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Optimal Sizing of Distributed Power Flow Controller Based on Jellyfish Optimizer

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Abstract- *In the family of Flexible AC Transmission Systems (FACTS) controllers, the distributed power flow controller (DPFC) can control powerfully all the system's parameters like bus voltages magnitude, transmission angle, and line impedances with high redundancy and a wide range of compensation. In this paper, IEEE-14 bus IEEE-30 bus, and IEEE-118 bus systems are taken for the testing of the proposed approach. The optimal placement of the series and shunt converters of the DPFC is decided by the most critical bus and most critical line associated with that bus respectively. The sizing of the DPFC is decided based on the minimization of active power losses of the systems. The loss function is considered an objective function and the limits of the bus voltages magnitudes, bus voltage angles, thermal limits of the lines, and level of compensation of the DPFC are taken as the system's constraints. To solve complex problems in various fields, meta-heuristic optimizations are more popular. Among the meta-heuristic optimizers, the jellyfish optimizer is one that is based on the behavior of jellyfish in the ocean. The optimization of the objective function with constraints has been solved by time-varying acceleration coefficients (TVAC) particle swarm optimization (PSO), artificial bee colony (ABC), genetic algorithm (GA), and metaheuristic optimizer jellyfish methods. Results show that all the optimization techniques provide solutions with minimum losses. Among these methods, the solution of the jellyfish optimizer has the lowest active power losses, highest convergence rate, less number of iterations, and also takes less computational time.*

Keywords—FACTS, DPFC, Losses, Stability, Jellyfish optimizer.

1. INTRODUCTION

The electrical power systems of the whole world are heavily interlinked. The reason behind this is not only to provide electricity to the consumer but also to make a balance between demand and supply at minimum cost with maximum reliability [1]. Lower reliability requires further improvement in the operation and control of the existing power system's transmission lines. The idea of the FACTS controller was developed to regulate the transmission line's power flow in normal and in addition to abnormal situations [2]. The basic conccept and control streghtegy of various FACTS device are presented in [3, 4] The optimal placement, type (series, shunt, and combination of both) and size of FACTS devices can simultaneously control the bus voltages, line impedances, and transmission angles which will result in full control over true and reactive powers between the transmission lines. The optimal placement of static voltage compensator (SVC) based on improvement in voltage stability has been investigated in [5–7]. In [8], the thyristor control series reactor (TCSC) has been taken to increase the voltage stability margin (VSM) by changing the value of line impedance. VSM has been increased using SVC and TCSC in the system by applying the particle-swarm-optimization (PSO) technique in the research paper [9]. Heuristic search methods, which are rapid, effective, and trustworthy, complete the proper placement of these devices [10, 11]. In [12], the applications of the FACTS devices and serires capicitor were discussed for the compensation in the transmission system under various fault conditions. FACTS device SVC was used in [13] for the congestion management using descrete particle swarm optimization. The concept of a unified-power-flow-controller (UPFC) that combines series and shunt devices has been proposed in [14, 15], and it is capable of compensating true and reactive powers separately. The most powerful and latest FACTS device is the Distributed Power Flow Controller (DPFC) which has also a mix of series and shunt converters as in the Unified Power Flow Controller (UPFC) [16]. The active power exchange between series and shunt converters occurs via a dc capacitor connection in UPFC, whereas in the DPFC, this process occurs over a transmission line with a third harmonic frequency, and the dc-link is removed. The DPFC can compensate for the problem associated with the power system like distortion in frequency, current, and voltage. These difficulties can also be efficiently resolved by DPFC by the use Artificial Neural Network (ANN) controller [17, 18]. The series and shunt FACTS devices should be placed at the most severe line and

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most severe bus between the power systems respectively. the various methodology has been developed and discussed for the investigation of the most severe line and bus for the power system network [19]. Depends on the stability of transmission line voltage, LinebStability Index (Lmn), Fast voltage Stability Index (FVSI), Line Stability Factor (Lqp) and Critical Boundary Index (CBI) are the most popular and accurate methods for the determination of most critical line [20]. Similarly, based on the bus voltage stability L-index, electrical degree centrality measures, and are the most popular and accurate methods for the determination of the most critical bus in a power system [21].

In the last few decades, many metaheuristics optimization techniques inspired by nature and human are devloped. They are classified based on their inspiration. Swarm based optimizers deal with behaviour of indivisual componet to each other [22]. This paradism inspires the Artificial Bee Colony (ABC), Ant Colony Optimization (ACO), Particle Swarm Optimization (PSO), and Jellyfish optimizer. Among the recently proposed Swarm Intelligence Optimizers (SIO), jellyfish is one which based on behavior of jellyfish and provides global optimization solution. The simulation of jellyfish is based on time control mechanism, ocean currents, and motion inside swarm. Time control mechanism is used to switch the motions. This optimizer takes a smaller number of iterations instead of exhaustive trials to provide optimal solution. The jellyfish optimizer has three behaviors: motion that follows the ocean current, active motion in the swarm, and passive motion in the swarm. The motion in parallel with ocean current promote the exploration ability to find better position to take in more food. Active motion provides random search which may help to access more regions but if the optimal solution is in the vicinity of best so far, the jellyfish may not be reach to it. Passive motion moves the current solution with selected step size within the upper and lower bound. The jellyfish optimizer can solve a variety of problems due to its versatility over other optimizers [23].

