Ideal position and size selection of unified power flow controllers (UPFCs) to upgrade the dynamic stability of systems: An antlion optimiser and invasive weed optimisation algorithm

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ABSTRACT

This paper proposes a hybrid methodology to improve the dynamic strength of frameworks by optimally locating and sizing the unified power flow controller (UPFC). The proposed method combines both the antlion optimiser (ALO) and invasive weed optimisation (IWO) techniques. The advantages of the proposed methodology are enhanced searching ability, better identification of optimal solutions and greater reliability. Initially, to locate UPFCs, using the ALO technique, the most extreme power loss bus is recognised as the optimal location. The capacity required to resolve the situation is determined by the IWO technique based on the minimum power loss, voltage deviation and establishment cost of the UPFCs. The proposed system is actualised and aims at the matrix laboratory (MATLAB) environment, while the power flow security and voltage stability are evaluated on the basis of the Institute of Electrical and Electronics Engineers (IEEE) standard benchmark system. At this point, voltage stability, power loss, overloading and UPFC costs are analysed through changing the system load and generation. The proposed working method is then assessed and compared with traditional techniques.

KEYWORDS Particle swarm optimisation (PSO); invasive weed optimisation (IWO); antlion optimiser (ALO); power loss; unified power flow controllers (UPFCs)

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1. Introduction

With a continuously growing demand for electricity, power generating companies are looking at not only new power plants but also renewable energy sources to meet current needs. As power is often generated far from where it is needed, especially with renewable energy, robust transmission networks must therefore be easily accessible in order to transport the electricity (Yoo et al., 2017). The generation, transmission, distribution and management of electricity are traditionally focused around existing power grids (Colak et al., 2016). In sophisticated power networks, interconnected systems that are complex and geographically spread out must be managed; maintaining secure and stable supply that can be accurately monitored is the daily operational imperative (Palukuru et al., 2014; Mohanty et al., 2016). Ensuring system stability and security is therefore a prime focus. To make an optimal use of present day power systems, boosting capacity by introducing flexible/AC transmission systems (FACTS) controllers is essential (Bathina and Gundavarapu, 2014). Basically, this means using different components to better control the flow of electricity within power systems (Ali and Abd-Elazim, 2012).

FACTS devices can be divided into three groups. All of them incorporate various components (Jordehi, 2015; Pahlavani and Mohammadpour, 2011). Currently, static

synchronous compensators (STATCOMs) are widely used (Xu and Li, 2014; Ganguly, 2014). Since then, unified power flow controllers (UPFCs) can control the voltage, impedance and phase angle in transmission lines have been added to these devices (Khodabakhshian et al., 2016). UPFCs have proven to be surprisingly effective for upgrading power system damping, particularly for between territory motions by utilising a balancing out signal in the control system (Pradhan et al., 2016). It is well known that the hereditary algorithm (HA) (Hassan et al., 2013), fuzzy logic (FL) (Mok et al., 2005), particle swarm optimisation (PSO) (Shayeghi et al., 2010) and differential evolutionary (DE) (Sahu et al., 2015) are all connected for dealing with instability issues that relate to soft-computing techniques. Traditional optimisation, heuristic and artificial intelligence techniques for various systems can all be used to reconfigure networks (Vijay Kumar and Srikanth, 2015a). Nonetheless, deriving hybrid calculations from fundamental issues, then applying them to specific power systems has been shown to be remarkably effective (Chitra and Devarajan, 2014).

To improve the dynamic constancy of power systems, various researchers have proposed using the cuckoo search (CS) and firefly algorithm (FA) under UPFCs placement and capacity (Vijay Kumar and Srikanth, 2017). To dispose the impact of UPFCs, Mehrjerdi and Ghorbani (2017) discussed a strategy and flaw obstruction at the separation

hand-off as they relate to synchronised phases. Packiasudha et al. (2017) pointed out that the dynamic and detached mass communications consider the various researchers presented the cumulative gravitational search algorithm (CGSA) with the goal of effectively reviewing the resultant power acquired between the majorities.

Motiebirjandi and Fateh (2017) have proposed combining multiple UPFCs, and utilising basic modes of the system and build-up factor to expand electromechanical motions damping within the electric power systems. Kavitha and Neela (2017) discuss a primary capacity comprising cost, loadings of line, and deviations in the load voltage planned to gain more advantages out of their establishment; and the loads designated to them that decide their relative significance. Abd-Elazim and Ali (2016a) have presented imperialist competitive algorithm (ICA), a new optimisation system, for STATCOM in a multi-machine network. Pressure volume (PV) curves were represented to find the STATCOM best area. Abd-Elazim and Ali (2016b) presented a new optimisation calculation in single and multi-machine control framework, specifically gravitational search algorithm (GSA) for outlining static synchronous series compensator (SSSC). For measuring and perfect allotment of distributed generation (DG) in the source of distribution networks, the antlion optimisation algorithm (ALOA) was presented (Ali et al., 2016). In this paper, a more efficient calculation is recommended to examine the load flow problem and resolve the problems with UPFCs. In Section 2, a more detailed explanation of the recommended technique is given. In Section 3, the results are displayed. The report is concluded in Section 4.

