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Optimization of Wind Turbine Connections in Wind Farms

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ABSTRACT

The increase in specific diseases and the expansion of environmental pollution have drawn more attention to these destructive phenomena. Thermal power plants, as sources of pollutant gas emissions, are recognized as contributors to global warming and environmental degradation. Although wind power plants contribute to reducing environmental pollution by supplying the power system load, the random and unpredictable nature of wind increases the output power variability of these plants, raises system risk levels, and complicates their operation. The economic distribution of energy, the design of internal farm networks, and the calculation of system costs have become additional topics of study in new networks. This article focuses on optimizing the connections of wind turbines in wind farms. Accordingly, the shortest path for transmitting the generated power of wind turbines to the consumption network and the number of paths are determined. A genetic optimization algorithm is used in this process. Simulation results using MATLAB software demonstrate the optimal selection of the number and length of paths in the shortest possible time for a sample wind farm.

1. INTRODUCTION

The layout of turbines in a wind farm is a highly significant issue. The development of wind generation sources in new networks has become a top policy priority. However, the vast area required for wind farms hinders the placement of turbines to ensure a substantial production in the network. Therefore, to achieve a production level of several hundred megawatts from wind farms, it is necessary to formulate the objective functions of wind farm design to increase the turbine rate to the land area belonging to the farm. Notably, the constraints of this issue are the wake effect and the results obtained from wind measurement in the wind farm. After designing the farm and accurately determining the turbine placement, the issue of the electrical connection of wind turbines arises. Given that wind farms typically have wind speeds greater than 8 meters per second, for safety reasons, the power transmission from wind turbines to the network cannot be done via overhead lines. Hence, power transmission must be done underground. Digging and laying cables underground, in addition to the extra cable costs compared to overhead lines, impose additional electrical infrastructure costs on wind farms. Therefore, optimization in determining the shortest path for transmitting the generated power of wind turbines to the consumption network becomes significant.

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Initially, the layout of wind turbines in a farm is influenced by the wind speed and wind arrangement in the farm. The point with the highest average wind power during wind measurement studies is where the most turbines will be installed. It is worth mentioning that in small wind farms, the cabling design usually lacks a specific design, and the internal farm connections become important when dealing with large wind farms. In [1], the authors included the term "large wind farm" in their article title. This article examines the clustering effect of Markov China's wind farm on the dynamic fluctuations of the output power of the plant. They categorized 25 out of 80 wind turbines based on distance and showed how clustering these 25 turbines into three separate groups could reduce dynamic fluctuations in farm power and improve its control performance. In [2] and [3], the optimization of internal cabling in wind farms has been studied. Given the expectation that by 2030, approximately 20% of the electricity in the United States will be sourced from offshore and coastal wind farms, studying this issue to reduce the land area occupied by wind turbines becomes crucial. These references present graphical images of clustering and cabling of the wind farm with the least digging and cable consumption while maintaining energy delivery reliability. In [4], the effect of natural land features such as water routes has been added to the optimization problem of digging and cabling the internal circuit of the wind farm. In [5], the problem was investigated using a specific bird flight algorithm. In [6], the authors introduced the traditional optimization problem of the internal circuit of a wind power plant with the aim of reducing energy losses during the operation period of the production unit and solved this nonlinear problem using their introduced method called linear integer programming. In [7], this problem was solved using mapping theory, leading to the introduction of new problems around the internal circuit of wind power plants in recent years. In [8], the active power control of wind farm production using active control elements in the internal network of the farm and in the presence of wind farm clustering was proposed. The authors divided the internal control system into four levels: turbine performance, wind farm regulation, power collection, and wind energy management to propose their idea. In [9], the same issue was solved by estimating short-term active power and observing reliability constraints while maintaining frequency within nominal limits.

In [10], the voltage sag profile of a wind farm was investigated in a probabilistic environment. Power quality as a criterion for measuring the performance quality of power networks is currently proposed, leading to the addition of elements like FACTS devices to improve the output parameters of wind farms. The fluctuations in wind turbine production power necessitate the installation of FACTS devices to improve stability conditions and operation from this source. Consequently, the performance of FACTS devices on one line of the internal network of a wind farm changes the network impedance, causing serious problems for distance and overcurrent protection which are set based on line impedance. Therefore, in new networks equipped with wind turbines and FACTS devices, there is a serious issue in setting the different zones of distance relays that operate based on the observed network impedance [11]. When a short circuit occurs in the network, this type of relay is responsible for line protection and determining the fault distance to the relay. Generally, the primary protection is handled by distance relays, and the backup protection of the farm is handled by overcurrent relays. This is due to the speed and precedence of the distance relay operation over overcurrent relays [12]. With the continuous change in observed impedance by wind turbines, impedance-sensitive relays malfunction [13-15]. The malfunction of distance relays (as the primary protection of the farm) increases the likelihood of serious damage to the internal network of the wind farm and its turbines [16]. In reference [17], the authors searched for the best cabling route for a depicted wind farm. Naturally, reducing cable length reduces the copper losses of the farm and increases the total farm production, which was considered the evaluation criterion for the study's accuracy.