The Proposed method has been tested on IEEE-14 bus, IEEE-30 bus, and IEEE-118 bus systems available in [24]. The most critical lines and most critical buses of these two systems are considered same as already evaluated in [25]. These critical lines and buses are also considered optimal locations for series and shunt converters of the DPFC in the proposed system. The objective function is to minimize the system losses which are dependent on the power system's parameters like bus voltages magnitude, line impedances, line conductance, bus voltages angles, and compensation level of FACTS controllers with some constraints of these parameters and other parameters. Time-Varying Acceleration Coefficients (TVAC), PSO, Artificial-Bee-Colony (ABC), Genetic Algorithm (GA), and Jellyfish Optimization techniques are used to optimize the objective function with constraints. The solution of optimization problem is found with jellyfish optimizer in minimum number of iterations, less computational time, and with fast convergence rate as compared to other optimizers used. In the results and discussions section, the obtained results have been analyzed and discussed in form of tables and graphs.

2. The DPFC FACTS Controller

The DPFC consists of one shunt converter at sending end bus and many series converters placed in the line. The shunt converter of the DPFC is placed at the most critical bus, whereas the series converters are placed on the most critical line associated with the most critical bus. There is no dc-link between these two types of converters which reduces the risk of failure of the whole system if any fail to work. The transmission line works as a medium of sharing power between series and parallel converters in the case of DPFC rather than a common dc link as present in the unified power flow controller (UPFC) [26]. Fig. 1 illustrates the block representation of the DPFC controller. The performance of DPFC has been tested on two bus system during unbalance fault condition using sequence componets in [27].

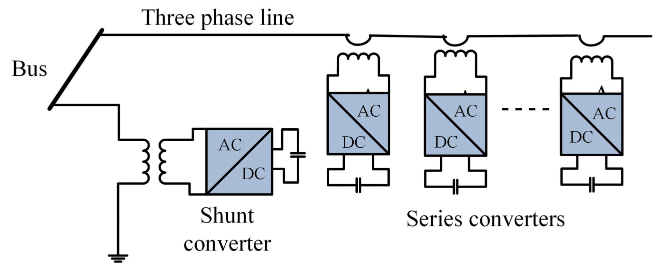

Fig. 1. Block diagram of DPFC [27]

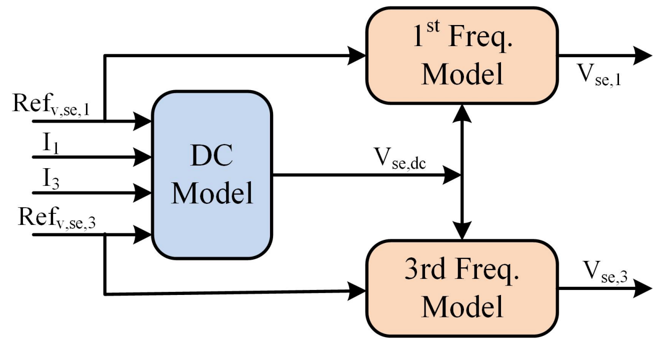

Fig. 2. Series converter modeling

2.1. Series Converter Modelling of the DPFC

The series converter of the DPFC has AC/DC side mathematical modeling. The voltage and current of the AC side have two frequency components one is at the normal operating frequency and is at the frequency of the third harmonic as shown in Fig. 2.

The AC side voltage can be evaluated by multiplication of the DC side voltage and AC reference signal as:

$$V_{se} = refv_{,se}.V_{se,dc} \tag{1}$$

$$V_{se,1} = refv_{,se,1}.V_{se,dc} \tag{2}$$

$$V_{se,3} = refv_{,se,3}.V_{se,dc} \tag{3}$$

$$V_{se} = V_{se,1} + V_{se,3} \tag{4}$$

Where: V_{se}, $V_{se,1}$ and $V_{se,3}$are AC side series converter total voltage, series voltage at fundamental frequency, and series voltage at third harmonic respectively. And, $V_{se,dc}$, $refv_{,se}$, $refv_{,se,1}$ and $refv_{,se,3}$ are dc side series converter voltage, reference voltage for ac side voltage at fundamental frequency and reference voltage for ac side voltage at third hormonic frequency, respectively. The DC side converter voltage is directly related to $I_{dc,se}$ the reference AC and has two components. So, DC voltage is approximated as:

$$C_{se}\frac{dV_{dc,se}}{dt} = I_{dc,se} = refv_{,se}.I = (refv_{,se,1} + refv_{,se,3}) (I_1 + I_3) \tag{5}$$

After neglecting the DC side ripple, the DC side voltage in terms of Park's transformation can be formulated as:

$$C_{se}\frac{dV_{dc,se}}{dt} = \frac{1}{2}(refv_{,se,3,d}.I_{3,d} + refv_{,se,3,q}.I_{3,q}) + \frac{1}{2}(refv_{,se,3,d}.I_{3,d} + refv_{,se,3,q}.I_{3,q}) \tag{6}$$

Where: C_{se}, I_1, and I_3 are capacitance of series converter, current at normal operating frequency, and current at third harmonic frequency, respectively.

