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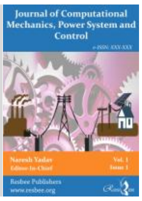

HPSOSSA: Enhancement of Dynamic Stability by Optimal Placement of UPFC

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Abstract: This paper proposes a hybrid approach on the basis of the Optimal Positioning and Sizing (OPAS) to enhance the dynamic stability for Unified Power Flow Controller (UPFC). Moreover, the maximum power loss bus is recognized during the optimum positioning by putting the UPFC, as the generator outage have effects on the power flow constraints namely voltage, real and reactive power flow, and loss of power. By exploiting the Particle Swarm Optimization (PSO) method, the optimum position is determined. According to violated power flow quantities, the Salp Swarm Algorithm (SSA) optimizes, which is necessary for UPFC quantity in order to get better initial operating circumstance. Subsequently, the proposed and conventional methods are simulated in the MATLAB platform and the performance of the proposed approach is examined by comparing conventional approaches like Genetic Algorithm (GA), PSO, and Artificial Bee Colony (ABC). Finally, the results revealed that the performance of the proposed approach is enhanced and validate it's possible to resolve the crisis.

Keywords: optimal location; sizing; UPFC; power system; voltage

Nomenclature

Abbreviations	Descriptions
DS	Distribution System
OPAS	Optimal Positioning and Sizing
DG	Distributed Generation
MFA	Moth–Flame Algorithm
LSF	Loss Sensitivity Factors
RDS	Radial Distribution system
ABC	Artificial Bee Colony
UPFC	Unified Power Flow Controller
DFO	Dragonfly Optimization
SOO	Single-Objective Optimization
PSO	Particle Swarm Optimization
APL	Active Power Loss
BFOA	Bacterial Foraging Optimization Algorithm
SVC	Static Var Compensator
GWO	Grey Wolf Optimization
MOO	Multi-Objective Optimization
TCSC	Thyristor-Controlled Series Compensation
MBA	Mine Blast Algorithm

1. Introduction

Nowadays, power systems restructuring have foisted profitable competition between electric usage, generating extremely stressed operating circumstances. This shows the minimized operating margins, patterns, and overloading transmission line congestion that conduct the power system almost voltage instability. Further distribution companies wish to exploit the conventional transmission system to its utmost, hence circumventing the additional construction cost of new power transfer passages. So, there is a maximized requirement to gaze into the safe level for operations of the power system [18].

During the contingency, the risk index is a phrase, which considers the probability of the incident of a contingency as well as the seriousness of the system state [19]. The result of the contingency and the operating circumstance, when compared with the divergence of the nominal voltage of each system bus, are the main aspects, which creates the severity function. As a numerical value, the clear quantification of the system risk offers a superior comprehension of the system condition, as the pre-defined operating process might be set only for standard contingencies, as well as not present for undermined occurrence.

Voltage Stability is predominately associated with the reactive power planning issue, which contains the analysis of the contingency, whereas appropriate circumstances of reactive power reserves are vital for the stable operation of the power system [20] [21]. By installing the FACTS devices reactive power supports enhances, which is a restorative for eluding voltage instability. The optimal positioning of the FACTS device and the optimal number of MVAR generated/absorbed using the device has an intense effect on the Voltage Stability of the system for real-time security evaluation. The SVC represents a shunt connected device and is frequently exploited for Voltage Profile enhancement, due to its low-cost while comparing with the STATCOM [22].

In [9], by the variable susceptance approach the modeling of the SVC was done and the firing angle technique was also dealt. The SVC positioning and N−2 contingencies were considered to augment the loadability margin and also Bender's decomposition approach was also exploited in [10]. The SVC compensator for voltage stability enhancement was presented in [11]. To discover the optimal positioning and rating of the TCSC and SVC, a bifurcation analysis was exploited in [12]. The positioning for SVC is to conserve the bus voltage as constant, as a result of that maximize the Voltage Stability on the basis of the sensitivity method was presented in [13]. In [14] [15], for the best positioning of FACTS devices, the analysis of the stability index was also presented to manage voltage and reactive power.

The UPFC is considered as the trendy FACTS devices, its major power reclines in its ability to manage reactive and active power concurrently. Theoretically, a UPFC can carry out power flow control, voltage support, and dynamic stability enhancement in a similar device. In order to attain such functionality, it is uniformly significant to resolve a suitable position for installation of UPFC. The efficiency of UPFC differs while it is installed in different positions. The positioning of UPFC in the best possible position is determined on the basis of several performance indices. Because of the high UPFC cost, it is significant to determine their optimal location to convene the preferred objective.