This article focuses on optimizing the connections of wind turbines in wind farms. Accordingly, the shortest path for transmitting the generated power of wind turbines to the consumption network and the number of paths are determined. A genetic optimization algorithm is used in this process. For this purpose, the modeling of the problem is presented in the second section. The simulation method and its results are presented and analyzed in the third section, and finally, the conclusion is provided in the fourth section.

2. MODELING

In the defined problem of this article, the locations of the branches or internal substations of the wind power plant, as the connection points of the wind turbines or cabling branches, are predetermined. Therefore, after selecting the location of each substation, usually determined optimally based on turbine placement, land features, turbine clustering, etc., the number of internal substations or nodes is denoted by N, and the paths or total edges (or cabling lines) connecting two substations in the overall graph-like plan of the problem are denoted by E in a two-dimensional diagram (with x and y coordinates).

Thus, in this graphical map, there will be edges and nodes that are marked as E and N, respectively. In some nodes (or N), there might be one or two (as the most frequent case) or several edges (or cable lines). Since the location of N nodes is based on the best wind point in the wind farm determined by the wind measurement stage, the placement of each turbine is predetermined based on the problem constraints, and the geographical map of it must be used to draw the entire problem graph. Figure 1 and Table 1 show the location of the substations. In Figure 1, the points marked with circles indicate the location of wind turbines, and the point marked with a square (at the coordinates x=820, y=460) indicates the connection point of the wind power plant to the power system or the PCC.

The well-known problem is to select the shortest path length between the substations depicted in Figure 1, which will be the solution to the problem.

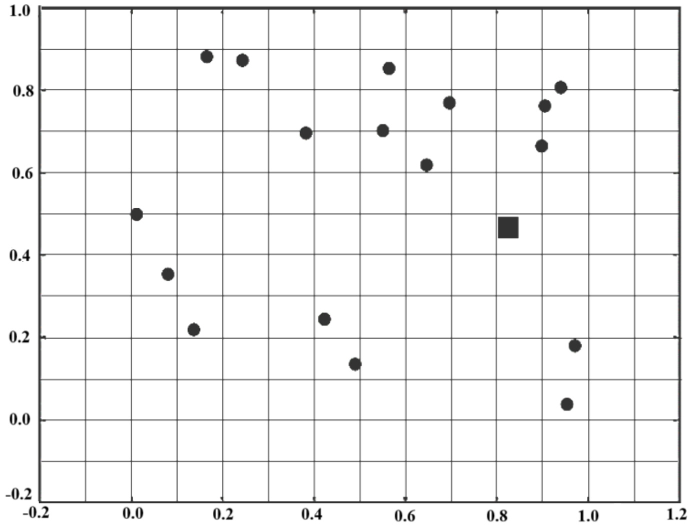

Fig. 1. Test network showing the layout of the wind turbine placement (marked with ●) in a wind farm and the PCC point (marked with ■) as the connection point of this farm to the power system on the Y-X diagram.

Table 1. Geographical positions of the substations and wind turbine branches on the Y-X diagram.

Post Number	X	Y	Post Number	X	Y
1	890	175	10	620	640
2	875	230	11	500	10
3	850	560	12	360	80
4	800	940	13	250	420
5	776	690	14	220	130
6	760	910	15	190	975
7	700	550	16	130	490
8	690	380	17	30	950
9	675	900			

According to the flowchart provided in this article, the optimal routing of any other map can be easily generalized and derived. The overall problem-solving process is listed as follows:

1. Initially, the locations of the posts must be input into the problem-solving computer program. As mentioned, these locations are determined based on feasibility studies conducted in wind measurement studies. In this research, the cable routing is performed using a collective intelligence algorithm as illustrated in Figure 1.

2. Based on the geographical map of the problem, which includes the locations of the posts, a table of geographical locations was prepared. In this article, Table 1 shows the geographical locations of the posts based on X and Y coordinates. It is noteworthy that these coordinates can be easily obtained using GPS as well. The accuracy of this information is a crucial requirement for the computer program.

