

Whale Optimization Algorithm based ATC Enhancement by Installing FACTS and Wind Generators in Deregulated Power System

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Abstract

The assessment and enhancement of the Available Transfer Capability (ATC) for Transmission Companies (TRANSCOs) is considered to a significant exercise in the marketing process of deregulated power system. The determination of value of ATC serves to operate the system efficiently in reliable and secure conditions. The integration of wind energy sources, particularly due to environmental concerns, the grid receives significant attention among market participants. The speed of the wind and its air density severely influence the characteristics of wind as it is intermittent in nature. Its dynamic aspect has some impact on the estimation of ATC value of the system. Hence, it is essential to sense the wind speed and other factors in order to have a rigorous value for ATC. The primary focus of this work is to evaluate the performance of ATC and the voltage profile of the TRANSCOs participating in the day-ahead dynamic electricity market by considering various benefit margins. It has been accomplished by the combined operation of optimal placement of STATCOM and renewable sources of wind generators. The wind generators and STATCOM are effectively supplying the real and reactive power into the system, enhancing the characteristics of voltage profile and value of ATC. An AC power flow method blended with a novel whale optimization algorithm is employed for tuning the proposed system parameters and identifying the optimal location and size of both STATCOM and wind generators. Since benefit margins are treated as essential components for improving the reliability of TRANSCOs, it also been included while attempting to improve the value of ATC in a dynamic market. To validate the ingenuity of the devised strategy, it is rigorously tested on a modified IEEE 39 bus system over 24-hour time period. The simulation experiment on MATLAB reveals that the suggested technique provides better outcomes when compared with the existing algorithm.

Keywords: Deregulation, Available Transfer Capability, FACTS Devices, Wind generations, Benefit Margins, Whale Optimization. Algorithm

1. Introduction

In a restructured power system, Available Transfer Capability is an additional transmission capability of the existing transmission system for further more power transfer activities over and above the previously committed transactions. Hence, ATC determines the quantity of power that can be transmitted through its specified network so that cost and efficient operation of the system is ensured. Different methodologies have been

recommended in literature with the integration of renewable energy sources. Similarly, there are reports which explain the evaluation techniques for the solution of ATC values [1]. The approaches are broadly classified as deterministic and probabilistic methods. Deterministic methods include DC power flow, repeated power flow, continuous power flow, optimal power flow, and distribution factor approaches. Deterministic methods deal with some kinds of uncertainties like transmission line outages and intermittent

performance of wind and solar power generation [2].

The role of FACTS devices and renewable energy sources [3-15] in enhancing the value of ATC is quite remarkable. It enhances the stability and loadable limits of transmission systems. These components act as a dynamic alternative to the traditional techniques by the way of extended flexibility, minimum cost with less environmental impacts.

The researchers implemented various compensating devices with optimization techniques for enhancing the ATC and voltage profile of TRANSCOs in bilateral and hybrid electricity market. The impact on ATC of a system has been analysed by installing Thyristor Controlled Series Capacitor (TCSC) with hydro and wind power generations [3]. Wind energy has been modelled as an active power and investigated for 24 hours. The location which provides improved value of ATC are considered as an optimal point for the placement of TCSC. A bi-level optimization problem has been reported [4] where the upper-level task involves ATC computation and the lower-level task pertains to Economic Dispatch (ED). This bi-level formulation is subsequently modeled into a Mixed Linear Integer Programming (MILP) problem, addressed through conventional optimization approaches. The effectiveness of this approach is validated using actual wind data from the IEEE 118 bus system. In [5], a multi stage operational strategy is presented, to enhance and assess ATC with the addition of renewable energy resources and FACTS devices are described. The suggested ATC optimization engine exploits the method of pattern search optimization technique for getting the solution for ATC. It is revealed that the PV system considerably enhances the value of ATC.

An interval optimization-based method is outlined in [6], for assessing ATC using uncertainty bounds, eliminating the requirement for precise wind energy probabilistic distribution data. The application of robust duality theory and the big-M algorithm facilitates the conversion of the max-min problem into an efficient computational format. The proposed approach is examined on IEEE-118 bus system, with the outcome demonstrating its effectiveness. In [7], a methodology is presented for computing Day Ahead Dynamic ATC (DATC) values for wind generators. The Distribution Factor Analysis (DFA) is linked with Data Envelopment Analysis (DEA) and the classical Sequential

Quadratic Program (SQP) to calculate DATC. Additionally, an Artificial Neural Network (ANN) is employed to forecast time-series wind speeds, aiding in DATC evaluation. This approach investigates the influence of wind generators and employs DFA to establish the dynamic voltage stability point for DATC evaluation. The model's validity is verified using the New England 39 bus and South Indian 181 bus systems. A study conducted by [8] focuses on evaluating ATC values while accounting for uncertain factors such as load, wind energy, and transmission line outages. To mitigate the computational load associated with Monte Carlo simulations, a statistically balanced surrogate model is proposed for ATC solution. This approach effectively addresses uncertainties in base case scenarios and credible contingencies involving load and wind generation variations, as well as transmission component failures.