2.2. Shunt Converter Modelling of the DPFC

To inject the third harmonic current, the shunt converter is placed among the ground and neutral point of the star-delta transformer as depicted in Fig. 3.

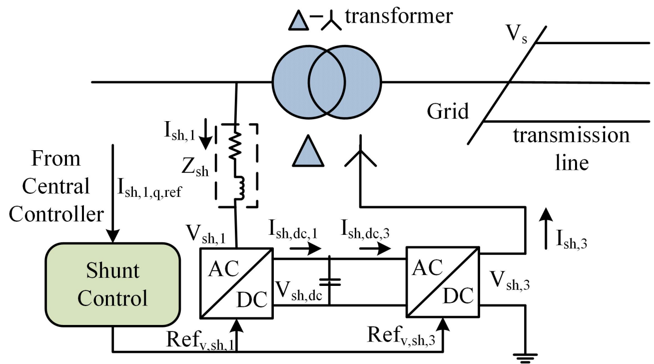

Fig. 3. Shunt converter modeling

Like series converter modeling the AC side voltage of the parallel converter can be written as:

$$V_{sh,1} = refv_{,sh,1}.V_{sh,dc} \quad (7)$$

$$V_{sh,3} = refv_{,sh,3}.V_{sh,dc} \quad (8)$$

Where: $V_{sh,1} = refv_{,sh,1}$ and $V_{sh,3} = refv_{,sh,3}$ are the modulation amplitude in p.u.

DC side capacitor voltage can be written as:

$$C_{sh}\frac{dV_{sh,dc}}{dt} = I_{sh,dc,1} - I_{sh,dc,3} \quad (9)$$

Where: C_{sh}, $I_{sh,dc,1}$, and$I_{sh,dc,3}$are the capacitance of shunt convertor, dc side shunt converter voltage at fundamental frequency, and dc side shunt converter voltage at third hormonic frequency, respectively.

After applying the single-phase d-q Park's transformation, the capacitor voltage becomes:

$$C_{sh}\frac{dV_{sh,dc}}{dt} = \frac{3}{2}(refv_{,sh,1,d}.I_{sh,1,d} + refv_{,sh,1,q}.I_{sh,1,q}) - \frac{1}{2}(refv_{,sh,3,d}.I_{sh,3,d} + refv_{,sh,3,q}.I_{sh,3,q}) \quad (10)$$

3. Problem Identification

3.1. Objective Function

Power drift dispersal in transmission grid is mainly decided by the overall system active power loss. Transmission real power loss play an important role in power generation, dispatch, and generator scheduling. The active power at each network node is added to represent the losses that take place in a network. By upholding appropriate values, losses are eliminated and the associated financial expenses are decreased. Total power losses (TPL) over all branches of the considered networks serve as the goal function in this study since it aims to discover how capacitors should be installed to reduce active power loss in distribution systems. Devices called Flexible Alternating Current Transmission Systems (FACTS) have been suggested as a practical approach to managing bus voltage and controlling power flow in electrical power systems, resulting in lower system losses and increased stability. Installation of these devices in an appropriate place may result in line flow control, bus voltage maintenance at a specified level, and improved power system security. In any electrical network the line conductors have real power losses mainly, and these losses are formulated as [6]:

$$P_{loss} = \sum_{i=1}^{m} G_{lk}[V_l^2 + V_k^2 - 2V_lV_k\cos\delta_{lk}] \quad (11)$$

Where: 'm' is the total branches in the system, G_{lk}as well $B_{lk}$are the conductance and substance respectively of line 'i' connected among the bus 'l' and 'k', $V_l$and $V_k$are the bus voltage magnitude of bus 'l' and 'k' respectively, $\delta_{lk}$is bus voltage angle difference of bus 'l' and 'k' respectively.

3.2. Constraints

Following are the constraints [4]:

$$P_{G_l} - P_{D_l} - \sum_{l=1}^{n} V_lV_k[G_{lk}\cos(\delta_{lk}) + B_{lk}\sin(\delta_{lk})] = 0 \quad (12)$$

$$Q_{G_l} - Q_{D_l} - \sum_{l=1}^{n} V_lV_k[G_{lk}\sin(\delta_{lk}) - B_{lk}\cos(\delta_{lk})] = 0 \quad (13)$$

$$V_{l\_\min} \le V_l \le V_{l\_\max} \quad (14)$$

$$S_{lk} \le S_{lk\_\max} \quad (15)$$

$$Q_{DPFC}^{\min} \le Q_{DPFC} \le Q_{DPFC}^{\max} \quad (16)$$

Where: $P_{G_l}$and$P_{D_l}$are the generated real power as well as demanded active power respectively at bus 'l', $Q_{G_l}$and Q_{D_l} are the generated reactive power as well as demanded reactive power respectively at bus 'l', $V_{l\_\max}$ and $V_{l_\min}$are the upper and lower limits of the bus voltage limits respectively of bus 'l', $S_{lk}$is the apparent power in conductor connected among bus 'l' as well as 'k', $S_{lk_\max}$is the maximum ofS_{lk}, $Q_{DPFC}$is the reactive power compensated by the DPFC, $Q_{DPFC}^{\min}$ and $Q_{DPFC}^{\max}$ are the lower and upper limits of Q_{DPFC} respectively.