According to the defined overall flowchart, this section presents the governing relationships in the form of a mathematical model. To minimize the route length, the search algorithm must find the minimum value for the following objective function:

$$min \sum_{i\epsilon L'} \sum_{j\epsilon L'} \sum_{b\epsilon B} t_{ij}.x_{ijb.} \tag{1}$$

where:

$$\sum_{i\in L_n} y_{ni} = 1, \qquad \forall n \in N. \tag{2}$$

$$\sum_{i\in L'} x_{0ib} \leq 1, \forall b \in B. \tag{3}$$

$$\sum_{j\epsilon L} x_{ijb} \leq 1, \forall i \in L, b \in B. \tag{4}$$

$$\sum_{i\in L'} Z_{nbi} \leq 1, \forall n\epsilon N, b\epsilon B. \tag{5}$$

$$\sum_{n\in N, j\in L'} m_{nijb} \leq c, \forall i \in L', b \in B. \tag{6}$$

In this problem, there are 17 posts (turbine locations) and we seek the shortest route length with a maximum of 8 cable routes. Thus, the total minimized route length should be within the range of TL. Therefore, we have:

$$\sum_{i=1}^{N} \sum_{j=1}^{M} \sum_{k=1}^{17} \sum_{L=1}^{8} Z_{ijL}\, S_k \leq TL \tag{7}$$

3. SIMULATION AND RESULTS

Initially, the positions of the posts are introduced into MATLAB software. Based on Table 1, the location data of each post were included in the computer program. Then, using the Line command, the route between the posts is drawn. Figure 2 displays the positions of the posts and the connecting routes from post number 1 to 17 in MATLAB.

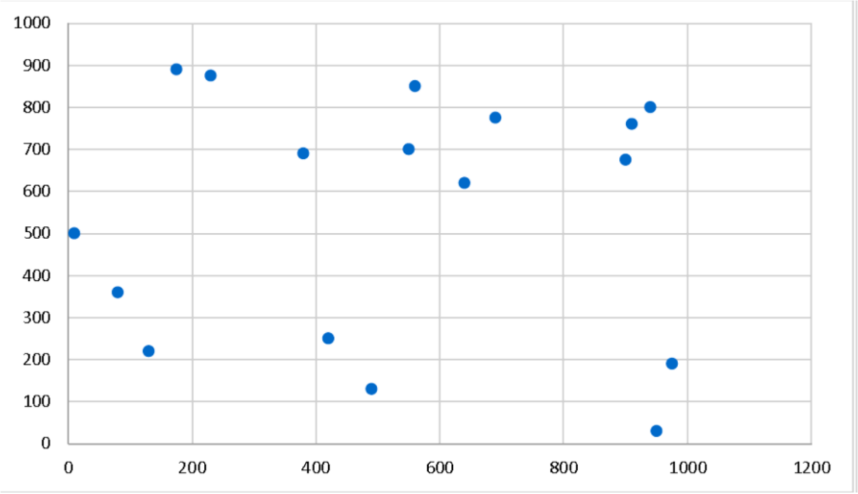

Fig. 2. Graph plotted in MATLAB showing the positions of 17 posts on the geographical map.

To measure the route length between two posts, the following relationship must be used:

L=sqrt(Xij^2+ Yij^2); (8)
Lt=Lt+L;

where Xijis the latitude between two posts, Yijis the longitude between two posts, and \(L\) is the route length between two posts, while Ltis the total length of all routes between the posts. In this study, a Genetic Algorithm optimizer is used to solve the TSP (Traveling Salesman Problem).

Figure 3 shows the performance chart of the Genetic Algorithm for solving the optimization problem. In the first stage, the chromosomes of the first generation create the next generation. The probability of genetic mutation (introduction of a new gene structure), denoted by the parameter Pm is considered very small in this study. Increasing this parameter reduces the likelihood of the algorithm being trapped in local minima but makes the problem-solving process time-consuming and prolonged. In the second stage of the algorithm's performance, the solution extracted from the first stage is evaluated, and the algorithm decides whether to continue solving and producing a new generation or whether the current generation of chromosomes sufficiently meets the stop criteria. If the algorithm's solution is negative, one iteration is added to the problem-solving process, and a new generation of chromosomes is produced with the help of the old generation. It should be noted that a part of the previous generation of chromosomes must also participate in producing the new generation. The reason for this continuous participation is the algorithm's route-solving nature. If the genetic algorithm uses a random function for producing new generations from the second stage onward, it will remain in its initial search and the chromosomes will never mature (approximate the optimal point).

The main question so far is how many turbines should be placed along one cable route? How many wind turbines should each cable route cover? How much power can each cable transfer? What is a cluster? What is a collector? To answer these questions and considering the selected routes, eight scenarios were defined to solve the problem. In scenarios one to eight, to optimally transfer the power of all turbines, one to eight cable routes were selected, respectively.