During the past decade, various optimization methods were exploited to determine the best position for UPFC to maximize/minimize several objectives when gratifying several constraints. Several models of UPFC namely voltage source model, uncoupled model, transformer model, and current injection model are exploited in simulation experiments.

The main objective of this paper is to develop a hybrid technique on the basis of the OPAS of UPFC for dynamic stability enhancement. Moreover, the huge amount of power loss bus is recognized at the supportive position in order to fix the UPFC; due to the outage of the generator, the UPFC has effects on the power flow constraints namely voltage, power loss, and real as well as reactive power flow. Using the PSO algorithm the optimum position is examined. On the basis of the violated power flow quantities, the Salp Swarm approach optimizes the necessary UPFC quantity to convalesce the first operating circumstance.

The rest of the paper is organized as follows: Section 2 describes the literature review, and section 3 defines the problem formulation. Section 4 defines the proposed hybrid PSOSSA for optimal placement of UPFC. Section 5 describes the results and discussions of the paper. Section 6 states the conclusion of the paper.

2. Literature Review

In 2018, Mohammad Jafar Hadidian-Moghaddam et al [1] presented a novel optimization technique to resolve the OPAS issue of DG in a DS. A new ALO was exploited with different objectives to resolve the optimization issue. These objectives were the minimization of acquired cost of energy from the upstream network because of a generation of DGs' power, consistency enhancement, and minimization of DGs' cost application, minimization for losses of DS and minimization of buses voltage deviation. This issue was resolved as a MOO besides an SOO.

In 2018, T.C. Subramanyam et al [2] addressed the problems in determining and localizing the positioning for fuel cells to join to DG systems. Here, the dual-phase intelligent technique was exploited to handle the problem. Initially, the neural network was used for the determination of optimal positioning, while in the next phase the optimal positioning of fuel cells was determined using the ABC method. An enhanced version of ABC was presented to evaluate the optimal sizing. The proposed approach was implemented with four IEEE bus systems and analyzed with five existing methods. The outcomes show a better performance of the presented technique. At last, the simulation outcome exposed that the proposed technique performs superior to conventional techniques.

In 2016, Somasundaram Alamelu et al [3] addressed an application of evolutionary methods to OPAS of UPFC that are formulated as multi and single-objective optimization issues. In the optimization process, the decision variables namely optimal positioning, both distance and line of UPFC from the transmitting end; and system reactive power reserves control parameters of UPFC were considered. Reduction of total costs with a UPFC installation cost as well as improvement of the loadability limit was contemplated as objectives. For optimal sizing and siting of UPFC, the CMAES and NSGA-II methods were exploited on IEEE 30 and 14 bus test systems.

In 2017, S. M. Abd Elazim and E. S. Ali [4] presented an MBA for OPAS of capacitors in several DS. Initially, the majority candidate buses for installing capacitors were recommended exploiting LSF. After that, the presented method was used to infer the capacitors size and their positions from the selected buses. Here, the objective model was framed to minimize the total cost and, as a result, to augment the net saving per year. The presented method was examined on 85 and 10 bus RDS. The attained outcomes by means of the proposed method were compared with others to emphasize their advantages. In addition, the outcomes were initiated to confirm the efficiency of the recommended method to reduce the losses and total cost.

In 2016, S. P. Mangaiyarkarasi and T. Sree Renga Raja [5] presented a novel modified severity index while accounted with the incidence of a contingency probability, enumerates the risk, which numerically explains how close the system is to voltage instability. It was chiefly exploited because of the inadequate reactive power maintained. To enhance the Voltage Profile of the system, the FACTS devices were used during line outages. Here, the SVC was contemplated, as the compensating device.

In 2017, Mohammad Mohammadi et al [6] developed a fuzzy based technique for DS feeder reconfiguration with respect to the DSTATCOM with an objective of reducing real operating cost and power loss. The DS tie switches, DSTATCOM position, and size was optimally decided to attain a suitable operational state. In the proposed method, the fuzzy membership function for loss sensitivity was exploited.

