this paper a critical analysis of stability enhancement of a two synchronous machine power system is carried out by the synchronized design of PSS and SVC. However for optimal placement of SVC and for the power system to respond effectively to non linearities the PID controller of the PSS needs to be tuned vigorously with appropriate tuning methods. The ZN tuning technique is one of the simplest and easiest techniques to get optimal results. However it fails to respond to non linearities. Another intelligent nature based optimization technique called FPA is utilized to solve complex optimal problems in a precise and quick manner. Hence with the combination of FPA as well as ZN technique, the PID controller is tuned dynamically to get better power transfer capability, operational consistency and hence greater system stability. To justify the efficiency of FPA tuned ZN-PID, the power system is subjected to two external disturbances. These include introduction of heavy load and spontaneous increase in reactive power of system. The results verify the efficacy of the proposed controller in mitigation of oscillations and enhancement of system stability performance in terms of robustness, improved system dynamic stability, enhanced time response, increased efficiency and improved overall system performance. Furthermore the root locus analysis of the two machine system additionally justifies the stability of system in all three cases of controller design. In addition to it the FFT analysis of the system demonstrates the substantial reduction in THD to 1.21% in case of FP based ZN PID as compared to ZN-PID which is 1.81% and conventional-PID being 17.02%.

APPENDIX

Table 3. Specification of the components used in two machine system

Components	Values
Transmission line	Number of phases=3
	frequency=60Hz
	Resistance per unit length=0.01755 Ω/Km
	Inductance per unit length= 0.8737e-3 H/Km
	Capacitance per unit length= 13.33e-9 F/Km
	Length of line =350 Km
Machine1(M1)	Xd=1.305, X'd=0.296, X"d=0.252, Xq=0.474 X"q=0.243, X_L=0.18
Machine2(M2)	Xd=1.305, X'd=0.296, X"d=0.252, Xq=0.474 X"q=0.243, X_L=0.18
T1	1000MVA, 60Hz, 13.8KV/500KV,
T2	5000MVA, 60Hz, 13.8KV/500KV
SVC	Nominal voltage= 500e3V L-L
	Frequency=60Hz
	Three-phase base power= 200e6VA
PID controller parameters	Kp= 0.6 Ku, Ti= Tu/2 and Td=Tu/8