4. Jellyfish Optimizer

In this work mainly three optimization techniques are considered for the comparative study. Among the swarm-based optimization, the jellyfish is one algorithm in which movement is governed by a time control mechanism.

The food search is completed by their movements in the ocean. They are highly prone to movement in the food location where the amount of food is abundant. This algorithm is utilized in this problem as it has better exploration ability. This attribute is utilized to find out the global optimum point. The jellyfish has two types of movement: Passive Motion and Active Motion through which a jellyfish moves inside a jellyfish swarm as depicted flowchart of this optimization in Fig. 4 [28].

Jellyfish have active (type B) and passive motions (type A) in swarm. Just after the formation of swarm, jellyfish have passive motion and after a few moments, they achieve active motion. The passive motion of jellyfish is expressed as:

$$X_i(t+1) = X_i(t) + \gamma \times random\ \ (0,\ 1) \times (U_b - L_b) \quad (17)$$

where γ>0 is the movement factor and it represents the distance of the motion, U_b represents the upper boundary limit, and L_b is the lower boundary limit. To obtain passive motion, a jellyfish (j) is chosen randomly. A directional quantity from interest (i) to considered jellyfish has been taken to find the route of motion. Whenever the food amount at the selected jellyfish becomes more than the food quantity available at the jellyfish of interest, the

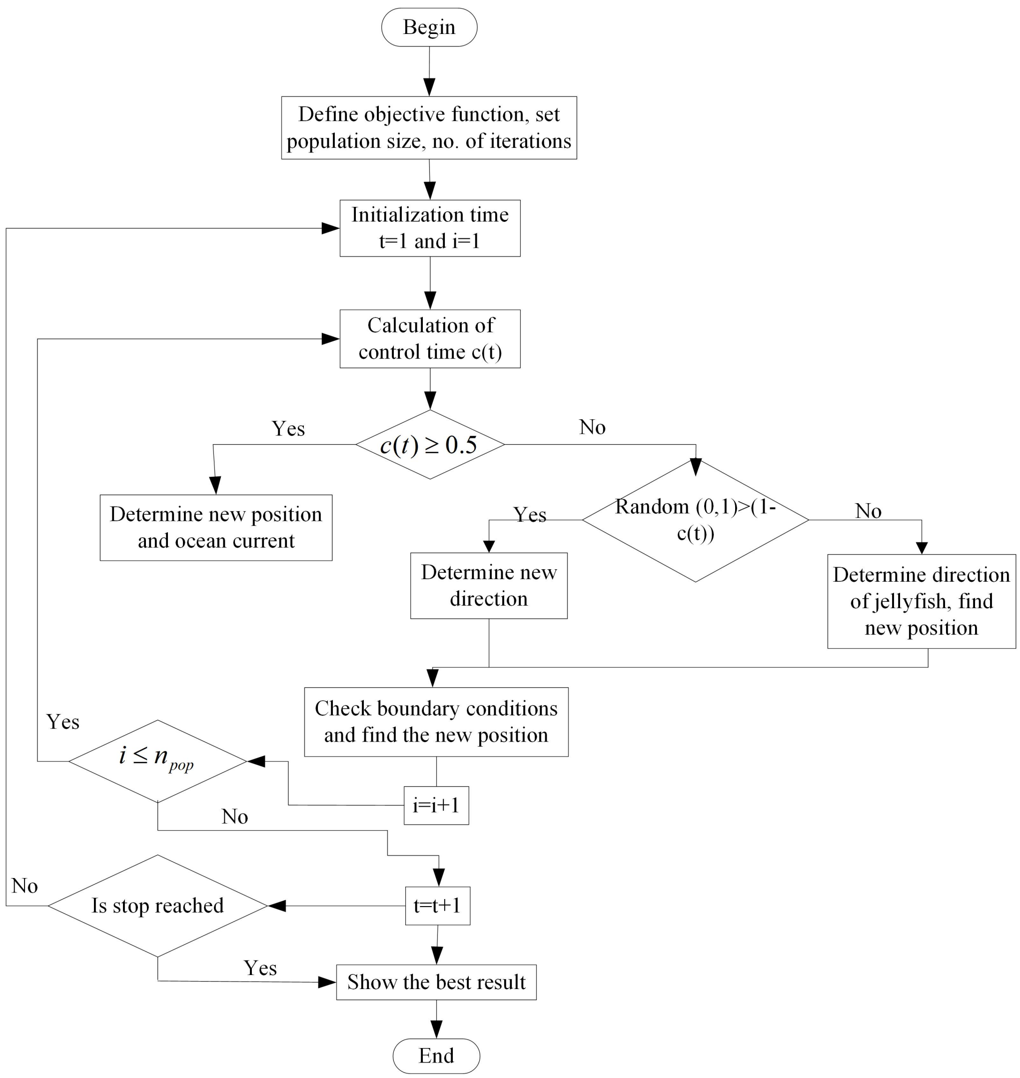

Fig. 4. Flowchart of jellyfish optimization

latter starts moving towards the former. So, both the jellyfish move towards directions having food.

