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HYBRID AC/MT-HVDC TRANSMISSION LINES AND ITS EFFECTIVE OPERATION USING ENHANCED-FISH SWARM OPTIMIZER

Prabhat Kumar Srivastava[1]
Ezhilarasan G.
Divya Paikaray
Sakshi Singh
Manish Srivastava
Anshu Kumar

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A B S T R A C T

Multi-Terminal-High Voltage Direct Current (MT-HVDC) transmission lines are used to transmit electricity over long distances with lower losses compared to traditional Alternating Current (AC) transmission lines. However, HVDC transmission lines have limitations in terms of their ability to handle AC system faults and the need for expensive AC/DC converters at each end of the line. To address these limitations, a hybrid AC/MT-HVDC transmission line can be used. This type of transmission line combines the benefits of both AC and DC transmission, allowing for more efficient and reliable operation. In this article, an Enhanced-Fish Swarm Optimizer (E-FSO) is presented for the efficient maintenance of hybrid AC/MT-HVDC transmission lines. An external repository is included in the proposed E-FSO to preserve that is not dominant. Additionally, fuzzy decision-making is used to choose the hybrid AC/HVDC transmission lines' optimal compromise operating point. In these systems, in addition to the complete control of AC line through parameters for the dedicated generators and transformers connections, and Volt-Ampere Reactive (VAR) compensations, the Voltage Source Converters (VSCs) action and response controllable voltage is engaged. The outcomes of the experiment show the efficacy and dominance of the suggested algorithm, which has high stability indices compared to several competitive algorithms. Nevertheless, the suggested E-FSO is effective in producing a compromise operating point that satisfies the operator's needs while also obtaining well-diversified solutions.

1. INTRODUCTION

Many electrical networks, particularly those in developing nations, have struggled during the past two decades to keep up with the ever-increasing demand for electric power. Limitations on the pricing of energy produced from traditional sources and greater expenses of upgrading conventional

[1] Corresponding author: Prabhat Kumar Srivastava
Email: prabhat.srivastava@galgotiasuniversity.edu.in

transmission infrastructure are two challenges that many electrical networks face to fulfill rising load demand. This decreases systems' reliability, security, and power quality. A significant agreement to tackle climate change was also agreed upon by parties to UN Framework Convention on Climate Change in wake of the Paris Agreement of 2015. Many nations throughout the world have set their sights on achieving the goals of this agreement by 2050, which requires them to have power systems that are completely free of carbon emissions and sustainable (Elsayed et al., 2021). Large-scale renewable energy facilities that have been developed are typically located distant from load centers, necessitating a modernization of transmission networks. Similarly to this, and interconnection of power grids from distant nations requires cost-effective and effective transmission remedies for increasing operational security height while also maximizing operational flexibility and reliability. This is necessary to use available renewable resources, run reserves between power networks, and lessen the impact of peak load (Awad et al., 2019). To provide flexibility when employing more terminals of current connections, the device is upgraded to become an MT-HVDC system. Additionally, an MT system is converted into a mesh HVDC grid by adding extra paths. This updated system may provide redundancy, increase transmission system flexibility, and integrate a variety of renewable energy sources. Because of its benefits, VSC-based HVDC is being used more in different parts of the world to transport significant amounts of electric power across great distances. HVDC is a cost-effective means to transport huge amounts of across large distances of electric power, such as connecting remote major renewable power sources (Biswas et al., 2019). Additionally, HVDC is frequently used for underground/undersea cables that transmit electric power. Advanced controls of linked AC sides are made possible by separate capacities for monitoring VSC active and reactive capacities, which may be done independently of transmitted DC power.

Modular multi-level converters are used to construct MT-HVDC grids utilizing parallel VSC topologies. MPO is a novel optimization algorithm that draws inspiration from nature and numerous tactics used by predators to enhance the rate at which their victims are captured. The comparison of VSC-HVDC's economic benefits to AC options for connecting bulk networks (Saya 2018). A nonlinear paradigm created using General Algebraic Modeling System (GAMS) program has been employed by Interior Point Optimizer (IPO) to address this issue. To support multiple converter operation modes, an extended OPF was put into place. These studies entirely ignored the role played by tap transformers and VAR compensators inside the AC system, even though approaches utilized in these reports were heavily reliant on the initial starting point (Warid 2020).