The evaluation of CBM in the context of renewable energy resources is explored in [9]. The method overcomes the problems associated with the iteration process. To solve this problem, the paper brings in the wind generation in the process of CBM computations. Grounded in graph theory, this methodology is harnessed to compute CBM considering the presence of multiple defective areas, with a particular emphasis on incorporating renewable energy resources. In [10], a strategy employing co-simulation for Integrated Transmission and Distribution (ITD) has been highlighted to take care of the multi operational functions at DN like volt or var optimization to analyse its effect on TN. A Multi-Agent System (MAS) based approach has been employed to formulate the methodology. The optimization challenge encompassing both Transmission and Distribution (T&D), within a unified ITD platform, is resolved using the pattern search algorithm. Additionally, the computation of ATC is addressed, incorporating the wind power, as elaborated in [11]. The reactive power limit is governed by the generator's capability curve. Real time wind speed characteristics data for wind energy out calculation are worked out. An investigation has been carried out to analyse the power generation against change in the value of ATC under normal and contingency conditions.

The integration process of wind turbines with the other power system affects the value of the ATC. Wind turbine output is computed by a formulation which includes the direction of the wind and its wake effect is specified in [12]. The

selection of congestion areas aims in knowing the status of congested lines arising from variation in the transactions. These areas are identified by TCDF values and the optimal placement of wind turbines and battery energy storage scheme is guided by the ATCDF values within these identified zones. An optimal location of buses for the placement of wind turbines using a sensitive formula is realised in [13]. TCDF values are used to form the zones. The system's optimal point is established using the ATCDF. Wind turbines are strategically placed at each bus within specific zones, as determined by TCDF values. Subsequently, the ATC value is computed, revealing that the implementation of wind turbines according to this approach leads to an enhancement in ATC values.

The integration of renewable energy sources, including solar, wind, and hydro, with a conventional thermal power plant to achieve minimized thermal power generation costs is expounded upon in [14]. The investigation is scheduled for about 24 hours' time period. May fly optimization algorithm (MA) which blends the merits of evolutionary and swarm-based algorithm to yield better results. In the case of a single objective function, the cost criterion demonstrates an improvement of over 13%. In the context of multi-objective optimization, the enhancement exceeds 19% and the ATC values are improved over 56%. The consequence of CBM on with and without wind generation has been stated [15]. To evaluate the influence of ATC, the introduction of wind generators replaces conventional power generators within the system. This approach is structured using graph theory to calculate CBM, which is then integrated with ATC through repeated power flow analysis. The outcomes highlight that assessing ATC without considering CBM can result in overestimation or underestimation of ATC values. This misestimation could potentially compromise system security and impede proper utilization of transmission network resources.

The scope of this assignment is to bring out the solution for the enhancement of ATC value using FACTS controllers by integrating renewable energy resources with the traditional power system. The optimal size and locations of FACTS and wind generators are identified by the novel whale optimization algorithm. The influence of various transfer capacity margins is also considered in this problem while enhancing the value of ATC.

2. Problem Formulation

Available Transfer Capability (ATC) quantifies the remaining transmission capacity within the physical network that can accommodate additional commercial transactions beyond existing commitments. The focus of this paper is on accounting for diverse benefit margins, which encompass elements such as Transmission Reliability Margin (TRM) and Capacity Benefit Margin (CBM). These margins are taken into consideration across various contingency scenarios as part of the ATC calculation process.

$$ATC = TTC - ETC - TRM - CBM \quad (1)$$

2.1 Objective function

The primary goal is to ascertain the ATC in order to optimize power exchange between two zones, while adhering to a range of constraints to ensure that there are no deviations of voltage, thermal, or stability limits. The ATC formulation can be elucidated as follows:

$$\text{Maximize } ATC = \sum_{j \in i} P_{Gj} \quad (2)$$

2.2 Equality Constraints:

The equality constraints can be expressed using the power balance equations as:

The equations for real power injection at any bus 'i' can be represented as follows, derived from load flow analysis:

$$P_i - \sum_{j=1}^N V_i V_j [G_{ij} \sin(\delta_{ij}) - B_{ij} \cos(\delta_{ij})] = 0 \quad (3)$$

The equations for reactive power injection at any bus 'i' can be represented as follows, derived from load flow analysis:

$$Q_i - \sum_{j=1}^N V_i V_j [G_{ij} \cos(\delta_{ij}) - B_{ij} \sin(\delta_{ij})] = 0 \quad (4)$$

$$P_i = P_{Gi} + P_{Wi} - P_{Di} \quad (5)$$

$$Q_i = Q_{Gi} - Q_{Di} \quad (6)$$

2.3 Inequality Constraints:

The considered inequality constraints are outlined below:

$$V_{i \min} < V_i < V_{i \max} ; V_{j \min} < V_j < V_{j \max} \quad (7)$$

$$\delta_{i \min} < \delta_i < \delta_{i \max} ; \delta_{j \min} < \delta_j < \delta_{j \max} \quad (8)$$

$$P_{Gi \min} < P_{Gi} < P_{Gi \max}; P_{Gj \min} < P_{Gj} < P_{Gj \max} \quad (9)$$

$$P_{ij \min} < P_{ij} < P_{ij \max}; Q_{ij \min} < Q_{ij} < Q_{ij \max} \quad (10)$$