FPA switch probability p_r	p_r=0.8

REFERENCES

1. G. Zhang, Chen, et al. "Coordinated supplementary damping control of DFIG and PSS to suppress inter-area oscillations with optimally controlled plant dynamics." IEEE Transactions on Sustainable Energy 9.2 (2018): 780-791.
2. Chen, Lei, et al. "Reduced-order model for computing frequency oscillation mode of power systems." IET Generation, Transmission & Distribution 12.11 (2018): 2799-2803.
3. Sundaram, N. Mohana, C. Udhayashankar, and Rani Thottungal. "An Investigation of Small-Signal Stability of IEEE 14 Bus System with AVR, PSS and Performance Comparison with FACTS Devices." Intelligent and Efficient Electrical Systems. Springer, Singapore, 2018. 175-185.
4. He, Ping, et al. "Small-Signal Stability Improvement of a DFIG Integrated Power System Using PSS and SVC." 2018 IEEE International Conference on Electro/Information Technology (EIT). IEEE, 2018.
5. Khatoon, Naseeb, and Sajida Shaik. "A Survey on Different types of Flexible AC Transmission Systems (FACTS) Controllers." International Journal of Engineering Development and Research 4.5 (2017): 796-814.
6. Shahgholian, G., et al. "Transient stability enhancement of a two-machine power system using SVC and PSS: A comparative study." Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON), 2017 14th International Conference on. IEEE, 2017.
7. Chaib, Lakhdar, Abdelghani Choucha, and Salem Arif. "Optimal design and tuning of novel fractional order PID power system stabilizer using a new metaheuristic Bat algorithm." Ain Shams Engineering Journal 8.2 (2017): 113-125.
8. Chia, Kim Seng. "Ziegler-Nichols Based Proportional-Integral-Derivative Controller for a Line Tracking Robot." (2018).
9. Peesapati, Rajagopal, Vinod Kumar Yadav, and Niranjan Kumar. "Flower pollination algorithm based multi-objective congestion management considering optimal capacities of distributed generations." Energy 147 (2018): 980-994.
10. Abdelaziz, Almoataz Y., and Ehab S. Ali. "Static VAR compensator damping controller design based on flower pollination algorithm for a multi-machine power system." Electric Power Components and Systems 43.11 (2015): 1268-1277.
11. Bairamkulov, Rassul, Alex Ruderman, and Yakov L. Familiant. "Time domain optimization of voltage and current THD for a three-phase cascaded H-Bridge inverter." Power Electronics and Motion Control Conference (PEMC), 2016 IEEE International. IEEE, 2016.
12. Obaid, Zeyad Assi, L. M. Cipcigan, and Mazin T. Muhssin. "Power system oscillations and control: Classifications and PSSs' design methods: A review." Renewable and Sustainable Energy Reviews 79 (2017): 839-849.
13. Shafiullah, Md, et al. "Designing lead-lag PSS employing backtracking search algorithm to improve power system damping." 2017 9th IEEE-GCC Conference and Exhibition (GCCCE). IEEE, 2017.
14. Shaik, Mohammad Rafee, and A. Srinivasula Reddy. "Optimal placement and sizing of FACTS device to overcome contingencies in power systems." Signal Processing, Communication, Power and Embedded System (SCOPES), 2016 International Conference on. IEEE, 2016.
15. Abazari, Saeed, Abbas Arab Dardori, and Mojtaba BARKHORDARI. "FACTS DEVICE WIDE AREA ROBUST CONTROL FOR DAMPING
16. POWER SYSTEM INTER-AREA OSCILLATIONS: A COMPARISON BETWEEN SVC AND TCSC." UNIVERSITY POLITEHNICA OF BUCHAREST SCIENTIFIC BULLETIN SERIES C-ELECTRICAL ENGINEERING AND COMPUTER SCIENCE 77.1 (2015): 141-156.
17. Abro, Bilawal, Parkash Gujar, and Muharram Ali. "302. Voltage Stability Improvement by Using FACTS Device Static VAR Compensator (SVC)." (2016).
18. Arzeha, N. A., Mustafa, M. W., & Idris, R. M. (2012, June). Fuzzy-based Static VAR Compensator controller for damping power system disturbances. In Power Engineering and Optimization Conference (PEDCO) Melaka, Malaysia, 2012 Ieee International (pp. 538-542). IEEE.
19. Thanh, TU Diep Cong, and Kyoung Kwan Ahn. "Nonlinear PID control to improve the control performance of 2 axes pneumatic artificial muscle manipulator using neural network." Mechatronics 16.9 (2006): 577-587.
20. Meshram, P. M., and Rohit G. Kanojiya. "Tuning of PID controller using Ziegler-Nichols method for speed control of DC motor." Advances in Engineering, Science and Management (ICAESM), 2012 International Conference on. IEEE, 2012.
21. Nisi, K., B. Nagaraj, and A. Agalya. "Tuning of a PID controller using evolutionary multi objective optimization methodologies and application to the pulp and paper industry." International Journal of Machine Learning and Cybernetics (2018): 1-11.
22. Chidambaram, M., and Nikita Saxena. "Refined Ziegler–Nichols Tuning Method for Unstable SISO Systems." Relay Tuning of PID Controllers. Springer, Singapore, 2018. 127-150.
23. Kayabekir, Aylin Ece, et al. "A comprehensive review of the flower pollination algorithm for solving engineering problems." Nature-Inspired Algorithms and Applied Optimization. Springer, Cham, 2018. 171-188.
24. Madasu, Satya Dinesh, MLS Sai Kumar, and Arun Kumar Singh. "A Multi-objective Flower Pollination Algorithm-Based Frequency Controller in Power System." Soft Computing in Data Analytics. Springer, Singapore, 2019. 257-266.
25. Pambudy, Mohammad Musofa Mulya, Sasongko Pramono Hadi, and Husni Rois Ali. "Flower pollination algorithm for optimal control in multi-machine system with GUPFC." Information Technology and Electrical Engineering (ICITEE), 2014 6th International Conference on. IEEE, 2014.
26. Lakshmi, D., A. Peer Fathima, and Ranganath Muthu. "A novel flower pollination algorithm to solve load frequency control for a hydro-thermal deregulated power system." Circuits and Systems 7.04 (2016): 166.
27. Nabil, Emad. "A modified flower pollination algorithm for global optimization." Expert Systems with Applications 57 (2016): 192-203.
28. Dash, Puja, Lalit Chandra Saikia, and Nidul Sinha. "Flower pollination algorithm optimized PI-PD cascade controller in automatic generation control of a multi-area power system." International Journal of Electrical Power & Energy Systems 82 (2016): 19-28.
29. Abdel-Baset, Mohamed, and Ibrahim Hezam. "A hybrid flower pollination algorithm for engineering optimization problems." International Journal of Computer Applications 140.12 (2016).
30. Barisal, A. K. "Comparative performance analysis of teaching learning based optimization for automatic load frequency control of multi-source power systems." International Journal of Electrical Power & Energy Systems 66 (2015): 67-77.
31. Corriou, Jean-Pierre. "Stability Analysis." Process Control. Springer, Cham, 2018. 117-142.
32. Ebrahimzadeh, Esmaeil, et al. "Harmonic stability and resonance analysis in large PMSG-based wind power plants." IEEE Transactions on Sustainable Energy 9.1 (2018): 12-23.