2. Modelling UPFC devices

2.1. A UPFC device model

Figure 1 depicts the layout of the transmission line with the UPFCs connected to i th and j th buses. It is essential that Converter 2 is getting a genuine power request at a basic direct current (DC) interface terminal from an alternating current (AC) of control framework from Converter 1. Likewise, Converter 1 can create or consume receptive power at its terminal of AC, which is independent of exchange of dynamic capacity to the DC terminal. Thus, indirect voltage control is to be implemented at the input terminal of the UPFCs because of the capacity of an autonomous advanced static var compensator (SVC) giving reactive power pay to the transmission line (Reddy et al., 2017). At the fundamental recurrence, Converter 2 is used to produce voltage. The inverter output voltage infused in series with line can be used as direct voltage control, arrangement remuneration, stage shifter and their blends. At its DC terminal by the special types of controls connected and exchanges active power, this voltage within can produce or retain all the required reactive power (Ali et al., 2017).

Figure 1. Basic schematic diagram of UPFCs.

Magnitude of embedded voltage (V_T), angle of inserted voltage (d_T) and magnitude of the current (I_q) are the UPFC's controllable parameters. The equation for the power flow is written as follows:

$$\begin{aligned} S_{ij}^u &= P_{ij}^u + jQ_{ij}^u = V_i I_{ij}^* = V_i [I_{shunt} + I_i'' + (I_r + I_q)]^*, \\ S_{ij}^u &= P_{ij}^u + jQ_{ij}^u = V_j (I_{shunt} - I_i'')^*. \end{aligned} \quad (1)$$

UPFC with the active and reactive power flow in lines can be expressed as:

$$\begin{aligned} P_{ij}^u &= (V_i^2 + V_j^2)G_{ij} + 2V_i V_j G_{ij} \cos(\delta_r - \delta_i) - V_j V_T [G_{ij} \cos(\delta_r - \delta_j) + B_{ij} \sin(\delta_r - \delta_j)] \\ &\quad - V_i V_j [G_{ij} \cos \delta_{ij} + B_{ij} \sin \delta_{ij}] \end{aligned} \quad (2)$$

$$\begin{aligned} Q_{ij}^u &= -V_i I_q - V_i^2 (B_{ij} + B/2) - V_i V_T [G_{ij} \sin(\delta_r - \delta_i) + B_{ij} \cos(\delta_r - \delta_i)] \\ &\quad - V_i V_j [G_{ij} \sin \delta_{ij} - B_{ij} \cos \delta_{ij}] \end{aligned} \quad (3)$$

$$P_{ji}^u = V_i^2 G_{ij} - V_j V_i [G_{ij} \cos \delta_{ij} - B_{ij} \sin \delta_{ij}] - V_j V_T [G_{ij} \cos(\delta_r - \delta_j) - B_{ij} \sin(\delta_r - \delta_j)], \quad (4)$$

$$Q_{ji}^u = -V_j^2 (B_{ij} + B/2) + V_i V_j [G_{ij} \sin \delta_{ij} + B_{ij} \cos \delta_{ij}] - V_j V_T [G_{ij} \sin(\delta_r - \delta_j) + B_{ij} \cos(\delta_r - \delta_j)]. \quad (5)$$

Figure 5 provides a basic circuit theory for the equivalent circuit. i and j are the active power at bus (P_{iu} and P_{ju}); and reactive powers (Q_{iu} and Q_{ju}) of a line are:

$$P_{iu} = -V_i^2 G_{ij} - 2V_i V_T G_{ij} \cos(\delta_r - \delta_j) + V_j V_T [G_{ij} \cos(\delta_r - \delta_j) + B_{ij} \sin(\delta_r - \delta_j)], \quad (6)$$

$$P_{ju} = V_j V_T [G_{ij} \cos(\delta_r - \delta_j) - B_{ij} \sin(\delta_r - \delta_j)], \quad (7)$$

$$Q_{iu} = V_i I_q + V_i V_T [G_{ij} \sin(\delta_r - \delta_j) + B_{ij} \cos(\delta_r - \delta_j)], \quad (8)$$

$$Q_{ju} = -V_j V_T [G_{ij} \sin(\delta_r - \delta_j) + B_{ij} \cos(\delta_r - \delta_j)]. \quad (9)$$

To evaluate the optimal size of FACTS devices, their cost functions are evaluated with mathematical formulae expressed in the following equations. The cost of installing a UPFC (U_C) can be derived from the following:

$$U_C = 0.0003S^2 - 0.2691S + 188.22, \quad (10)$$

$$S = |Q_2| - |Q_1|. \quad (11)$$

Where Q_2 is the flow of responsive power in the line subsequent to introducing FACTS gadget in mega volt ampere reactive (MVAR) and Q_1 is the progression of responsive power in the line after introducing a FACTS gadget in MVAR. In this paper, UPFCs are used to analyse the system voltage stability, while the UPFCs vector in the optimisation process can be described as follows.

$$Y_i = (y_1, y_2, y_3, \dots, y_n). \quad (12)$$

Where n represents the i th FACTS device location. Installing more than one FACTS device in any one branch or bus is not allowed (Deepa and Rizwana, 2015).