While evaluating bilateral transaction for ATC assessment, the alteration in generation at the seller bus and the corresponding adjustment in demand at the buyer bus can be computed as follows:

$$P_{Gm} = \lambda P_{Gm}^{\circ} \quad P_{Dn} = \lambda P_{Dn}^{\circ} \quad (11)$$

While the loadability factor λ is optimized to its maximum within the set constraints, the parameter P_{Dn} signifies the maximum power quantity transferred to the buyer bus n . Consequently, the ATC can be expressed as:

$$ATC = \lambda_{\max} P_{Dn}^{\circ} - P_{Dn}^{\circ} \quad (12)$$

2.4 Modelling of Wind Power Generation

The fluctuation patterns of wind speed can be mathematically depicted using the Weibull probability distribution function $f_v(v)$, which involves parameters like the shape factor k , the scale factor c , and the wind velocity v measured in meters per second (m/s). The PDF governing wind speed within a specific time is outlined as follows.

$$f_v(v) = \left(\frac{k}{c}\right) \left(\frac{v}{c}\right)^{(k-1)} e^{-\left(\frac{v}{c}\right)^k}, 0 < v < \infty \quad (13)$$

The wind speed's correlation with the wind turbine's output power is mathematically described using the following equation.

$$P_W = \begin{cases} 0 & 0 \leq v_i \leq v_{in,i} \\ P_{r,i} \frac{v_i - v_{in,i}}{v_{r,i} - v_{in,i}} & v_{in,i} \leq v_i \leq v_{r,i} \\ P_{r,i} P_{r,j} & v_{r,i} \leq v_i \leq v_{o,i} \\ 0 & v_{o,i} \leq v_i \end{cases} \quad (14)$$

Were

$f_v(v)$ – Wei-bull probability function

$P_{r,i}$ – Wind turbine rated power

v_i – Wind speed at i^{th} bus

$v_{in,i}$ & $v_{r,i}$ – Rated cut-in speeds

$v_{o,i}$ – Rated cut-out speed

3. Whale Optimization Algorithm

The swarm intelligence-based nature-inspired whale optimization algorithm was developed by S. Mirjalili and A. Lewis in 2016. The characteristic of bubble net surfing for whales with its spiral encircling hunting method makes it a very powerful ability to catch its prey [16, 17], as shown in Fig. 1. The objective of complex nonlinear optimization problem is evaluated by humpback whale hunting characteristics. Humpback whales have two predatory techniques throughout their process: one is to lower the surrounding mechanism and the second is to spiral model position updating. This WOA overcomes the drawbacks of slow convergence rate unlike other heuristic algorithms like PSO, ACO and gives global optima.

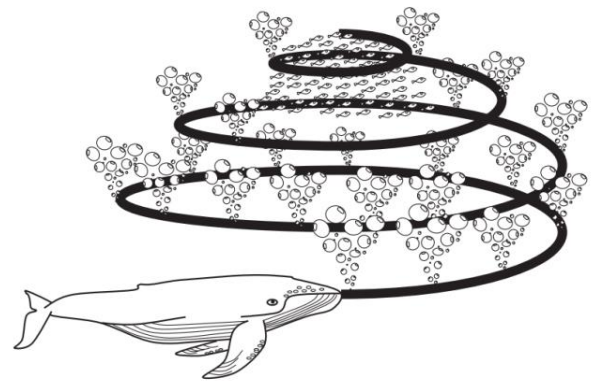


Fig. 1. Whale bubble-net foraging practice

The complex mathematical modelling of the hunting process is represented through three stages as follows:

3.1 Surrounding Prey

In the initial hunting phase, the approach entails encircling the prey to identify the most promising candidate solution. Subsequently, the fittest solution is employed to update the current position. This encircling behavior, reminiscent of whales surrounding their prey, can be portrayed as:

$$X(t+1) = X^*(t) - A \cdot D \quad (15)$$

$$D = |C \cdot X^*(t) - X(t)| \quad (16)$$

Here, 't' represents the current iteration number. 'A' and 'C' denotes coefficient vectors, while 'X' resembles the position vector and X^* refers to the position vector associated with the best candidate solution. With each iteration of search operation, X^* is continually updated to yield

an improved solution. A and C are mathematically represented as:

$$A = 2a \cdot \eta - a \quad (17)$$

$$C = 2 \cdot \eta \quad (18)$$

Here, 'a' decrement from 2 to 0 linearly and $\eta \in [0,1]$.

3.2 Bubble-net attack strategy

The humpback whales bubble net strategy is mathematically portrayed with reducing the encircling mechanism and updating spiral position. The encircle decrementing behaviour is obtained by decreasing the value of 'a' in Eq. (17). The helix movement of humpback whale is mathematically formulated as:

$$X(t + 1) = D' \cdot e^{bl} \cdot \cos(2\pi l) + X^*(t) \quad (19)$$

$$D' = |X^*(t) - X(t)| \quad (20)$$

Here D' is the best optimal distance obtained so far between the whale and prey, $l \in [-1,1]$ and 'b' defines the spiral shape. The sunchronic behaviour of decrementing encircling mechanism or the position update of whale in the spiral are modelled with same probability.