Every evaluation of VSC-HVDC technology does frequently limited to the configuration of two terminals in these papers. The complexity of their regulation and use increases when MT-HVDC is combined with AC grids. The multi-objective hybrid AC/MT-HVDC system operating models objectives are to maximize technical and economic advantages while minimizing generated emissions from power plants (Duman et al., 2023). Although FSO offers many benefits, users should be aware of some of its drawbacks as well. Here are a few of the Enhanced-Fish Swarm Optimizer (E-FSO) algorithm's drawbacks. The E-FSO has many benefits and has shown encouraging results when used to solve optimization issues, users should be aware of its drawbacks and carefully examine what is appropriate for their particular problem area. The main contributions of the paper are,

- Create an accurate model for determining how hybrid AC/DC grids should operate for maximum efficiency.
- The single and multi-objective frameworks are used to manage the functioning of AC/MT-HVDC power systems.
- The updated process of locations based on dominant priority, every iteration is changed, and E-FSO integrates an external repository.

The article's remaining sections are broken down as follows: In Section II, an overview of current research is provided; in Section III, the suggested methodology is explained in greater detail; and in Section IV, experimental data sets and simulation results are presented and discussed. The analysis is finished in Section V, which also makes recommendations for more research.

2. RELATED WORKS

The Fitness Distance Balance (FDB) approach was applied to choose solution candidates that served as a guide for Phasor Particle Swarm Optimization (PPSO) search process, and two FDB-based PPSO variants were created (Shaheen et al., 2022). The paper (Elsayed et al., 2021) Improved Marine Predators' Optimization Algorithm (IMPOA) to address the economic dispatch problem for combined heat and power (CHP). “The Overall Fuel Cost (OFC) of cogeneration units while taking into account their operational constraints, this topic offers the best scheduling for heat and power-producing suppliers”. The paper (Aydemir and KutluOnay 2023) presented an “Improved Multi-Objective Marine Predators Optimizer (IMMPO)”. Its purpose is to ensure that hybrid alternating current and AC/MT-HVDC energy systems operate as efficiently as possible. The non-dominated prey will be preserved thanks to the inclusion of an external repository. The paper (Wang and Xiao 2022, Gu et al., 2020) suggested Elite Evolution strategy MPA (EEMPA) technique has thoroughly scanned solution space and significantly decreased the danger of becoming trapped in a local optimum. The paper (Abdel-Basset et al., 2022) investigated a swarm particle basis optimization. Optimal regression of energy system. Progressive group optimization's function in addressing an issue of reactive energy enhancement is the subject of extensive research and methods for enhancing every issue that must be addressed when energy efficiency is improved using the Particle Swarm Optimization (PSO) technique. The paper (Al Harthi et al., 2021) enhanced Marine Predators Algorithm (MPA)-based novel picture segmentation method. Within the population and attempting to locate other, better ones for those solutions by pushing them gradually toward the best solutions to prevent accelerating to local optima and randomly search space depending on a specific probability. The paper (Javed et al., 2021, Wu and Yu 2018) presented an Improved Marine Predator Optimization (IMPO) for AC/DC electrical networks incorporating both alternating and direct current performance optimization. The paper (Hotz and Utschick 2019, Wen et al., 2019) suggested hybridHV Alternating current-High Voltage Direct Current (HVAC-HVDC) grids to quickly regulate Direct Current(DC) voltage and frequency, achieve optimal power flow, and maintain stable operation under both normal and abnormal circumstances. In modeling robust droop control, load frequency management, and DC voltage regulation approaches, as well as the advent of hybrid HVAC-HVDC grids and related concerns.

3. PROPOSED METHODOLOGY

In this section, we discuss the Hybrid AC/MT-HVDC transmission lines and its effective operation using Enhanced-Fish Swarm Optimizer.