Table 2 compares these scenarios, and Figure 4 shows the bar chart comparing the total route length traversed in each scenario. In Table 2, the first column from the right indicates the number of cable routes in the test space or the scenario number, the second column shows the number of iterations of the Genetic Algorithm optimizer for each stage, the third column shows the total route length traversed by one or several cable routes in the test space, the fourth column shows the time spent to extract the optimal graph (problem solution), and columns five to twelve show the route length traversed by each cable route (from the longest route to the shortest route).

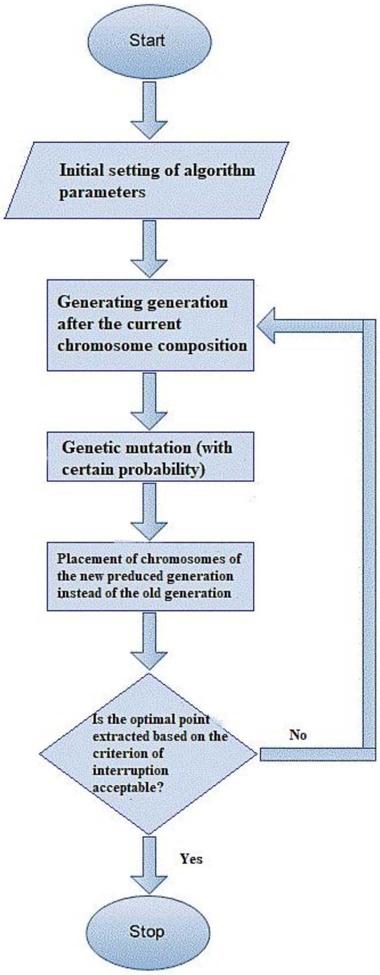

Fig. 3. Problem-solving chart using the Genetic Algorithm optimizer.

Table 2. Information on distances covered in different scenarios

Number of cabling routes	**Number of iterations of the algorithm**	**Total length of the route in kilometers**	**Time in seconds**	**Length of cabling routes from the longest distance to the shortest distance traveled in kilometers**							
				Path 1	Path 2	Path 3	Path 4	Path 5	Path 6	Path 7	Path 8
1	50	3.3933	28.69	3.3933							
2	50	3.2812	39.52	1.6797	1.6015						
3	50	3.2771	61.52	1.6015	1.2023	0.4733					
4	5	3.5443	3.93	1.2023	1.0634	0.8053	0.4733				
5	1	3.5958	8.83	1.3306	1.2023	0.4733	0.3632	0.2294			
6	1	3.8458	7.29	1.2670	0.7917	0.6617	0.4492	0.3650	0.3113		
7	1	4.0270	8.13	1.6015	0.5907	0.4817	0.4492	0.3632	0.3113	0.2294	
8	1	4.5009	8.23	1.0485	1.0269	0.5907	0.4817	0.4492	0.3632	0.3113	0.2294

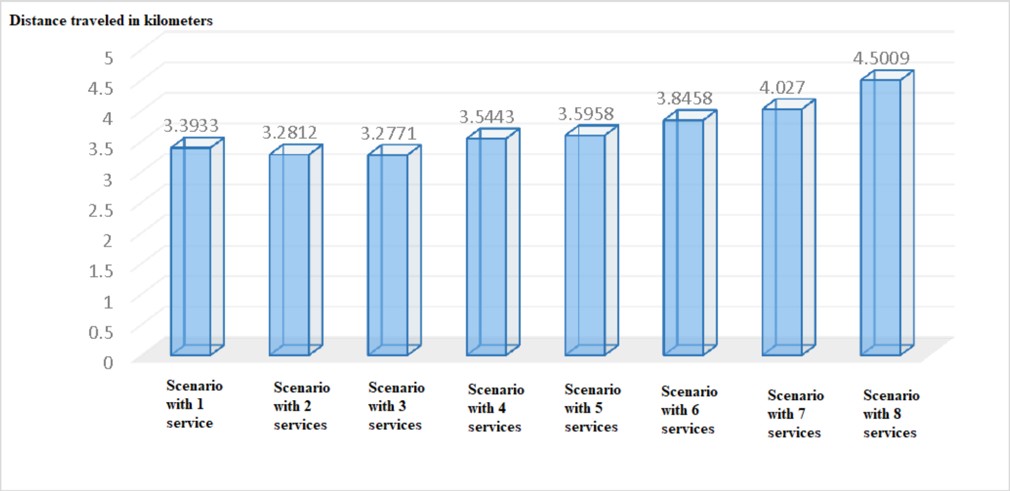

Fig. 4. Comparative distance chart in different scenarios

According to Figure 4, it is observed that in the third scenario, which has 3 cable routes in the test space, the shortest total distance traveled was recorded. In this scenario, the cable routes covered the following distances: Cable Route 1: 1.6015 kilometers, Cable Route 2: 1.2023 kilometers, Cable Route 3: 0.4733 kilometers, amounting to a total of 3.2771 kilometers. It is noteworthy that this solution was achieved in 61.52 seconds. Figure 5 shows the convergence of the proposed third scenario under optimized parameter settings of the genetic algorithm.