$$\vec{Step} = X_i(t+1) - X_i(t) \tag{18}$$

Where,

$$\vec{Step} = random\ (0,\ 1) \times \vec{Dir}. \tag{19}$$

And

$$\vec{Dir}. = \begin{cases} X_j(t) - X_i \ if \ f(X_i) \geq f(X_j) \\ X_i(t) - X_j \ if \ f(X_i) \langle \ f(X_j) \end{cases} \tag{20}$$

So,

$$X_i(t+1) = X_i + \vec{Step} \tag{21}$$

Utilizing the candidate solution and its velocity the technique of particle swarm optimization (PSO) with time-varying acceleration coefficients (TVAC) uses a population of candidate solutions to solve a problem that moves in the search space by following a mathematical equation. This optimization technique is a swarm intelligence-based algorithm. The evolutionary estimation method decides the relation and intelligence of the swarm. At the end of each iterative process, the particle discussed in this technique with the help of swarm intelligence tries to get the best solution. Further, it tries to move at its current speed, in the direction where the private best result is obtained [29]. Artificial Bee Colony Optimization is a swarm-based technique. In this paper, food positions are considered as population. This algorithm utilizes a set of computational agents known as honey bees [30].

5. Proposed Method

The proposed method follows the given steps:

1) Load the IEEE-14 bus and IEEE-30 bus systems with and without using DPFC in MATLAB PSAT and run power flow by choosing the Newton Raphson load flow method.
2) Note down the line flow data for both test systems.
3) Define the objective function as equation (11) in terms of line data, power angle, bus voltage, and reactive power compensation level of the DPFC.
4) Decide the equality constraints as in equations (12), (13), and inequality constraints as in equations (14), (15), and (16) with their boundary limits.
5) With the aid of the line flow data as found in step 2, solve the objective function using PSO, ABC, GA, and jellyfish optimization techniques.
6) Find the total active power losses, bus voltages, reactive power compensation level of the DPFC, and apparent power flow in the lines within the decided boundary limits.

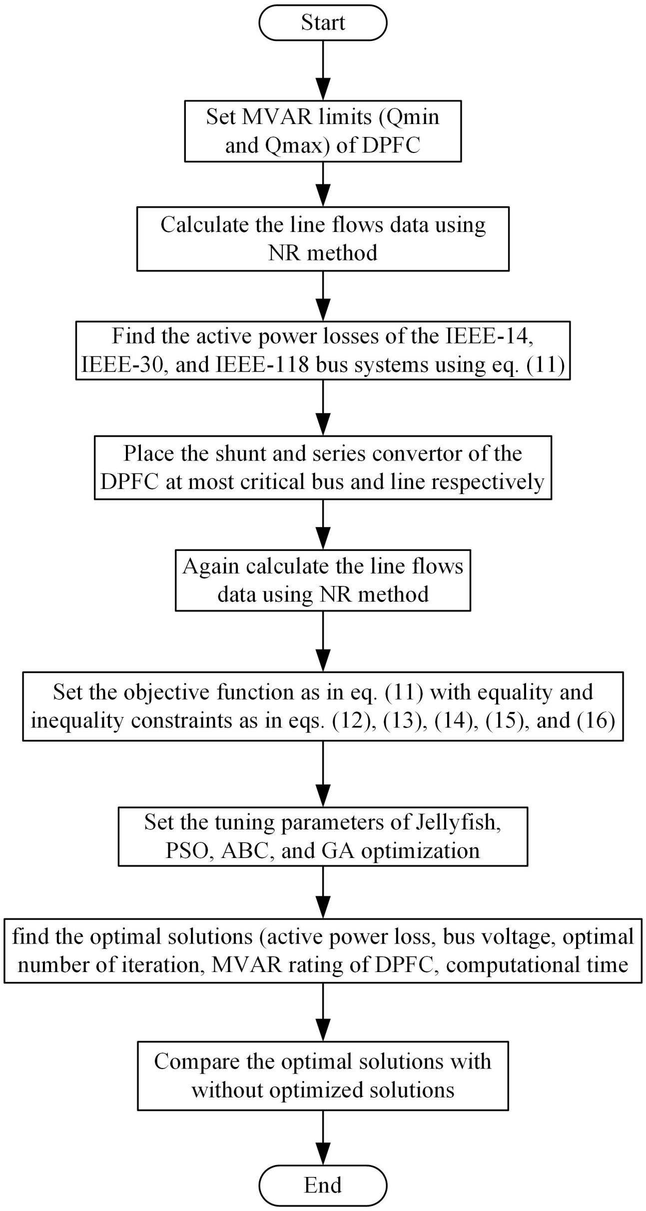

Fig. 5. Shunt converter modeling

7) Compare the calculated active power losses with and without using the DPFC device.
8) Finally, compare the obtained active power losses, number of iterations, and computational time by PSO, ABC, GA, and jellyfish optimizers.