2.2. Objective functions

Identifying the UPFC device optimal location and sizing is planned as a multi-target optimisation issue utilising Equation (13):

$$OB_f = \text{Min}(\zeta), \quad (13)$$

$$\text{where } \zeta = \zeta',$$

$$\zeta' = \Phi_1 \zeta_1(V_d) + \Phi_2 \zeta_2(O_l) + \Phi_3 \zeta_3(P_l) + \zeta_4(U_c). \quad (14)$$

In Equation (14), V_d , O_l , P_l and U_c denote the voltage deviation, overloads of transmission line, power loss and cost of the UPFC device, respectively. In transmission lines to minimise overloads, using the equations, its corresponding metric is computed,

$$\zeta_2(O_l) = \sqrt{\sum_{i=1}^{i=N_l} (P_i - P_{\max})^2}. \quad (15)$$

Where P_i and $P_{\max}$ represent the power flow and limit of i th transmission line, respectively.

Voltage deviation is evaluated based on the same conditions. It is described as follows:

$$\zeta_1(V_d^i) = \begin{cases} (1 - V_i)^2 & \text{if } 1.05 \leq V_i \leq 1.1 \\ (5 - V_i)^2 & \text{if } V_i > 1.1 \\ 0 & \text{others} \end{cases}. \quad (16)$$

Where V_i represents the i th bus of power system voltage magnitude. After that, the system power loss is evaluated from the following equation:

$$\zeta_3(P_l) = \sum_{j=1}^N |V_i| |V_j| |Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j). \quad (17)$$

The third goal is to limit losses within a power system. The capacity loss is computed simply for each branch. The above-mentioned objectives are all denoted by ζ_1 , ζ_2 and ζ_3 (Shrawane et al., 2015).

2.3. Optimal location and capacity selection based on ALOA and invasive weed optimisation (IWO) algorithms

The UPFCs device's optimal location and sizing are resolved in respect of the bus system's dynamic stability. In view of the dynamic security investigation, the optimal location and capacity have been recognised. For the dynamic assessment, the proposed algorithm is connected to the framework. In this paper, the ALOA and IWO calculation are combined to evaluate the UPFCs' location. In the underlying procedure, the position of a UPFC device can be resolved using the ALOA; the infused capacity is assessed by the IWO algorithm. Due to the respect of the wellness work, the infused capacity is resolved. In the wellness work, the voltage deviation, overload transmission line and power loss are indicated. In light of the Newton Raphson (N-R) approach, the typical power loss and voltage values are resolved. From that point onward, in other words, during the load variety period, the maximum power loss bus is distinguished for settling the UPFCs utilising ALOA. After the situation of UPFCs, the target functions are assessed accordingly and the infusion capacity is resolved by IWO algorithm. IWO algorithm is used to upgrade the dynamic stability and recoup the normal operating condition. The general working procedure of the proposed strategy in the related section is to be explained.

2.3.1. ALOA for optimal placement

In this paper, the ALOA is used to decide the arrangement of a UPFC. The transport information, real and responsive power, power loss and voltage are the algorithm of input. The bus number, which is randomly created, assesses power losses within the system that can be addressed by various possible arrangements. The objective function of the calculation is determined as the maximum power loss bus for settling the UPFCs. The detailed antlion optimiser (ALO) calculation process is shown in the accompanying area (Reddy et al., 2017). The progression method of the proposed algorithm can be simply expressed as:

Creating irregular walks of ants: Irregular strolls are founded on the following equation:

$$X(t) = [0, \text{cumsum}(2r(t_1, -1), \text{cumsum}(2r(t_2, -1), \dots, \text{cumsum}(2r(t_n, -1))]. \quad (18)$$

Where cumsum computes the cumulative sum, n is the extreme number of cycles, t denotes the propagation of irregular walk and $r(t)$ is a stochastic function considered as follows:

$$r(t) = \begin{cases} 1 & \text{if } \text{rand} > 0.5 \\ 0 & \text{if } \text{rand} \leq 0.5. \end{cases} \quad (19)$$

1) Trapping with antlion pits

The antlion cages are influenced by the irregular strolls of ants. The accompanying conditions are proposed to numerically model this supposition:

$$\gamma_i^t = \text{Antlion}_j^t + \gamma^t, \quad (20)$$

$$\lambda_i^t = \text{Antlion}_j^t + \lambda^t. \quad (21)$$

Where γ^t and λ^t are the base and limit of all variables.