In 2017, K.R. Devabalaji and K. Ravi [7] presented a novel method to decide the optimal sizing and positioning of DG and DSTATCOM was examined, and the objective model was designed for reducing operational costs, loss of power, and Voltage Profile enhancement of the system subjected to equality and inequality constraints. LSF was exploited to pre-determine the optimal position of DSTATCOM and DG. To determine the optimal size of the DSTATCOM and DG, the BFOA was presented. Here, the DSTATCOM and DG were concurrently allocated in the RDS and it was examined with various load models.

In 2018, Ahmed A. Zaki Diab and Hegazy Rezk [8] presented applications of DFO, GWO, and MFA optimization approaches for the capacitors optimum sitting in several RDSs. To determine the majority candidate buses, the loss sensitivity factor was applied. Subsequently, each optimization approach was used to locate optimum positioning as well as capacitors sizes for determining buses. Here, 69-, 33- and 118-bus RDSs were represented for examining the efficiency and effectiveness of examined methods. The convergence performance was validated for examined RDSs.

3. Problem Formulation

The UPFC is considered as the FACTS devices that offer independent control of the reactive as well as voltage magnitude, real power flows, and improves the dynamic stability of the system. Moreover, the UPFC comprises of dual switching converters such as shunt and series converter, and it starts working from a general DC link. Through coupling transformers, the converters are connected to the power system. The shunt converter is connected to the transmitting end node while the series converter is connected among the receiving and transmitting end. Moreover, it inserts an AC voltage with a controllable magnitude as well as in series manner the phase angle is connected with the transmission line. While the APL is abandoned, the UPFC can't able to produce or soak up the active power in two converters, and it needs to balance using the DC link. Conversely, the converters create or soak up the reactive power as well as the self-governing shunt reactive compensation for the line. Fig 1 demonstrates the basic model of the UPFC.

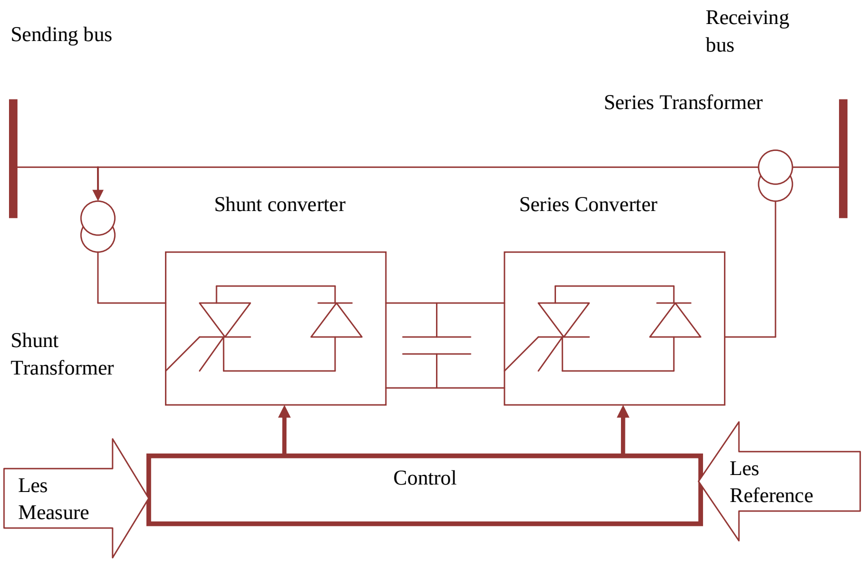

Fig. 1. *Schematic diagram of UPFC*

Here, the generator is related with the transmitting and receiving buses. The converters are related using the transformer. It comprises the converter impedances like shunt and series impedance. The converters are associated with the capacitor of DC link with the capacity of voltage. It is included in the UPFC power flow equation that is necessary to solve the power system pretentious quantities similar to equality and inequality constraints. It can happen because of the generators outage existing in the power system due to the exploitation side requirements insist contentment at all times.