The proposed algorithm is also graphically represented by flowchart as shown in Fig. 5.

6. Results and Discussions

In the following subsections, a comparison is conducted for the Jellyfish optimization and other recognized metaheuristic techniques such as ABC Optimization, PSO, and GA to show the success of the suggested optimizer. The IEEE-14 bus proposed system is studied and the work is further extended to the IEEE-30 bus power system. The tuning parameters has been considered chosen as in [28] and are shown by Table 1.

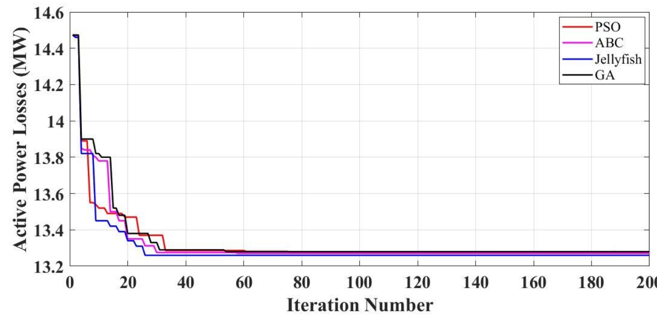

Fig. 6. Convergence graph of PSO, ABC, and jellyfish optimization for IEEE-14 bus structure

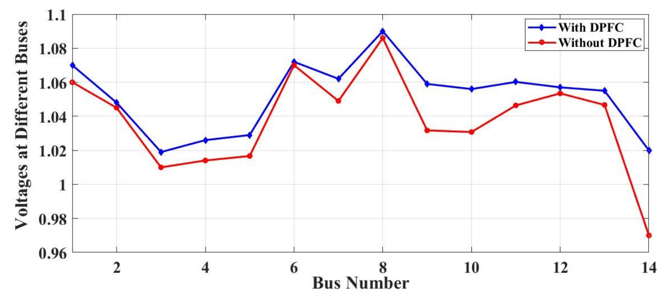

Fig. 7. Bus voltage magnitude (in p.u.) of IEEE-14 bus structure

6.1. IEEE-14 Bus Test System

IEEE-14 bus system having four transformers, two generators, three PMUs at buses 4, 2, and 9, three synchronous condensers, and a total of twenty branches are considered as a test structure. The test systems bus and line data are used in the same way as in [24]. The most severe line and bus of the IEEE-14 are bus number 14 and line (9–14) respectively which are evaluated during heavy loading conditions [25]. Consequently, to improve the voltage profile of buses and decrease the real power losses, the shunt converter of the DPFC is placed at bus number 14 and the series converter is connected in-line (9–14). The largest number of iterations for all optimization approaches is 200, and the population size is 20. To demonstrate the effect of DPFC on bus voltages and active power losses the reactive load has been increased to 30 MVAR at bus number 14. The MVA base for the test system is taken as 100 MVA. The reactive power compensation limit of the DPFC is kept between -100 MVAR to 100 MVAR. The voltage range of the generator buses and load buses are considered as 0.95 to 1.1 p.u. and 0.95 to 1.05 p.u. respectively. The lines flow data has been generated by the Newton Raphson method in MATLAB software. The real power loss before and after the heavy loading at bus number 14 is 13412 KW and 14473 KW correspondingly. Fig. 6 shows the real power losses vs iterations curve for all three considered optimization algorithms by using the DPFC FACTS controller.

It is observed that the real power losses in the IEEE-14 bus structure have been reduced from 14.473 MW to 13.26 MW with the use of DPFC in the system. The optimal compensation level of the DPFC is 28.96 MVAR. From Fig. 6, it is found that the jellyfish algorithm achieves the global solution at the least iteration number of 26. Whereas, the PSO ABC, and GA methods reached the best solution at 76, 58 and 54 iterations respectively. In addition, the active power loss values for TVAC PSO, ABC, and GA methods are higher than the jellyfish algorithm.

The voltage of all buses of IEEE-14 structure including and not considering DPFC FACTS device is shown in Fig. 7. The bus voltage magnitude of bus number 14 is 0.97 p.u. in heavy loading conditions, whereas, its value is improved to 1.0199 p.u.