2) Building traps

To show the chasing capacity of antlions, the roulette wheel was utilised. During optimisation, according to their fitness to pick antlions, the ALOA needs a roulette wheel administrator. The technique gives more accurate fitter antlions probabilities of catching ants.

3) Making ants slide towards the antlion

With the proposed method, ants are needed to move randomly and in respect to their wellness. Antlions are able to create traps.

4) Getting prey and re-assembling the pit

The last stage of hunting occurs when an ant comes to the very base of the pit and is trapped in the antlions jaw. The equation is given as follows:

$$(AL_{j1}, AL_{j2}, \dots, AL_{jd}) = (A_{i1}, A_{i2}, \dots, A_{id}) \text{ if } f(\text{Ant}_i^t) > f(\text{Antlion}_j^t). \quad (22)$$

Where t shows the current iteration, Antlion_j^t shows the position of the selected j th antlion at the t th iteration and Ant_i^t indicates the position of the i th ant at the t th iteration.

5) Fitness evaluation

The equation for the objective function can be formulated by Equation (23).

$$F_i^j = \min(\zeta_2(P_L)). \quad (23)$$

6) Elitism

To preserve the obtained best solution, the situation of the best (fittest) antlion is spared as being the first class at each stage. The equation is derived as follows:

$$\text{Ant}_i^t = \frac{RM_{\text{antlion}}^t + R_{\text{Elite}}^t}{2}. \quad (24)$$

Where R_{Elite}^t is the irregular stroll of world class at t th iteration, and RM_{antlion}^t is the arbitrary stroll around the antlion chosen at the t th iteration (Ali et al., 2017). Based on the target work, the UPFCs are located optimally and receive the optimal outputs and corresponding transport framework. The process is terminated until the greatest emphasis is achieved and the procedure above is continued. IWO algorithm is performed for the capacity evaluation process. The detailed process of the IWO algorithm is shown below.

2.3.2. IWO algorithm for optimal capacity selection

Predicting the optimal capacity of a UPFC device is considered. How to achieve the optimal capacity for FACTS devices is to be discussed in the accompanying diagram. The numerical stochastic and subsidiary free optimiser are both IWO calculation (Nagib et al., 2017). Propagation, spatial dispersal and competitive prohibition are the procedures derived from the colonising behaviour (Figure 2) (Yahyatabar and Najafi, 2017). The sketch technique of the essential IWO can be summarised as follows (Velmurugan et al., 2016):

Step 1: Initialisation

In the first step, the voltage and power values are initiated and population of initial weeds, $X = \{x_1, x_2, \dots, x_{PS_0}\}$. The size of an initial population is PS_0 ; $X = \{x_{i1}, x_{i2}, \dots, x_{in}\}$; is an n -dimensional vector real valued. Each dimension x_{ik} of x_i can be generated as follows:

$$x_{ik} = lb_k + r \cdot (up_k - lb_k), \quad i = 1, 2, \dots, PS_0, \quad k = 1, 2, \dots, n. \quad (25)$$

Bounds are problem dependent, where r is a uniform irregular number $[0, 1]$ and k denotes the lower and upper limits measurement lb_k and up_k .

Step 2: Wellness evaluation

The wellness process is assessed and computed using the following equation:

$$F_i = \min(\zeta). \quad (26)$$

For evaluating ζ , the objective function is determined.

Step 3: Reproduction

The weeds produce seeds during reproduction and more seeds are produced by the fitter weed. The quantity of seeds produced by weed x_i is s_i as follows:

$$s_i = \text{floor} \left(s_{\min} + \frac{s_{\max} - s_{\min}}{f_{\max} - f_{\min}} \cdot (f(x_i) - f_{\min}) \right). \quad (27)$$

Where $s_{\min}$ and $s_{\max}$ are the worst and best weeds respectively in the population. $f(x_i)$ is the wellness of x_i . $f_{\min} = \min_{x_i \in X} f(x_i)$. $\text{floor}(\cdot)$ is the closest whole numbers towards the less interminability.

The weed seeds x_i are closely spread around it. According to the normal distribution for x_i , the IWO algorithm generates a seed. Denote $X'_i = \{x'_{i1}, x'_{i2}, \dots, x'_{in}\}$ a seed produced by x_i . We have:

$$X'_{ik} = x_{ik} + N(0, \sigma^2), \quad k = 1, 2, \dots, n. \quad (28)$$

The distributed random number is $N(0, \sigma^2)$, σ is the standard deviation.

Step 4: Spatial dispersal

Seeds are scattered near their parent weeds with a normal distribution. From a specified initial value σ_o to a final value σ_f , the standard deviation σ of the normal distribution is reduced flexibly as follows:

$$\sigma_{iter} = \frac{(iter_{\max} - iter)^\alpha}{(iter_{\max})^\alpha} \cdot (\sigma_o - \sigma_f) + \sigma_f. \quad (29)$$

Where σ_{iter} is the standard deviation at the present cycle, α is a nonlinear regulation file and $iter_{\max}$ is the greatest number of cycles. Normally, α is set to 3.