3.1 AC/MT-HVDC grids with the VSC model

The distinct types of converters are typically used for two terminals HVDC lines that are VSCs and Current Source Converters (CSCs). The MT-HVDC systems are recommended as a viable alternative for modernizing the transmission networks linking various producing and load centers since power gadgets and converter technologies have advanced. What separates the VSCs-HVDC from the CSCs-HVDC are its capabilities of managing the voltage at the AC side and, therefore, the reactive capacity. The VSCs are typically represented as controlled voltage sources. An AC line with comparable inductance and resistance is used to represent the phase reactors and linking transformers between the conversion j and l in the AC grid $\left(O_{lj} + jY_{lj}\right)$. The overall increased perceived power of j[th] VSCs of the l[th] AC line is supplied at;

$$T_{lj} + O_{lj} + iR_{lj} = U_{T_l J_{lj}} *, j = 1,2, \ldots, M_{UTD,} l = 1,2, \ldots, M_{BD,} \quad (1)$$

Calculations for the injection current through the l[th] AC grid to the j[th] VSCs are as follows:

$$J_{lj} = \frac{U_{T_l} - U_{D_j}}{Q_{jl} + iW_{jl}} \quad (2)$$

The action/response lines at the opposite side where the AC is connected, on each side of the VSC, could be shown as follows using (1) and (2);

$$Od_j = Ud_j^2 H_{jl} + Ut_l Ud_j \left[H_{jl} cos\left(\theta_{lj}\right) + A_{jl} sin\left(\theta_{lj}\right)\right] \quad (3)$$

$$Rd_j = -Ud_j^2 At_l + Ut_l Ud_j \left[H_{jl} cos\left(\theta_{lj}\right) + A_{jl} cos\left(\theta_{lj}\right)\right] \quad (4)$$

$$Ot_j = Ut_l^2 H_{jl} - Ut_l Ud_j \left[H_{jl} cos\left(\theta_{lj}\right) + A_{jl} sin\left(\theta_{lj}\right)\right] \quad (5)$$

$$Rt_l = -Ut_l^2 A_{jl} + Ut_l Ud_j \left[H_{jl} cos\left(\theta_{lj}\right) - A_{jl} cos\left(\theta_{lj}\right)\right] \quad (6)$$

3.2 AC/MT-HVDC grids performance within an economic environment

As was already indicated, the answer to the ecological and financial activities issue is a method for moving control that, by optimizing a certain objective function while keeping the operational variable restrictions, yields the best values of the control variables for a given load scenario. The Optimal Power Flow (OPF) formulation allows for the simultaneous consideration of a wide range of goals, including the minimization of gasoline expense, the reduction of pollutants from the power plants that affect the surroundings, the reduction of current power outages exceed AC/HVDC transmission lines, and VSC stages, etc.

Since they provide several advantages, choosing these various aims to solve the suggested issue is crucial. Reduced active power losses through AC, HVDC transmission lines, and VSC stations reflect a technical aspect, while reduced fuel costs and reduced emissions from the generating stations represent economic and environmental aspects, respectively. As a result of the above, the suggested issue is a fish-swarm optimization since it calls for the simultaneous optimization of several objective functions.

The typical form of the OPF issue is as follows:

$$MinE = \{E_1(w,z), E_2(w,z) \ldots, E_n(w,z)\} \quad (7)$$

$$h(w,z) = 0 \quad (8)$$

$$g(w,z) \leq 0 \quad (9)$$

This study models the optimum AC/HVDC transmission line operating issue as a multifaceted, multi-objective, complex issue.