Table 1. The tunning parameter of different algorithm

Metaheuristic optimizer jellyfish	PSO	ABC	GA
Population size = 20 Max. no. of iterations = 200	Population size = 20 Constriction factor = 0.80 Max. no. of iterations = 200 Learning rate = 2.05, inertia weight = 0.5	No. of food source = 20 Limit = 100 Max. no. of iterations = 200 Acceleration coefficient upper bound = 1	Population rate =20 Crossover-rate = 0.7 Mutation-rate = 0.1 Parent rate = 0.8

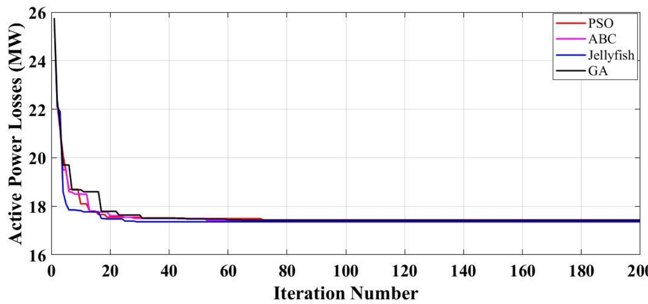

Fig. 8. Convergence graph of PSO, ABC, and jellyfish optimization for IEEE-30 bus system

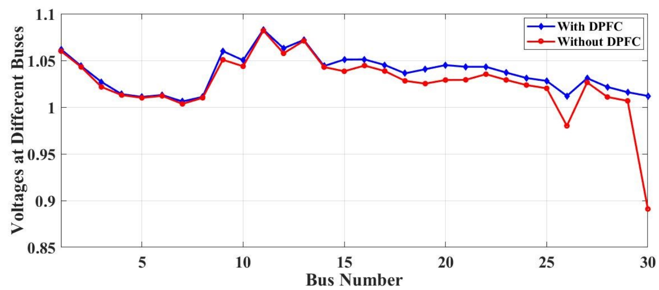

Fig. 9. Bus Voltage magnitude (in p.u.) of IEEE-30 bus system

after placing the DPFC at the most appropriate location. The optimal solutions of all adopted optimization methods are shown in Table 2.The computation time of jellyfish optimizer is 1.3122 seconds which is very less in comparison to others as shown in Table 3.

6.2. IEEE-30 Bus Test System

In the present study, IEEE 30 Bus test system has been utilized for the validation of the proposed study. This system consists of four PMUs incorporated at buses 2, 8, 26, and 30. In addition, this test system consists of six synchronous-based DGs, four transformers, three synchronous condensers, and a total of 41 branch lines connecting the buses. The detailed bus and line data can be obtained from [24]. Further, the most severe bus and line of this test system have been obtained from [25]. Therefore, to optimize the bus voltage profile and reduce the active power losses, the shunt converter of the DPFC has been placed at bus number 30 and the series converter has been incorporated in line (27-30). In the optimization algorithm utilized for the present study the population size considered is 20 and the performance of all the three techniques discussed has been observed till 200 iterations.

To examine the effect of DPFC on bus voltages and active power losses, the reactive load has been increased up to 30 MVAR at bus number 30. 100 MVA is taken as base MVA for the test system, the reactive power compensation limit of the DPFC is kept between -100 MVAR to 100 MVAR, as well as 0.95 to 1.10 p.u. and 0.950 to 1.050 p.u. are considered as the voltage range of the generator-bus and load-bus respectively. The flow data has been generated by the Newton Raphson method in MATLAB software. The real power loss before and after the heavy loading at bus number 30 is 17.615 MW and 25.76 MW respectively. Fig. 8 depicts the convergence curve for all three considered optimization algorithms by using the DPFC FACTS controller.

With the introduction of DPFC in the system, the real power losses of the IEEE-30 bus structure were decreased from 25.76 MW to 17.36 MW. The optimal compensation level of the DPFC is 31.372 MVAR. From Fig. 8, it is found that the jellyfish algorithm gives the global solution with only 29 iterations. Whereas, TVAC PSO, ABC, and GA methods reached the best solution at 72, 53, and 67 iterations respectively. Also, the active power loss values for TVAC PSO,ABC, and GA methods are higher than the jellyfish algorithm.

Figure 9 depicts the voltage of all buses in an IEEE-30 bus structure considering and lacking a DPFC FACTS device. The bus voltage magnitude of bus number 30 is 0.891 p.u. in heavy loading conditions, whereas, its value is improved to 1.012 p.u. after placing the DPFC at the most appropriate location. The optimal solutions of all adopted optimization methods are shown in Table 4. The computational time of jellyfish optimizer, TVAC PSO, ABC, and GA methods are 1.6716, 1.9614, 1.8142, and 1.8913 respectively as shown in Table 5. It is observed that the computational time of jellyfish algorithm is very less in comparison to other optimizers.

6.3. IEEE-118 Bus System

The proposed method is also employed on IEEE-118 bus test system to examine the applicability on large system. This system has 53 generators, 186 transmission lines, 9 transformers and 89 load buses. Under heavy MVA loading condition, the most critical line and most severe bus of the IEEE-118 bus system were obtained in [31] as line number (46-47) and bus number 47 respectively. Therefore, to optimize the bus voltage profile and reduce the active power losses, the shunt converter of the DPFC has been placed at bus number 47 and the series converter has been incorporated in line (46-47). In the optimization algorithm utilized for the present study the population size considered is 20 and the performance of all the three techniques discussed has been observed till 200 iterations.