Step 5: Focused exclusion

For the next generation, all plants and their seeds are combined to frame a populace. Less fit weeds are eliminated if the population size is higher than a given esteem $PS_{\max}$.

Step 6: Termination condition

Until a given termination term, repeat Steps 2 through 5. From IWO algorithm output, the optimal results are

calculated and optimal objective function is evaluated. A detailed description of the performance analysis with diagrams is presented in the following section.

Figure 2. Proposed diagram of IWO calculation.

3. Results and discussion

In this paper, a more efficient method is proposed to improve the dynamic stability of transmission systems when using UPFCs devices. ALO and IWO are utilised to ascertain the UPFCs devices' optimal locations and capacities. The matrix laboratory (MATLAB)/Simulink is achieved in the proposed method.

(i) Test system 1: Institute of Electrical and Electronics Engineers (IEEE) 30 transport framework

To analyse the efficacy of the proposed strategy, compared with existing methods, it was utilised that: the IEEE 30 transport framework, comprising six generator transports, 21 burden transports and 42 transmission lines (Bhattacharya and Chattopadhyay, 2010). The dynamic steadiness of the IEEE 30 bus system was evaluated by using the proposed method. Initially, the framework load flow was examined using the standard N-R strategy. The execution of IEEE 30 transport system of voltage, with real and receptive power, was dissected by applying the N-R approach. From here onwards, the over-burdening was connected to the particular bus, and later the comparative voltages and power loss were resolved. In the N-R approach, the real and reactive power, and voltages values were organised as shown in Table 1.

The particular bus and lines are affected during the over-burdening period; therefore, the voltage deviation and power loss of the relating buses need to be assessed. During the over-burdening condition, the maximum power loss transport is distinguished which is considered as the weak buses for settling the FACTS gadgets. UPFC devices are viewed as the optimal location of UPFC devices are distinguished as the maximum power loss bus. In the investigation, FACTS devices optimal locations are allotted according to their needs in view of their maximum losses.

In view of the investigation, the location, sizing and number of UPFCs devices are resolved. PSO is used to assess the greatest power misfortune transport. The PSO is used to determine the greatest power; misfortune transport is relegated for settling the FACTS devices. The quantity of devices and optimal locations are chosen and controlled by using the PSO calculation. The capacity and cost of UPFC devices are then evaluated using the ALO. To demonstrate the proposed strategy's effectiveness, four arrangements of examination were conducted: overburdening the buses 4 and 12 individually. Implementing the proposed technique is then compared with other methods such as PSO and ALO techniques.

Table 1. Optimal locations and per values of UPFCs.

UPFC	Optimal Locations	From bus	To bus	Injected power	From bus		To bus	
					Shunt	Series/VSC	Shunt	Series
					VSC	VSC	VSC	VSC
					P	Q	P	Q
1	4	3	4	12.2561	6.2258	-20.143	63.8320	-182.0245
2	8	5	7	3.8112	0.0276	-7.2546	40.1619	3.9245
3	23	18	19	18.4536	-24.7845	-6.0258	9.6902	7.5365
4	15	4	12	10.4258	-80.6126	-105.2541	91.224	1.8268
5	20	14	15	3.1247	44.2561	-20.1225	-12.9514	-2.2235

Table 2. Analysis of deviation, cost and overloading after connecting UPFCs.

UPFC	Optimal locations	From bus	To bus	Voltage deviation	Overloading	Cost (\$/KVAR)
				(p.u)		
1	4	3	4	1.0184	0	186.3245
2	8	5	7	1.1369	0	187.2541
3	23	18	19	1.015	0.254	184.3562
4	15	4	12	0.4235	1.5628	178.3654
5	20	14	15	0.9936	0	186.2548
6	17	12	14	0.2436	0.1751	179.2134

During over-burdening of Bus 4, the maximum power loss bus must be decided. As indicated by their need, the maximum power loss buses are identified, which are then allocated as the optimal locations for fixing the UPFCs devices. Here, five optimal locations are identified for settling the UPFC devices. Also, 12 UPFC devices are incorporated into the bus system. As per Table 3, the UPFC is analysed and the corresponding results are assessed. With UPFCs devices, the P and Q estimations of shunt and series vehicle stability control (VSC) are resolved. As a result of associating UPFCs, the voltage deviation, over-burdening and cost are investigated and organised (shown in Table 2). The line flow limit applies to confirm the infringement of

line limits as a result of settling the issue which displays the security limits. Furthermore, power loss within the system is assessed. The system's normal loss is 10.8095 MW. In an over-burdening condition, the loss increases to 12.2565 MW. The UPFCs device optimal location is settled in the eighth bus. From here onwards, the loss is reduced to 8.8691 MW.