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Initialize the whale's population  $X_i$  ( $i = 1, 2, \dots, n$ )
Calculate the fitness of each agent
 $X^*$  = the best search agent
while ( $t <$  maximum number of iterations)
  for each search agent
    Update a, A, C, l, and p
    If1 ( $p < 0.5$ )
      If2 ( $|A| < 1$ )
        Update the position of the current search agent by the Eq. (16)
      else If2 ( $|A| \geq 1$ )
        Select a random search agent ( $X_{rand}$ )
        Update the position of the current search agent by the Eq. (21)
      end if2
    else if1 ( $p \geq 0.5$ )
      Update the position of the current search by the Eq. (19)
    end if1
  end for
  Check if any search agent goes beyond the search space or else amend it
  Calculate the fitness function value of each search agent
  Update  $X^*$  if it is better
   $t = t + 1$ 
end while
return  $X^*$ 

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Fig. 2. Pseudo-Code of Whale Optimization algorithm

3.3 Hunting Prey Stage

At this stage, 'A' vector is employed to hunt the prey. The randomly chosen search agent, X_{rand} with $|A| > 1$ is used to update the position of whale in contrast with $-1 < A < 1$ to perform WOA for global search. The hunting prey stage is mathematically modelled as:

$$X(t + 1) = X_{rand}(t) - A \cdot D \quad (21)$$

$$D = |C \cdot X_{rand} - X(t)| \quad (22)$$

4. Results and Discussions

The proposed Whale Optimization Algorithm (WOA) has been evaluated on a modified IEEE-39 bus test system to illustrate its applicability and efficiency. This system is integrated with renewable energy sources of three wind energy units and FACTS devices comprising of three STATCOM units. The line and bus data for the IEEE-39 bus test system have been sourced from [18] and its schematic diagram is shown in Fig. 3. It consists of 10 thermal generators, 39 buses, 21 loads and 46 transmission lines respectively. The base case load demand for the proposed test system is 6255.07 MVA.

The prime objective of this study is to improve the exchange of real power between seller and buyer buses, while diligently adhering to standard operating constraints. The simulations are carried out using MATLAB 19.0 environment, a system equipped with an I5 processor, operating at 2.40 GHz clock speed and processing 4 GB RAM. The proposed methodology is devised to analyze and refine power generation strategies, encompassing both wind and thermal plants, in conjunction with the deployment of STATCOMs. Since the process is tuned as a day ahead energy market problem, the load demand is examined for about 24-hour time horizon to compute the value of ATC for each demand. The load demands for 24 hours are graphically presented in fig 4. The proposed test system is divided into three distinct areas and the corresponding bus numbers are detailed in Table 1.