3.3 Fish-Swarm Optimizer (FSO)

Fish-Swarm Optimizer (FSO) is a metaheuristic optimization algorithm that is inspired by the behavior of fish in a swarm. It is used to solve complex optimization problems by searching for the best solution in a large search space. The FSO algorithm works by simulating the behavior of a swarm of fish. In the algorithm, each fish represents a potential solution to the optimization problem. The swarm of fish moves in the search space, and each fish adjusts its position based on its fitness and the fitness of the other fish in the swarm. Algorithm 1 can be expressed mathematically as follows:

Algorithm 1: Fish-Swarm Optimizer (FSO)

1. Initialize the swarm of fish with a random set of positions.
2. Evaluate the fitness of each fish in the swarm based on the optimization objective.
3. Choose a leader fish from the swarm based on its fitness.
4. Update the position of each fish in the swarm based on its fitness and the position of the leader fish.
5. Repeat steps 2-4 until a stopping criterion is met.

In step 4, the position of each fish is updated based on its fitness and the position of the leader fish. The position update is based on a set of rules that simulate the behavior of fish in a swarm. The position update is performed using the following equation:

$$new_{position} = current_{position} + step_{size} * (leader_{position} - current_{position}) + randomness \quad (10)$$

Where $step_{size}$ is a parameter that controls the size of the step taken by the fish, $leader_{position}$ is the position of the leader fish, $current_{position}$ is the current position of the fish, and randomness is a random vector that is added to the step to add diversity to the search.

In the context of hybrid AC/MT-HVDC transmission lines, FSO can be used to optimize the operation of the transmission line network. The algorithm can be used to determine the best configuration of the transmission line network to minimize power losses and improve the stability of the AC system. The FSO algorithm works by simulating the behavior of a swarm of fish, where each fish represents a potential solution. The algorithm then evaluates each solution based on a fitness function, which measures how well the solution meets the desired optimization objective. The fish then adjust their positions in the search space based on their fitness and the position of the other fish in the swarm. By using FSO to optimize the operation of hybrid AC/MT-HVDC transmission lines, it is possible to achieve more efficient and reliable operation. The algorithm can be used to determine the optimal placement of HVDC links and control devices, as well as the best settings for the control system.

3.4 Enhanced-Fish Swarm Optimizer (E-FSO) for optimum performance of AC/HVDC systems

In hybrid AC/MT-HVDC transmission lines, the E-FSO algorithm can be used to optimize the control system parameters and improve the efficiency and stability of the transmission line. The objective function to be minimized can be defined as the total cost of power transmission, which includes the cost of energy losses and the cost of control system operation. Algorithm 2 can be expressed mathematically as follows:

Algorithm 2: Enhanced-Fish Swarm Optimizer (E-FSO)

1. Initialize the fish swarm population and set the iteration counter t=0.
2. For each fish in the swarm, calculate its fitness value using the objective function.
3. Update the fish position and velocity using the following equations:
4. $v(i,j,t+1) = wv(i,j,t) + c_1 r_1 * \left(p_{best}(j,t) - x(i,j,t)\right) + c_2 r_2 (\, g_{best}(j,t) - x(i,j,t)$
5. $x(i,j,t+1) = x(i,j,t) + v(i,j,t+1)$

where i is the fish index, j is the control system parameter index, w is the inertia weight, c_1 and c_2 are the cognitive and social learning coefficients, r1 and r2 are random numbers between 0 and 1, $p_{best}(j,t)$ is the personal best position of the fish in the jth parameter dimension at iteration t, and $g_{best}(j,t)$ is the global best position of all fish in the jth parameter dimension at iteration t. Evaluate the fitness value of the updated fish positions and update the personal and global best positions. Repeat steps 2-4 until a stopping criterion is met.

The E-FSO algorithm can be combined with other optimization techniques, such as gradient-based optimization or fuzzy logic, to further improve the performance of the hybrid AC/MT-HVDC transmission line. The effective operation of the transmission line depends on the accurate modeling and control of the system, as well as the proper selection and tuning of the control system parameters. The advantage of using E-FSO for power flow control optimization is that it can handle multi-objective optimization problems, where multiple conflicting objectives are considered simultaneously. This is important in the context of hybrid AC/MT-HVDC transmission lines, where multiple performance metrics such as losses and stability must be optimized simultaneously.

In summary, using E-FSO for power flow control optimization in hybrid AC/MT-HVDC transmission lines can lead to more efficient and reliable operation. The algorithm can find the optimal settings for the power flow controller parameters, which can improve system performance and reduce losses.