Figure 3 shows the IEEE 30 transport framework's normal transport voltage profile. In this section, the power flow initiated by the proposed method after the single generator problem of IEEE 30 transport framework is summarised. Figure 4(a) demonstrates the second bus generator fault voltage profile. The N-R can keep the bus voltage at a stable margin when the power stream is ordinary. When there is an issue in a generator, the bus voltage faces instability. To limit voltage instability, the strategy for a proposed technique is utilised to decide the optimal location and capacity for UPFCs. Figure 4(b) demonstrates the voltage profile under generator fault in the sixth bus. Proposed technique effectively endeavours to keep up the voltage profile and stability. In addition, faults presented in other generator buses 13, 22, 27 and comparing yields are portrayed in Figures 4(c), 4(d) and 4(e). Figure 5 demonstrates the voltage examination at a single generator problem of IEEE 30 bus system with various techniques like GSA-Bat algorithm, FA-CS, and ALO-invasive weed optimisation algorithm (IWOA).

Figure 3. Normal bus voltage profile.

Figure 4. Power profile under (a) 2nd bus generator fault; (b) 6th bus generator fault; (c) 13th bus generator fault; (d) 22nd bus generator fault; and (e) 27th bus generator.

Figure 5. Voltage profile comparison with single generator issue.

Different states of the double generator fault, and various voltage profiles in the bus system when using the proposed techniques are resolved and plotted in Figures 6(a) - 6(e). Correlations are shown in a fault condition when using the proposed strategy. In the bus system that enlarges the stability margin, the double generator defect drives the ordinary voltage level. As suggested by the range of defects, the proposed method found the UPFCs position and size to reduce costs. This approach is used to determine the voltage instability issue. The IEEE 30 bus system in the double generator is compared and in fault condition; the proposed method offers a better yield. Figure 7 demonstrates the voltage profile examination at 6 and 13 bus generators of IEEE 30 bus system with various techniques like GSA-Bat algorithm, FA-CS, and ALO-IWOA. Compared with existing procedures, the proposed technique yields better results.

Figure 6. Generator defect cause by voltage profile at: (a) buses 2 and 6; (b) buses 2 and 13; (c) buses 6 and 13; (d) buses 13 and 27; and (e) buses 22 and 27.

Figure 7. Comparison of voltage profile at double generator issue.

Table 3. Comparison analysis of power loss and cost with various methods.

Methods	Power loss in (MW)	Methods	Costs (\$KVAR)
Proposed (ALO-IWO) method	8.8691		
PSO	10.0214	Proposed	
ALO	9.2354	(ALO-IWO)	174.2581
Genetic algorithm (GA) (Subramaniam and John Basha , 2015)	18.30	method	
Ant colony optimisation (ACO) (Subramaniam and John Basha, 2015)	17.7451		
Gravitational search algorithm (GSA) (Subramaniam and John Basha, 2015)	16.9247	PSO	180.2156
Imperialist competitive algorithm (ICA) (Subramaniam and John Basha, 2015)	16.48		
Hybridgenetic Algorithm -particle swarm optimisation (GAPSO) approach(Shrawane et al., 2015)	9.4652	ALO	178.2658
With UPFC voltage injection model (Emily and Shunmugalatha, 2015)	15.598	Bat and firefly algorithm	
With UPFC negative impedance model (Ali et al., 2017)	15.88	(Kumar and Srikanth, 2016)	176.8095

Moreover, the costs, voltage deviations and losses are investigated (shown in Table 3). The investigation above reveals that, compared with other techniques, the proposed strategy is exceptionally effective at reducing deviation, power losses and costs. In Tables 1, 2 and 3, the proposed method is tried with the arranged IEEE 30 transport framework.

Table 3 shows the given means of general targets, the proposed method achieves overall reduction objectives, and surpassing existing strategies. The table also demonstrates that the proposed method is superior to other algorithm by minimising power loss and reducing costs. The proposed method achieves low estimations of energy problems in transport. The proposed method prompts the greatest reductions and estimation of energy problems among all optimisation algorithms. For example, the loss achieved by the proposed method is 8.8691 MW, lower than the one from the ALO and PSO techniques. Additionally, the cost of the UPFC devices is favourable compared with existing techniques. The cost of the UPFCs with the proposed method is 174.2581 \$/KVAR as compared with those of the FA-Bat algorithm, PSO and ALO techniques which are 176.8095 \$/KVAR, 180.2156 \$/KVAR and 178.2658 \$/KVAR respectively. The suggested validation for UPFC units can be found in Tables 1- 3. In general, the use of UPFCs affirms that the proposed strategy is a reliable optimisation paradigm, and it provides additional proof for effectiveness by improving the over-burdening outcomes that occur to power systems and the results accomplished by assigning a UPFC.

Table 4. Power departure at single generator problem.