Generally, the power system adds to the contentment for a total demand for the usage. Moreover, the system generators need to assure the total demand of the clients and the transmission lines power loss. Here, it is represented as the power balance or equality constraints circumstance of the power system. The generators contained in the system acquire outage; it might add to the loss of power and have an effect on the dynamic stability environment. In eq. (1), the necessary power balance condition is denoted.

$$\sum_{m=1}^{N_G} P_C^m = D + \sum_{n=1}^{N_G}\left(R_L^m + RP_L^m\right) \tag{1}$$

where D refers to the demand, P_C^m indicates the power generated in the m^{th} bus, RP_L^m and R_L^m represents the reactive and real power losses of the n^{th} bus that are computed using eq. (2) and (3).

$$R_L^m = |V_m||V_n||Z_{mn}|\sum_{n=1}^{N}\cos\left(\beta_{mn} - \delta_m - \delta_n\right) \tag{2}$$

$$RP_L^m = |V_m||V_n||Z_{mn}|\sum_{n=1}^{N}\sin\left(\beta_{mn} - \delta_m - \delta_n\right) \tag{3}$$

Where V_m and V_n indicate the m^{th} and n^{th} bus voltage, Z_{mn} indicates matrix of bus admittance, β_{mn} represent the angle connecting the buses m^{th} and n^{th}, δ_m and δ_n represent the load angles of m^{th} and n^{th}

Moreover, the inequality constraints such as real, voltage, and reactive power flow that is affected because of the dispute of the generation unit. The power system dynamic stability primarily regarded as the VOLTAGE STABILITY of each node. At each bus at the range [0.95 to 1.05] pu the stable power flow requires the voltage. Eq. (4) states the change in voltage.

$$\Delta V_m = \frac{1}{\sqrt{1}}\sqrt{\sum_{m=1}^{1}\left(V_m^k\right)^2} \tag{4}$$

$$\Delta V_m^k = V_{slack} - \sum_{m=1}^{n} X_m\left(\frac{R_L^m - nRP_L^m}{V_m}\right) \tag{5}$$

By means of V_{slack} indicates the voltage of the slack bus, V_m indicates the bus voltage, ΔV_m^k indicates the voltage stability index of the bus m. Here, $m = 1,2,3,4 \ldots n$ X_m indicates the impedance of the m^{th} bus, PR_L^m and R_L^m indicates the reactive and real powers of the bus m and n. The voltage of the bus lies among the limits that are $V_m^{min} \le V_m \le V_m^{max}$. In eq. (6) and (7), the reactive and real powers of the particular bus are denoted.

$$R_L^m = |V_m||V_n|\sum_{n=1}^{N_T} C_{mn}\cos\delta_{mn} + S_{mn}\sin\delta_{mn} \quad (6)$$

$$RP_L^m = |V_m||V_n|\sum_{n=1}^{N_T} C_{mn}\sin\delta_{mn} - S_{mn}\cos\delta_{mn} \quad (7)$$

Where V_m and V_n represent the voltage of m and n buses correspondingly, N^T indicates the total number of buses, δ_{mn} indicates the angle among m and n buses correspondingly, C_{mn} and S_{mn} represents the susceptance and conductance values correspondingly. Based on these constraints, exploiting the proposed hybrid technique the optimum position and the UPFC is evaluated.

4. Proposed Hybrid PSOSSA for optimal placement of UPFC

4.1 Conventional SSA Algorithm

In 2017, Mirjalili introduced SSA [16], which is a novel optimization method created to resolve many types of optimization issues. It imitates the Salps behavior in nature; it is a class from the Salpidae's species, and that are barrel-shaped planktonic tunicate. Additionally, they are alike to jellyfishes in tissues, as well as stirring behavior and their weights possess a maximum water percentage.

Initially, SSA divides the population into two sets such as the followers and the leader. Here, the front salp of the chain is represented as the leader, and the other salps are represented as the followers. In n -dimensions, the location of the salps is identified that symbolize the problem search space and n signifies the problem's variables. These salps explore for a source of food that denotes the objective of the Swarm. The location needs to update often, hence the eq. (8) is exploited to do this deed to the salp leader.

$$y_q^1 = \begin{cases} S_q + r_1\left(\left(u_q - l_q\right)\times r_2 + l_q\right) r_3 \le 0 \\ S_q - r_1\left(\left(u_q - l_q\right)\times r_2 + l_q\right) r_3 \le 0 \end{cases} \quad (8)$$

Where y_q^1 indicates the leader position within q^{th} dimension, where the source of food in this dimension is S_q, the lower and the upper bounds are l_q and u_q, respectively. r_2 and r_3 are produced arbitrarily in the range [0, 1] to preserve the search space. In addition, the parameter r_1 represents the significant coefficient of this technique, because of its part in the balancing among the exploitation stage and the exploration stage and it is computed by using eq. (9).

$$r_1 = 2e^{-\left(\frac{\Delta t}{t_{max}}\right)^2} \quad (9)$$

Where, t and t_{max} designate the current and the max iterations' number, correspondingly. Subsequently, in order to update the positions of leader's, the SSA initiates to update the followers' location by eq. (10).

$$y_p^q = \frac{1}{2}\left(y_q^p + y_q^{p-1}\right) \quad (10)$$

y_p^q is the p^{th} position of the follower within q^{th} dimension and p is superior to 1.