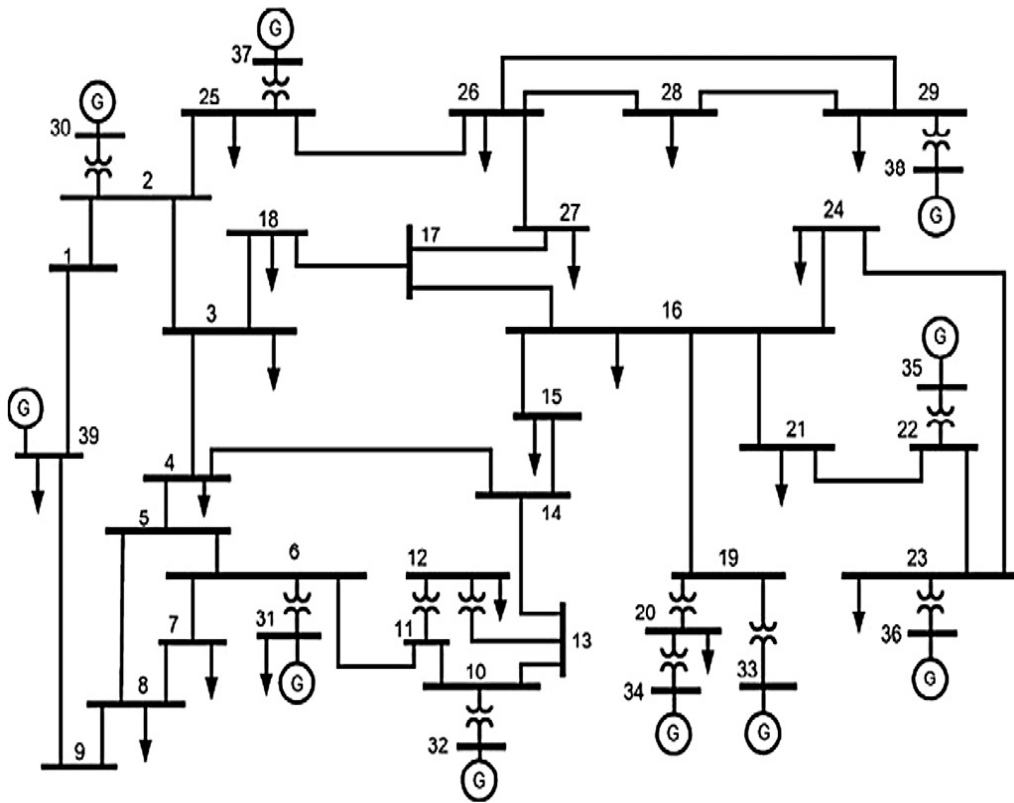


Fig. 3. Schematic diagram of IEEE-39 Bus test system

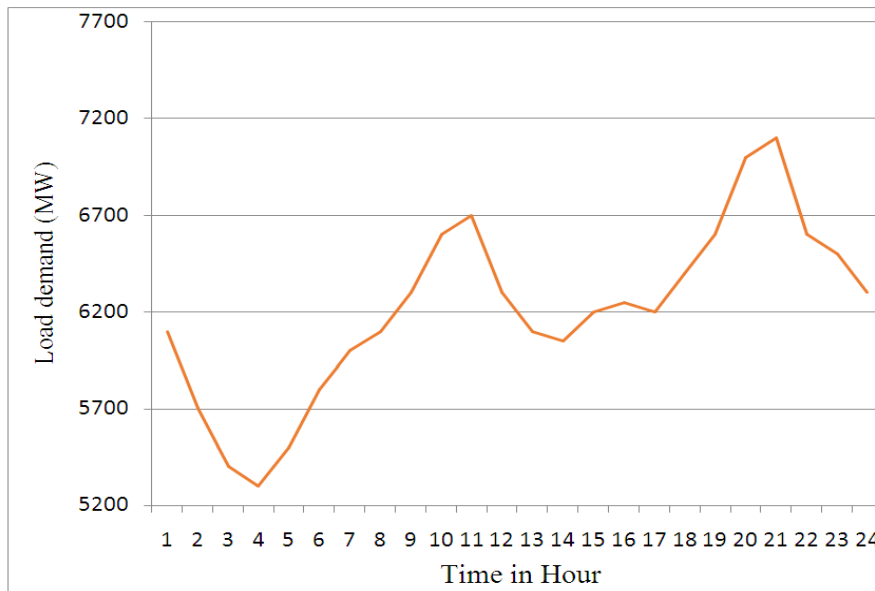


Fig. 4. Load demand of IEEE-39 Bus System

Table 1: Area and Bilateral Transaction details of IEEE 39 bus system

Area	Bus No	
Area 1	4,5,6,7,8,9,10,11,12,13,14,31,32,39	
Area 2	1,2,3,17,18,25,26,27,30,37	
Area 3	15,16,19,20,21,22,23,24,28,29,33,34,35, 36, 38	
Bilateral Transaction details		
Seller	Area 1	Bus No 32
Buyer	Area 2	Bus No 18

Table 2: Control Parameter of WOA

Control Parameters	Count
Size of sample Population	60
Maximum count of Iterations (N)	500
Variable Number (d)	10
Random number (r)	0 to 1

The proposed test system has been analyzed with two different cases for enhancement of ATC

- Case 1: Enhancement of ATC considering wind generators only
- Case 2: Enhancement of ATC considering wind generators with FACTS devices.

To evaluate the influence of wind power generators and STATCOM on ATC, the test system is enhanced

by designated area has a single wind generator allocated to it and are positioned at bus 32, bus 37, and at bus 34. All wind generators are standardized with the same rating. The dynamic model for these wind generators is sourced from [19]. Correspondingly, three STATCOM devices are positioned across Area 1, Area 2, and Area 3. The rating of each STATCOM is adjusted within the range of ± 5 MVAR.