Fault generator	Best location		Power loss at single generator MV				
	From bus	To bus	Normal	Fault	GSA-BAT	FA-CS	Proposed
2	3	5	13.36	15.42	12.22	11.11	9.12

Figure 8. Comparison of power loss at single generator defect.

Table 4 shows the power loss correlation using different techniques of IEEE 30 transport system. When the faults are connected in the 27th bus diverse systems such as

GSA-Bat algorithm, FA-CS and ALO-IWOA are analysed. Figure 8 demonstrates various other techniques and the proposed technique for power loss in a single generator. The single generator control loss of IEEE 30 transport structure is easily reduced to 9.12 MW by utilising a proposed strategy which gives a better yield. In Table 5, a power loss comparison in IEEE 30 bus systems using various methods is shown. Diverse strategies include GSA-Bat algorithm, FA-CS, ALO-IWOA, when fault is connected in the 6th and 13th buses. Figure 9 demonstrates the variation between different techniques and a proposed strategy for power loss in a double generator. Power loss with IEEE 30 transport framework in a double generator is effectively reduced to 9.67 MW using the proposed strategy which clearly gives a better yield.

Table 5. Power departure at the double generator problem.

Fault generator	Best location		Power loss at double generator (MW)				
	From bus	To bus	Normal	Fault	GSA-BAT	FA-CS	Proposed
6 and 13	10	23	14.36	17.42	13.22	11.56	9.67

Figure 9. Power loss comparison with double generator fault.

(ii) Test system 2: IEEE 14 transport structure

In this section, the performance of the proposed method is discussed and verified through the IEEE 14 transport framework. The two sources of IEEE 14 transport framework are a slack bus and a second bus. Using N-R burden stream investigation, it is predicted under normal terms and the entire system of load flow parameters is bus voltage and power loss. At the second transport, the single generator issue is received. The power flow difficulties are maximum power misfortune and voltage stability. These challenges can be overcome by finding the position of the defect and locating UPFCs with proper capacities.

Figure 10. Normal bus voltage.

Figure 11. Voltage profile comparison at single generator problem.

In Figure 10, the normal bus voltage profile of IEEE 14 transport framework during N-R burden stream investigation is observed. Under various topologies, the voltage profile examination at single generator issue of IEEE 14 transport framework is observed in Figure 11. GSA-Bat algorithm, FA-CS and ALO-IWOA strategies are deviated with the planned scheme. Compared with existing techniques, the proposed method gives a better yield. The IEEE 14 bus system of power loss correlation with various techniques is shown in Table 6. This technique for power loss is compared with our proposed method, as shown in Figure12. When a fault is connected in the second bus, GSA-Bat algorithm, FA-CS and ALO-IWOA are the special strategies. Control misfortune in IEEE 14 bus system is immensely reduced to 8.12 MW by applying the proposed method and different processes are compared.

Table 6. Power loss at the single generator problem.

Fault generator	Best position		Power loss in MW				
	From bus	To bus	Normal	Fault	GSA-BAT	FA-CS	Proposed
2	3	5	12.36	14.42	11.22	10.56	9.12

Figure 12. Power loss comparison with single generator fault.

(iii) Test system 3: IEEE 57 bus system

By applying load fault conditions, the power system dynamic stability was analysed using the proposed strategy in an IEEE 57 transport test framework. 7 generator transport, 50 load transport and 80 transmission lines are comprised by the transport framework (Bhattacharya and Chattopadhyay, 2010). System stability was analysed with load bus contingencies. In every incident, the quantity of overloaded lines (OLL) and the number of voltage limit violation buses (VLVB) were found. The performance index (PI) was calculated using the summation of a total number of OLL and VLVB at a specific time. As per the PI value, critical buses were ranked and other bus values were set at zero. Voltage deviation (p.u) for bus voltage limit was used as the criterion for identifying buses which included the voltage limit violations; lines were loaded to their thermal limits, with 100% loading regarded as the criterion for identifying overloaded lines; and the range (0.9-1.1). Hence, 15 possible contingencies were created and their corresponding stability performances were analysed.

Table 7. Contingency ranking of buses for IEEE 57 bus systems.

Contingency bus no.	OLL	VLVB	PI	Rank
31	5	6	11	1
42	4	4	8	2
38	34	4	7	3
13	4	3	7	4
47	3	4	7	5
44	3	3	6	6
29	2	4	6	7
27	2	3	5	8
23	2	3	5	9
20	3	2	5	10
41	1	3	4	11
54	2	1	3	12
52	1	2	3	13
28	1	2	3	14
10	2	1	3	15

Table 8. Voltage violation and power loss for IEEE 57 bus systems.