4.2 Conventional PSO Algorithm

PSO [17] imitates the evolvement of the information on social behavior and creates group communication behavior while sharing confidential information regarding migrating, hunting, or flocking. This group and its members signify a result and that is referred to as particles and swarm, correspondingly.

For updating the location, a particle depends on its knowledge and neighbors. The swarm initiates by producing a set of arbitrary particles and creating their positions y_p and velocity u_p in a dimension p^{th}. Subsequently, PSO initiates its major loop to calculate every particle by calculating a fitness function; the outcome is analyzed with its global and optimal values. The eq. (11) and (12) indicates the technique, which is exploited for updating the locations of particles.

$$y_{pq}^{(t+1)} = y_{pq}^{t} + u_{pq}^{(t+1)} \quad (11)$$

$$u_{pq}^{t+1} = wu_{pq}^{t} + c_1 r_1\left(y_{pq}^{p(t)} - y_{pq}^{(t)}\right) + c_2 r_2\left(y_{pq}^{g(t)} - y_{pq}^{(t)}\right) \quad (12)$$

where y_{pq} represents the p^{th} particle location in the q^{th} dimension, u_{pq} indicates the p^{th} velocity in the q^{th} dimension, t indicates the current iteration, w represents an inertia weight as well as used to enhance the speed of the population convergence. The constants c_1 and c_2 are acceleration coefficients. $y_{pq}^{p(t)}$ Indicates the optimal previous location of a particle p in q^{th} dimension; $y_{pq}^{g(t)}$ indicates the global optimal position in q^{th} dimension. r_1 and r_2 are arbitrary parameters $p \in$ [0, 1]. This series will be repeated until meeting the stopping criteria.

4.3 Proposed HPSOSSA Algorithm

This section clearly describes the organization of the proposed Hybridization of PSOSSA method. It is the combination of the PSO [23] and the SSA methods. The fundamental organization of the SSA method is modified by enhancing the updating stage of the position of population's. This modification combines the update method of the PSO into the foremost method of the SSA.

This combination includes additional suppleness to the SSA in discovering the population and assures the variety of method and attains the best value rapidly. Generally, the major organization of the proposed PSOSSA method is demonstrated in fig. 2. The initial step in the proposed PSOSSA is to describe the parameters and produce the population that indicates a set of the result is to determine the optimum position. After that, each result performance is validated by calculating the fitness function for each one and determines the optimal of them. Subsequently step in the proposed PSOSSA method is for the current population updation exploiting either the PSO or SSA method that depends on the fitness function quality. Here, if the fitness function probability, for the current solution, is higher than 0.5 subsequently the SSA, if not, the PSO is exploited. Afterward, the fitness function for each solution is calculated as well as the optimal result is determined following by population updation. After that step is to ensure if the stop circumstances are contented next return by the optimal result, or else, do again the preceding steps from calculating the probability to the conclusion.

The proposed method initiates by defining the primary values of the PSO and the SSA after that SSA produces an arbitrary population Y of size N in D dimension, subsequently, SSA computes the food fitness for each outcome y_p, $p = 1,2,.....N$. On the other hand, before calculating the objective model, each solution y_p is rehabilitated to a binary vector (so as to comprises only 1's and 0's) along with the value of an arbitrary threshold $\in$ [0, 1] exploiting eq. (13).

$$y_p(t+1) = \begin{cases} 1 \text{ if } \dfrac{1}{1+e^{-y_p(t)}} > \mu \\ 0 \quad \text{otherwise} \end{cases} \tag{13}$$

So, only the y_p elements that are equivalent to 1's are selected to indicate the power loss. The subsequent step is to calculate the objective model for each y_p stated in eq. (14).

$$f(y_p(t)) = \xi E_{yp(t)} + (1-\xi)\left(\left|\frac{y_p(t)}{C}\right|\right) \tag{14}$$

where $E_{y_p(t)}$ indicates the minimization of the voltage deviation; while the next term indicates the minimization of power loss. So as to calculate the power loss and voltage deviation, the parameter $\in$ [0, 1] is exploited. Subsequently, the probability of every fitness function is calculated using eq. (14).

$$\text{Prob} = \frac{f_p}{\sum_{p=1}^{N} f_p} \tag{15}$$

In accordance with the $\text{Pr}ob$ value, the current solution y_i is updated exploiting the PSO or the SSA. For instance, $\text{Prob} > 0.5$, subsequently the SSA is exploited as shown in eq. (8) to (10), otherwise, the PSO method as shown in eq. (11) and (12).