4. RESULTS AND DISCUSSION

The optimum multi-objective functioning of hybrid AC/MT-HVDC transmission lines is solved in this part using the suggested E-FSO, which is implemented in the MATLAB environment. In a hybrid AC/MT-HVDC transmission line, there are different voltage levels involved, including the AC grid voltage and the DC grid voltage. The voltage levels for the DC grid in a hybrid AC/MT-HVDC transmission line depend on the specific configuration of the system. Additionally, as shown in Figs. 2 and 3, the suggested technique significantly improved the bus values in AC and HVDC systems.

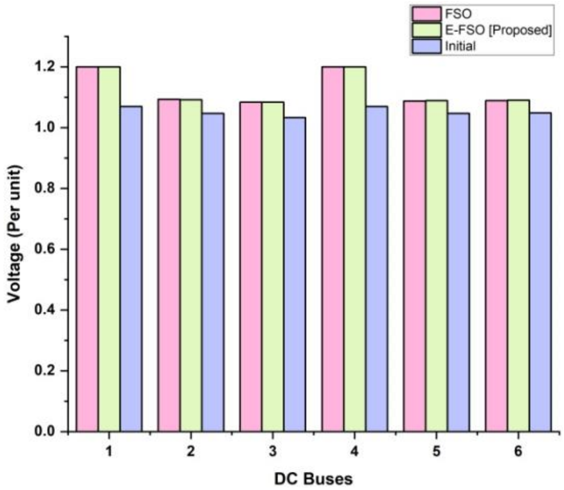

Figure 1. HVDC grid voltages for case 1

For case 1 in a hybrid AC/MT-HVDC transmission line, where there is one AC grid connected to one MT-HVDC converter station, the DC grid voltage level at the MT-HVDC converter station is determined by the specific DC voltage level required by the AC grid for power transmission. This voltage level is typically in the range of 300 kV to 500 kV. The E-FSO outperforms everyone else in operating the AC/MT-HVDC grid effectively to attain the lowest fuel cost.

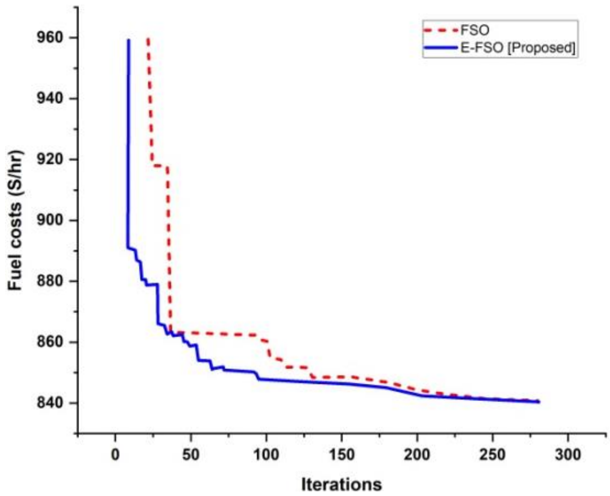

Figure 2. Convergence features between the proposed E-FSO and traditional FSO

E-FSO is expected to have better convergence characteristics than traditional FSO due to its additional features. E-FSO can converge to the optimal solution faster and with higher accuracy compared to traditional FSO, especially for complex and large-scale optimization problems.

Likewise, as demonstrated in Figs. 3 and 4, there has been a significant enhancement in the charge distribution in both AC/HVDC systems. These numbers make it obvious that the load bus and tap changer voltages are within the acceptable range of .95 to 1.14 p.u. Furthermore, the generator currents, DC bus voltages, and VSC voltages are all within the allowable voltage limits.