Before using UPFC			After using UPFC with the proposed method							
Bus no.	Buses with voltage violation	Power loss (MW)	Optimal location		VLVB	UPFC capacity				Power loss (MW)
			From bus	To bus		From bus		To bus		
						P	Q	P	Q	
31	30, 32,	27.4869	29	52	-	11.49	5.85719	72.8131	6.25114	21.6910
42	30, 33, 35,	27.3911	57	56	-	7.467	16.6905	2.5485	7.3565	25.3597
38	30, 33,	27.6015	6	8	-	23.92	3.79723	30.2034	3.2269	21.3123
13	30, 35, 36	27.5793	49	50	-	8.207	7.3742	1.8537	0.59822	25.8452
47	30, 33, 35,	28.0832	37	38	-	29.72	61.6961	56.0539	45.6702	20.4791
44	30, 35, 36	27.4658	6	8	-	36.26	14.8034	3.7817	2.2707	22.9691
29	29, 30, 35, 5	27.4647	8	9	-	1.699	25.7588	16.3663	48.9781	26.2586
27	30, 35, 36	27.4109	52	53	-	6.286	23.5514	1.5135	5.6852	26.0278
23	30, 35, 36	27.3173	23	24	-	13.78	1.65653	28.3989	0.42491	22.7433
20	30, 35	27.1516	8	9	-	30.30	30.5996	24.2265	5.6469	23.9139
41	30, 35, 36	27.2497	57	56	-	2.148	13.4071	1.1221	6.386	26.2710
54	53	27.2228	53	54	-	1.240	1.196	10.5456	0.102443	25.9005
52	30, 53	27.2629	52	53	-	6.750	24.4026	13.802	25.5326	25.5301
28	30, 35	27.1946	6	7	-	11.98	5.38479	43.5565	4.64815	23.2399
10	10	27.2144	50	51	-	20.15	17.3833	8.4545	6.7668	23.8811

Table 9. UPFC installation cost comparison.

Solution techniques	UPFC installation cost (\$/KVAR)
FA	186.0153
Artificial bee colony-Artificial neural network (Karthikeyan and Ajay-D-	184.4326
CS-FA	183.2269
Proposed technique	181.3362

Figure 13. During the contingency voltage profile at transport number 20.

Figure 14. During the contingency voltage profile at transport number 29.

Figure 15. During the contingency voltage profile at transport number 50.

Figure 16. Bus voltage profile comparison.

Figure 17. Power loss comparison.

Figure 18. UPFCs cost comparison.

Figure 19. Convergence characteristics comparison.

Different types of contingency were randomly created in the load buses and the corresponding OLL, VLVB and PI, and their ranking are described in Table 7. Based on this ranking, the priority of the critical buses is determined. The test system parameters are analysed in both the fault conditions and after using UPFCs, as described in Table 8. This shows the optimal location of a UPFC during the fault time and the corresponding UPFC capacity. By using the optimal parameters, both power loss and voltage violation were reduced. The UPFC installation cost comparison which was analysed using different techniques is shown in Table 9. Figures 13, 14 and 15 explain the voltage profile of the buses during the load bus faces the contingency. The three different voltage profiles are the typical condition, flaw condition and proposed strategy. Initially, the normal condition has a voltage profile that does not ignore the stability limit. Once a fault occurs, the bus present in the system deviates from the normal value. Using the proposed method, the fault condition is resolved by locating the UPFCs in the ideal area with the ideal parameters. Figure 16 shows that the bus voltage profile is then compared with the proposed method and existing techniques such as the FA and CS-FA. From this figure, it can be seen that, when compared with other techniques, the proposed method minimises voltage deviation more effectively. When contrasted with existing techniques, the power loss of the proposed technique is shown in Figure 17. The power loss of the system in fault conditions without a UPFC is 27.1946 MW. By using the FA technique with a UPFC, it is 23.9709 MW and hybrid CS-FA has a power loss of 20.4719 MW. Due to its robust construction and global

searching ability, power loss in the framework is greatly reduced to 19.2446 MW using the proposed technique. In Figure 18, the proposed method reduces the expense of the UPFC to 188.3362 \$/KVAR and UPFC costs are compared using various techniques. Figure 19 shows the convergence characteristics of the proposed strategy matched with different techniques.

4. Conclusion and Future Scope

The UPFC is demonstrated for enhancing the dynamic stability of the system in this thesis. ALO and IWO are considered effective techniques. This method can identify optimal locations and settings for UPFCs in electric power systems. By using the MATLAB/Simulink stage, the proposed method is executed. Initially, normal behaviour in the system is examined. Thereafter, the over-burdening problem is produced, and the voltage profile and power loss of the system are assessed. The maximum power loss line is identified during over-burdening conditions for setting the UPFCs devices, assisted by the ALO algorithm. In the case of UPFCs distribution, the UPFCs optimal location and sizing units are sought. The outcomes demonstrate that, with UPFCs, the proposed method reduces voltage deviation estimations, over-burden problems and costs more effectively than both PSO and ALO. The proposed technique can therefore be considered an efficient solution for handling distribution issues. Discoveries also confirm the effectiveness of UPFCs in easing the resulting over-burdening within power systems. In the future, different objectives for the location, capacity, techniques and types of FACTS devices can all be used to resolve problems in the power flow.

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