For each updated solution, the fitness function is calculated and updated the optimal solution. This progression is iterated until it meets the stop state (the proposed PSOSSA method pertained for the maximum iteration's number as a stop state).

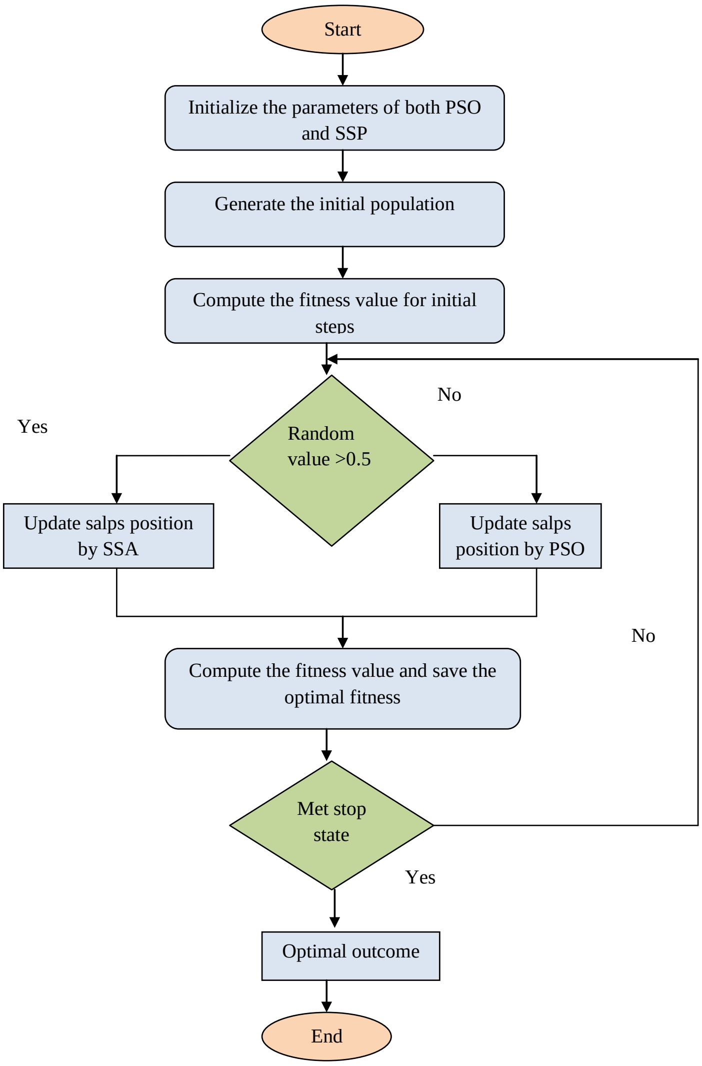

Fig. 2. *Flowchart of Proposed PSOSSA*

5. Results and Discussions

5.1 Simulation Procedure

The proposed technique is simulated in the MATLAB. In this section, the numerical outcomes of the proposed technique were shown and examined. The attained outcomes were compared with several operating environments. Here, the proposed method was tested in the IEEE bench mark systems such as IEEE 30 and 14 bus systems.

5.2 IEEE 30 Bus System

In this section, the dynamic stability of the IEEE 30 bus system is demonstrated. Here, the information regarding the power loss at normal circumstance also provided, for the single and double generator of the proposed hybrid approach and conventional approaches in IEEE 30 Bus system. Table 1 summarizes the comparative analysis of the proposed approach with different conventional methods such as PSO ABC, and GA for single generator problem is shown. Here, the obtained outcomes exposed the performance of the proposed technique, which outperforms existing techniques in terms of power loss in the IEEE 30 bus system. The performance analysis of the proposed method with different conventional methods like PSO ABC and GA for double generator problem is demonstrated in Table 2. Here, the attained result exhibits the proposed technique performance, and it outperforms the traditional approaches regarding the power loss in the IEEE 30 bus system.