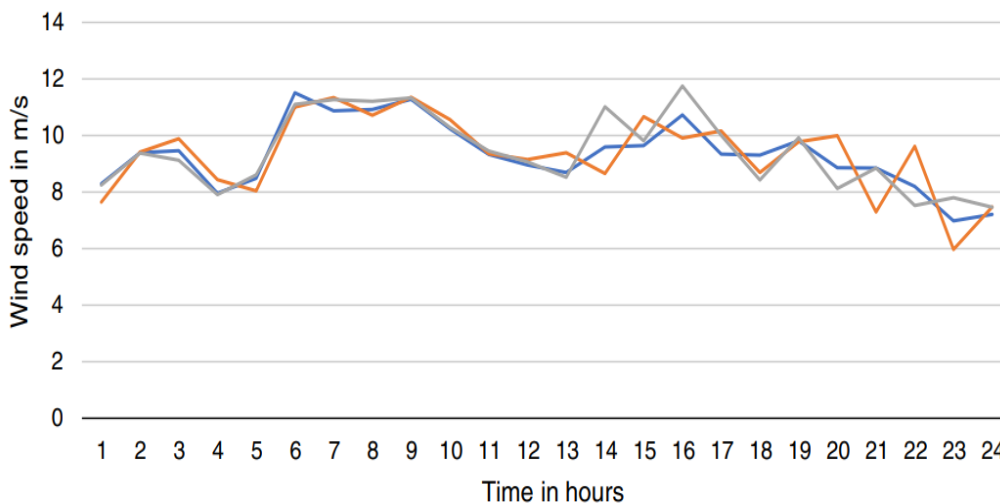


Fig. 5. Predicted wind speed of proposed test System

Table 3: Wind power generation of proposed test system

Hour (h)	Wind 1 (MW)	Wind 2 (MW)	Wind 3 (MW)
1	220	220	200
2	250	250	250
3	260	270	300
4	230	250	250
5	240	250	230
6	400	450	380
7	360	400	400
8	360	390	350
9	450	450	450
10	320	320	350
11	280	280	280
12	260	260	265
13	250	248	280
14	300	380	250
15	300	300	350
16	350	420	310
17	280	330	340
18	280	240	250
19	300	300	300
20	250	220	310
21	300	300	200
22	220	200	350
23	170	200	140
24	180	190	200

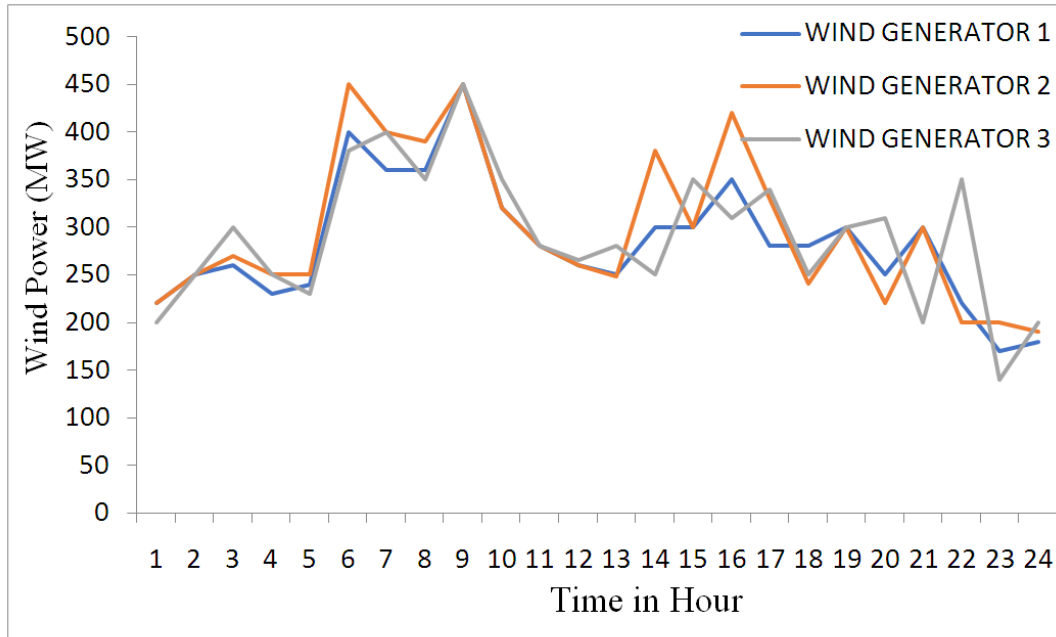


Fig. 6. Wind power generation of proposed test system

Table 4: Simulation results of ATC using proposed WOA

Hours	Linear programming Method	Dragon fly algorithm	Whale Optimization algorithm (Proposed Method)	
			Wind Generators Only (Case 1)	Wind with FACTS Devices (Case 2)
1	1169.4	1323.81	1407.49	1414.633
2	1491.2	1539.3	1569.557	1594.13
3	1463.7	1545.04	1382.08	1507.5061
4	1447	1530.26	1400.342	1557.099
5	1458	1539.98	1518.682	1554.7184
6	1455	1522.8	1383.226	1539.421
7	1097	1192.8	1254.368	1276.306
8	1048	1146.5	1232.385	1263.9252
9	873	999.1	1044.021	1051.5357
10	703	717.3	790.123	800.8659
11	532	649.492	853.045	856.8083
12	714	804.6	863.143	890.7889
13	1394	1438.07	1631.94	1683.8858
14	1415.81	1458.72	1631.169	1665.0018
15	1071.2	1178.7	1270.57	1284.3367
16	937.6	1062.22	1095.53	1106.2562
17	997.3	1133.72	1280.12	1284.5816
18	778.1	864	877.11	887.1585
19	591.9	707.41	732.63	771.3571
20	307.5	526.7	569.018	575.1462

21	201.22	369.501	622.93	652.8379
22	10	790.712	797.7129	808.5893
23	923.5	994.63	1095.5034	1182
24	10	1175.6	1184.3524	1184.4244