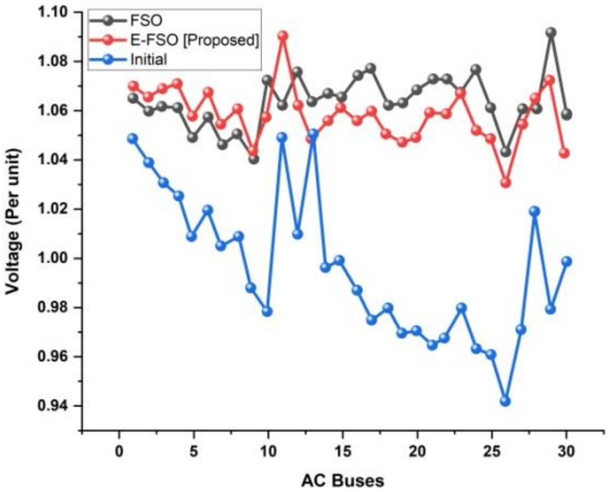

Figure 3. Voltages in AC part

The voltage levels in the AC part of the hybrid AC/MT-HVDC transmission line are typically in the range of 110 kV to 765 kV, depending on the specific transmission system and the location within the system. These voltages are used to transmit power from the generation source to the point of interconnection with the HVDC system.

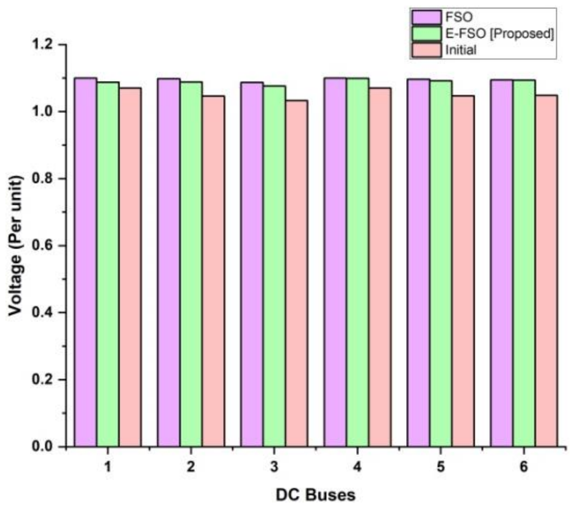

Figure 4. Voltages of HVDC grid for case 2

In case 2, the HVDC grid voltages must be carefully controlled to ensure the stable operation of the MT-HVDC system. The voltage levels must be maintained within a safe and stable range, despite changes in load and other system conditions. The specific voltage levels used in case 2 depend on the design and configuration of the MT-HVDC system. Generally, the voltage levels are set to be higher than the nominal voltage levels of the AC grid, to ensure that there is enough voltage headroom to support the load and maintain stability.

Here, we compare the accuracy and loss of the E-FSO with those of other approaches such as the Grey Wolf Optimizer (GWO) (Monica et al. 2022), Particle Swarm Optimizer (PSO) (Ramírez-Ochoa et al., 2022), and Fish Swarm Optimizer (FSO) (Malik et al., 2022).

The accuracy of a transmission line is typically measured by its ability to maintain consistent characteristic impedance and minimize signal reflections, attenuation, and crosstalk. Figure 5 shows the accuracy of the proposed system. The accuracy of consumption forecasting in current systems and the suggested system is indicated.

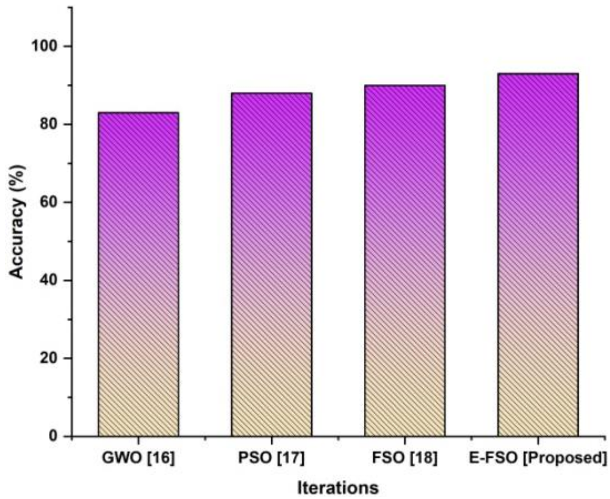

Figure 5. Accuracy of E-FSO and other methods

While the suggested system achieves the proposed 93% accuracy, GWO has obtained 83%, PSO has gained 88%, and FSO has attained 90%. It demonstrates that the suggested course of action is more successful than the existing one.