In Fig 3, the graphical representation of Voltage Profile for both the conventional and proposed methods for IEEE 30 Bus system is shown. The Voltage Profile is recognized for the conventional approach and proposed an approach, during the generator off time. The Voltage Profile at each bus is distorted at the generator shutdown period from the Voltage Profile analysis. However, the proposed approach is exploited to improve the VP normal condition by the UPFC.

Table 1. *Comparision of proposed and Conventional methods of Power loss in IEEE 30 Bus System for single generator Problem*

Methods	Fault generator in bus	Power loss (MW)
PSO	2	12.32
GA	2	11.45
ABC	2	13.42
Proposed	2	10.78

Table 2. *Comparision of proposed and Conventional methods of Power loss in IEEE 30 Bus System for Double generator Problem*

Methods	PSO		GA		ABC		Proposed	
Fault generator	22	27	22	27	22	27	22	27
Power loss (MW)	10.92	11.23	10.23	11.89	10.67	10.98	9.08	10.02

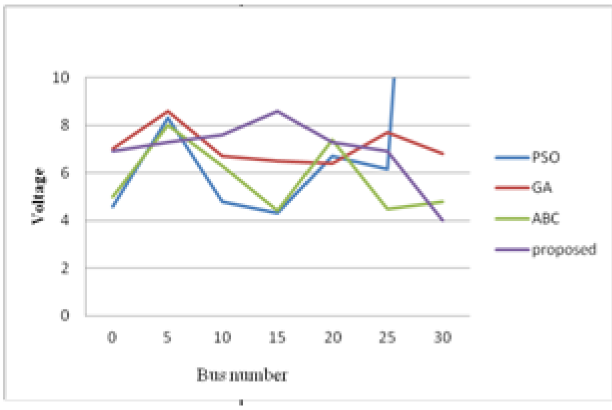

Fig. 3. *Graphical Representation of voltage profile for both the conventional and proposed method in IEEE 30 Bus system*

5.3 IEEE 14 Bus system

In this section, the dynamic stability of the IEEE 14 bus system is demonstrated. In Table 3, the performance analysis of the proposed technique with different conventional methods for single generator problem is demonstrated in the IEEE 14 Bus system. Here, the attained results exposed the performance of the proposed approach, which outperforms traditional approaches regarding power loss in the IEEE 14 bus system.

The performance analysis of the proposed method with different conventional methods like PSO ABC and GA for double generator problem is shown in Table 4. Here, the attained result exhibits the proposed technique performance, and it outperforms the traditional approaches regarding the power loss in the IEEE 14 bus system.

In Fig 4, the graphical representation of Voltage Profile for both the existing and proposed methods for IEEE 14 Bus system is revealed. From the analysis, it is clearly shown that the proposed approach improves the Voltage Profile than the conventional methods.

Table 3. *Comparison of proposed and Conventional methods of Power loss in IEEE 14 Bus System for Single generator Problem*

Methods	Fault generator in bus	Power loss (MW)
PSO	2	8.12
GA	2	8.48
ABC	2	9.14
Proposed	2	7.62

Table 4. *Comparison of proposed and Conventional methods of Power loss in IEEE 14 Bus System for Double generator Problem*

Methods	PSO		GA		ABC		Proposed	
Fault generator	22	27	22	27	22	27	22	27
Power loss (MW)	9.12	9.13	11.29	12.19	9.17	9.18	8.18	9.12

Fig. 4. *Graphical Representation of voltage profile for both the conventional and proposed method in IEEE 14 bus system*

6. Conclusion

The efficiency of the OPAS for UPFC in order to improve the dynamic stability was developed in this paper. The main benefit of the proposed approach, it has high efficiency in searching capability to discover the optimum solutions and correctness. Moreover, the proposed approach was evaluated in the IEEE 14 and 30 benchmark system as well as the efficiency was tested over various generator faults. At first, the single generator issue was carried out in different manners in the bus system and later double generator problem was established. In these circumstances, the power loss and the voltage profile was evaluated at normal circumstance, for both the proposed and conventional methods. Finally, the performance analysis shows that the proposed method efficiently improves the dynamic stability of the system because of the choice of optimum position and UPFC quantity was capable against the conventional methods.

Compliance with Ethical Standards

Conflicts of interest: Authors declared that they have no conflict of interest.

Human participants: The conducted research follows the ethical standards and the authors ensured that they have not conducted any studies with human participants or animals.

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