To test the compensation capabilty of the DPFC the MVAR loading at bus number 47 is increased up to 430 MVAR. The voltage range of generator and load buses are considered as from 0.95 to 1.10 and from 0.95 to 1.05 p.u., respectively. The system MVA bas is taken as 100 MVA. The reactive power compensation limit of the DPFC is choosen from -500 MVAR to 500 MVAR. The real power loss before and after the heavy loading at bus number 47 is 126.2107 MW and 157.8547 MW respectively. It is observed that the the active power loss of the IEEE-118 bus sytem get reduced from 157.8547 MW to 126.1101 MW after using the DPFC at appropiate loaction in the system as shown in Table 6. The jellyfish optimizer gives optimal solution in 61 iterations whereas PSO, ABC, and GA take 91, 76, and 84 iterations respectively to find out optimal solution as given in Table 7. The computation time taken by jellyfish optimizer is 1.9754 second which is very less among the other optimizers as shown in Table 7.

7. Conclusions

This paper presented a qualified analysis of three optimization techniques on IEEE-14 buses and IEEE-30 bus structures utilizing

Table 2. The optimal solution for sizing of DPFC

Sr. No.	Optimization Method	MVAR Rating of DPFC	Real Power Loss (MW)
1	Metaheuristic optimizer jellyfish	28.96	13.260
2	Particle swarm optimization (PSO)	29.215	13.279
3	Artificial bee colony (ABC)	29.231	13.271
4	Genetic algorithm (GA)	29.238	13.280

Table 3. No. of iterations and computational time for optimal solution for IEEE-14 bus system

Sr. No.	Optimization Method	Computation Time (Sec.)	Minimum No. of Iterations	Remarks
1	Metaheuristic optimizer jellyfish	1.3122	26	Minimum time and iterations
2	Particle swarm optimization (PSO)	1.5279	76	——-
3	Artificial bee colony (ABC)	1.4654	58	——-
4	Genetic algorithm (GA)	1.4301	54	——-

Table 4. The optimal solution for sizing of DPFC

Sr. No.	Optimization Method	MVAR Rating of DPFC	Real Power Loss (MW)
1	Metaheuristic optimizer jellyfish	31.372	17.36
2	Particle swarm optimization (PSO)	31.620	17.44
3	Artificial bee colony (ABC)	31.597	17.41
4	Genetic algorithm (GA)	31.608	17.43

Table 5. No. of iterations and computational time for optimal solution for IEEE-30 bus system

Sr. No.	Optimization Method	Computation Time (Sec.)	Minimum No. of Iterations	Remarks
1	Metaheuristic optimizer jellyfish	1.6716	29	Minimum time and minimum iterations
2	Particle swarm optimization (PSO)	1.9614	72	——-
3	Artificial bee colony (ABC)	1.8142	53	——-
4	Genetic algorithm (GA)	1.8913	67	——-

Table 6. The optimal solution for sizing of DPFC

Sr. No.	Optimization Method	MVAR Rating of DPFC	Real Power Loss (MW)
1	Metaheuristic optimizer jellyfish	427.554	126.1101
2	Particle swarm optimization (PSO)	429.646	127.1842
3	Artificial bee colony (ABC)	428.064	126.7917
4	Genetic algorithm (GA)	428.211	127.0543

Table 7. No. of iterations and computational time for optimal solution for IEEE-118 bus system

Sr. No.	Optimization Method	Computation Time (Sec.)	Minimum No. of Iterations	Remarks
1	Metaheuristic optimizer jellyfish	1.9754	61	Minimum time and minimum iterations
2	Particle swarm optimization (PSO)	2.7723	91	——-
3	Artificial bee colony (ABC)	2.2854	76	——-
4	Genetic algorithm (GA)	2.6027	84	——-

the most powerful device DPFC. For that, the most optimal locations of shunt and series converters of the DPFC are decided by the severity of the buses and lines of the systems respectively. Much research has already been done to decide the most critical bus and line of the systems. Based on that, the best possible location of the DPFC has been decided. The real power losses and voltage profiles of both systems have been calculated by TVAC PSO, ABC, GA, and Jellyfish optimization methods with certain constraints. It is observed that the real power losses of the systems get reduced from 14.473 MW to 13.26 MW, from 25.76 MW to 17.36 MW, and from 157.8547 MW to 126.1101 MW for IEEE-14 bus, IEEE-30 bus, and IEEE-118 bus system, respectively after placing both converters of the DPFC at the optimal location. And also, the voltage profiles of the IEEE-14 bus, and IEEE-30 bus systems get upgraded from 0.97 p.u. to 1.0199 p.u. and from 0.891 p.u. to 1.012 p.u., respectively after placing both converters of the DPFC at the optimal location. It can be observed that the jellyfish optimizer needs less running time than other comparative algorithms in terms of seconds. This means that the jellyfish got a faster convergence rate and a more effective global search ability. For test systems considered, for Jellyfish optimization maximum improvement has been found in comparing PSO, ABC, and GA optimization techniques.

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