Loss an optimization process entails identifying model parameter values that minimize the loss function. Stochastic Gradient Descent (SGD), is a method that iteratively modifies model parameters in the direction that minimizes a loss function. Figure 6 shows the loss of the proposed system.

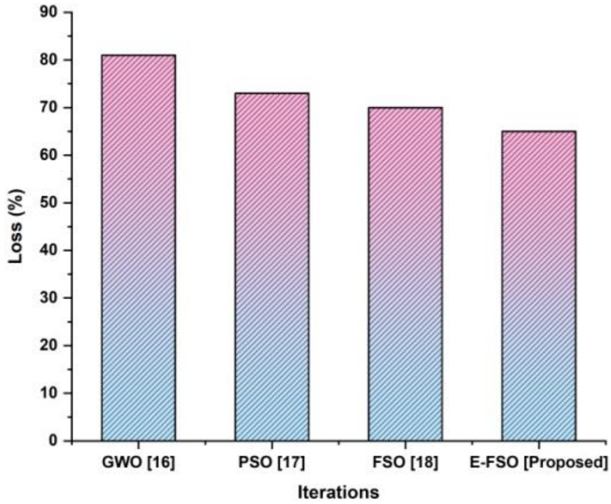

Figure.6. Loss of E-FSO and other methods

While the suggested system achieves the proposed 65% loss, GWO has obtained 81%, PSO has gained 73%, and FSO has attained 70%. It demonstrates that the suggested course of action is more successful than the existing one.

5. CONCLUSION

Based on this research, it can be concluded that the use of hybrid AC/MT-HVDC transmission lines can improve the overall efficiency and reliability of power transmission systems. The use of the E-FSO algorithm for the optimal operation of these transmission lines can further enhance their performance by optimizing the control variables and reducing the losses. E-FSO has shown promising results in improving the efficiency of hybrid AC/MT-HVDC transmission lines, minimizing the cost of power transmission, and reducing the environmental impact. The algorithm can effectively handle the non-linearity and multi-objective nature of the optimization problem, providing an optimal solution within a reasonable time frame. The simulation results show the recommended optimizer's effectiveness and supremacy over competitive methods for both single- and problems with multiple goals, with technological and financial advantages. Therefore, the application of E-FSO can play a significant role in the efficient and effective operation of hybrid AC/MT-HVDC transmission lines, ultimately leading to a more reliable and stable power grid. In the future, Hybrid AC/MT-HVDC transmission lines are subject to dynamic changes in the system, such as changes in load demand, faults, or system disturbances. It could explore the effectiveness of the E-FSO algorithm in dealing with such dynamic behavior, and how it compares to other optimization techniques.

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Prabhat Kumar Srivastava
Galgotias University, Greater Noida, Uttar Pradesh, India
prabhat.srivastava@galgotiasuniversity.edu.in
ORCID 0000-0002-6175-6544

Ezhilarasan G.
Jain Deemed to be University, Bangalore, India
g.ezhilarasan@jainuniversity.ac.in
ORCID 0000-0002-5335-2347

Divya Paikaray
Arka Jain University, Jamshedpur, Jharkhand, India
divya.p@arkajainuniversity.ac.in
ORCID 0000-0001-7886-1538

Sakshi Singh
Teerthanker Mahaveer University, Moradabad, Uttar Pradesh, India
sakshicisco@yahoo.co.in
ORCID 0009-0002-1202-300X

Manish Srivastava
Vivekananda Global University, Jaipur, India
manish.srivastava@vgu.ac.in
ORCID 0000-0001-9501-9422

Anshu Kumar
Noida Institute Of Engineering and Technology, Greater Noida, Uttar Pradesh, India
anshu.kumar@niet.co.in
ORCID 0009-0004-9066-9601