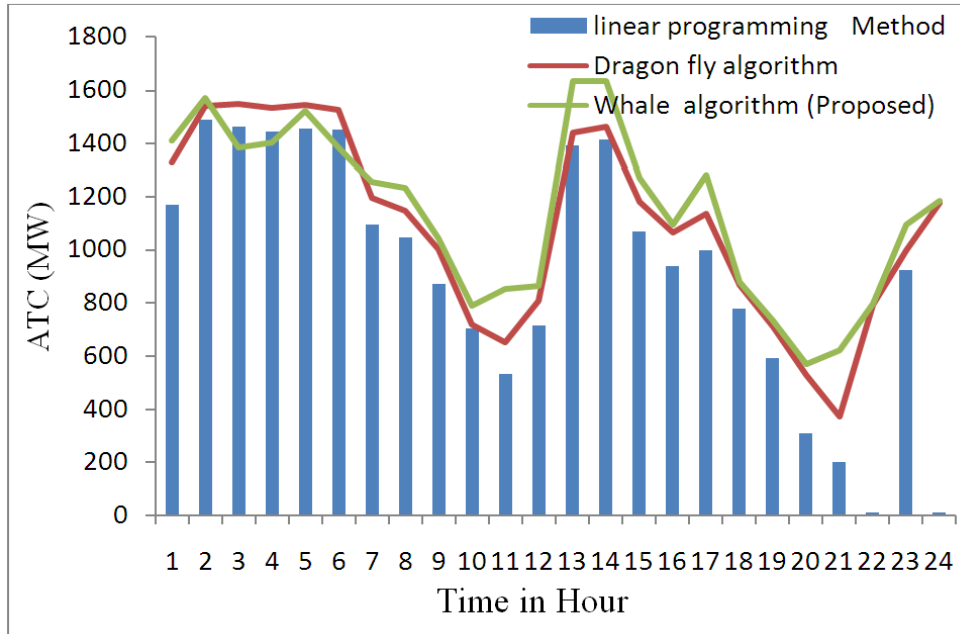


Fig. 7. Comparison of ATC of Proposed method with Existing methods

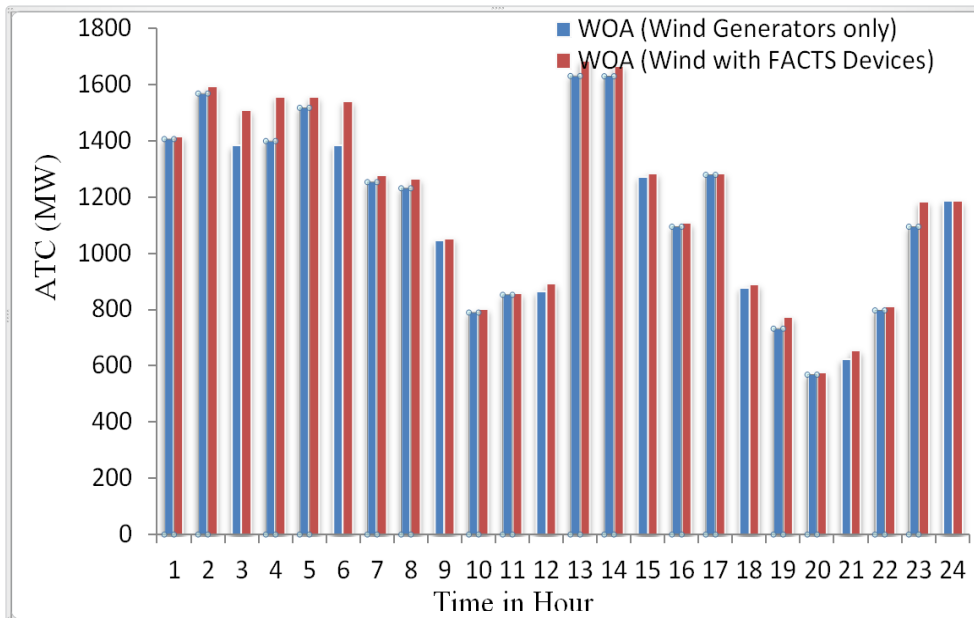


Fig. 8. Comparison of ATC of wind generators and Wind with FACTS Devices (Case 1 and Case 2)

Wind speed data has been collected from multiple locations within Great Britain, spanning the years 2011 to 2019. This data serves as the foundation for predicting wind speeds through the utilization of a neural network model, specifically the Neural Network-27 architecture. The neural network is trained using the five years of data, specifically

from 2015 to 2019. A total of 43,800 samples are used for training, with a division of 70% for training and 30% for testing.

The forecasted wind speeds at three distinct wind sites are presented in fig. 5. This forecasted wind speed data is then applied to estimate the wind

power output using WOA. The resultant power output from the wind generators is both numerically and visually exhibited in Table 3 and Fig. 6. This comprehensive process facilitates the assessment of wind generator performance based on the predicted wind speeds.

Table 4, presents the simulation outcomes of augmented ATC in a 24-hour timeframe, considering varying load demands. Notably, Case 2, involving wind combined with STATCOMs, exhibits greater ATC compared to Case 1, where only wind generators are used. The outcomes from the test cases are compared with existing approaches of Linear programming method and dragon fly algorithm [18] and shown in same table and graphically displayed in fig.7. The comparison of ATC of wind generators and wind with FACTS devices (Case 1 and Case 2) using proposed WOA is graphically displayed in fig. 8. From these findings, the proposed approach effectively improves the value of ATC for different load and different time period.

5. Conclusion

The status of ATC required should be informed well in advance by the system operator is crucial for effective transaction rescheduling and to avert congestion in the transmission systems. This work has been coined with a WOA method to enhance ATC and voltage profile of the transmission system using STATCOM with the integration of wind generators. The problem is modelled as a dynamic day ahead by including the effects of different benefit margins. The problem formulation adopts a dynamic day-ahead perspective, accounting for the influences of various benefit margins. The developed methodology is extensively tested on a modified IEEE-39 bus system, spanning a 24-hour period. The outcomes of the simulations vividly showcase the feasibility and practicality of the proposed method.

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References

- [1] Chansareewittaya, S. and Jirapong, P., 2015. Power transfer capability enhancement with multitype FACTS controllers using hybrid particle swarm optimization. *Electrical Engineering*, 97, pp.119-127.
- [2] Nireekshana, T., Rao, G.K. and Raju, S.S., 2016. Available transfer capability enhancement with FACTS using Cat Swarm Optimization. *Ain Shams Engineering Journal*, 7(1), pp.159-167.
- [3] Gupta, A. and Kumar, A., 2016. Impact of TCSC installation on ATC in a system incorporating wind and hydro generations. *Procedia Technology*, 25, pp.743-750.
- [4] Chen, H., Fang, X., Zhang, R., Jiang, T., Li, G. and Li, F., 2018. Available transfer capability evaluation in a deregulated electricity market considering correlated wind power. *IET Generation, Transmission & Distribution*, 12(1), pp.53-61.
- [5] Shukla, D., Singh, S.P. and Mohanty, S.R., 2018, December. Optimal strategy for ATC enhancement and assessment in presence of facts devices and renewable generation. In *2018 20th National Power Systems Conference (NPSC)* (pp. 1-6). IEEE.
- [6] Kou, X. and Li, F., 2018. Interval optimization for available transfer capability evaluation considering wind power uncertainty. *IEEE Transactions on Sustainable Energy*, 11(1), pp.250-259.
- [7] Karuppasamyandian, M., Jeyanthi, P.A., Devaraj, D. and Selvi, V.A.I., 2021. Day ahead dynamic available transfer capability evaluation incorporating probabilistic transmission capacity margins in presence of wind generators. *International Transactions on Electrical Energy Systems*, 31(1), p.e12693.
- [8] Sun, X., Tian, Z., Rao, Y., Li, Z. and Tricoli, P., 2020. Probabilistic available transfer capability assessment in power systems with wind power integration. *IET Renewable Power Generation*, 14(11), pp.1912-1920.
- [9] Mohammed, O.O., Mustafa, M.W., Aman, M.N., Salisu, S. and Otuoze, A.O., 2020. Capacity benefit margin assessment in the presence of renewable energy. *International Transactions on Electrical Energy Systems*, 30(9), p.etep12502.
- [10] Shukla, D., Singh, S.P., Thakur, A.K. and Mohanty, S.R., 2020. ATC assessment and enhancement of integrated transmission and distribution system considering the impact of active distribution network. *IET Renewable Power Generation*, 14(9), pp.1571-1583.
- [11] Narain, A., Srivastava, S.K. and Singh, S.N., 2022. Impact of wind power generation on

- ATC calculation with uncertain equal load. *Electrical Engineering*, pp.1-9.
- [12] Narain, A., Srivastava, S.K. and Singh, S.N., 2021. An ATCDF approach for ATC enhancement using charging/discharging of wind-battery system considering wind direction and wake effect of WTs. *International Transactions on Electrical Energy Systems*, 31(11), p.e13086.
- [13] Narain, A., Srivastava, S.K. and Singh, S.N., 2021. A novel sensitive based approach to ATC enhancement in wind power integrated transmission system. *SN Applied Sciences*, 3, pp.1-10.
- [14] Majumdar, K., Roy, P.K. and Banerjee, S., 2021. Implementation of multi-objective chaotic mayfly optimisation for hydro-thermal-solar-wind scheduling based on available transfer capability problem. *International Transactions on Electrical Energy Systems*, 31(11), p.e13029.
- [15] Mohammed, O.O., Mustafa, M.W., Salisu, S., Memon, A., Hussain, S., Otuoze, A.O. and Ibrahim, O., 2022. Assessment of the influence of wind energy incorporated capacity benefit margin in ATC computation. *Int. J. Appl. Power Eng.(IJAPE)*, 11(2), p.145.
- [16] Mirjalili, S. and Lewis, A., 2016. The whale optimization algorithm. *Advances in engineering software*, 95, pp.51-67.
- [17] Ning, G.Y. and Cao, D.Q., 2021. Improved whale optimization algorithm for solving constrained optimization problems. *Discrete Dynamics in Nature and Society*, 2021, pp.1-13.
- [18] Karuppasamyandiyan, M., Jeyanthi, P.A., Devaraj, D. and Selvi, V.A.I., 2021. Day ahead dynamic available transfer capability evaluation incorporating probabilistic transmission capacity margins in presence of wind generators. *International Transactions on Electrical Energy Systems*, 31(1), p.e12693.
- [19] Milano, F., 2008, April. Assessing adequate voltage stability analysis tools for networks with high wind power penetration. In *2008 Third International Conference on Electric Utility Deregulation and Restructuring and Power Technologies*, pp. 2492-2497. IEEE.