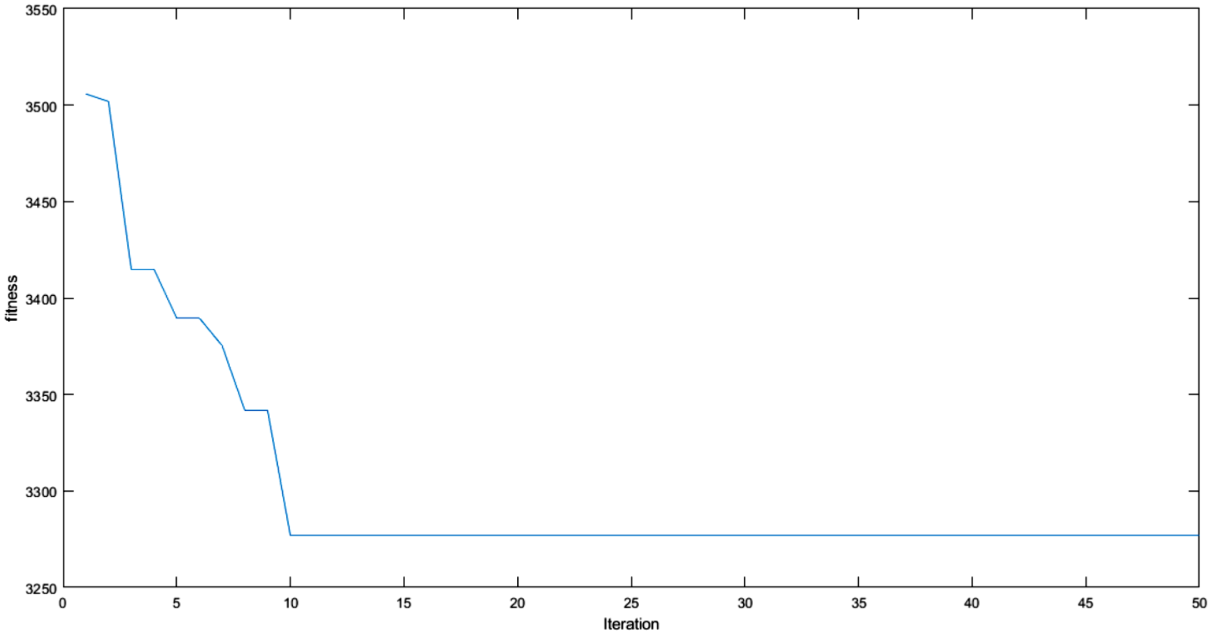

Fig. 5. Convergence of the proposed third scenario under optimized genetic algorithm parameters

4. CONCLUSION

In this study, the optimization of wind turbine connections in wind farms for the test space presented in Figure 1 was considered. Based on this, the shortest route for transferring the generated power of the wind turbines to the consumption network and the number of routes were determined. The genetic algorithm optimization was used in this context. Eight scenarios were defined to analyze the optimal number of cable routes required to solve the optimization problem effectively. The simulation results using MATLAB software demonstrated the optimal selection of the number of routes and the route length in the shortest possible time in the sample wind farm. According to the discussed content, the third scenario, which has 3 cable routes in the test space, recorded the shortest total distance traveled.

Transparency Statement

The data supporting this study are available upon reasonable request to the corresponding author, subject to ethical and confidentiality considerations.

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Declaration of Interest

The authors declare that they have no competing interests.

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REFERENCES

[1] Ma, Y., Runolfsson, T., & Jiang, J. (2011). Cluster analysis of wind turbines of large wind farm with diffusion distance. IET Renewable Power Generation, 5(2), 109–116. https://doi.org/10.1049/iet-rpg.2009.0005

[2] Dutta, S., & Overbye, T. J. (2011). A clustering based wind farm collector system cable layout design. In 2011 IEEE Power and Energy Conference at Illinois (pp. 1–6). IEEE. https://doi.org/10.1109/PECI.2011.5740480

[3] Dutta, S., & Overbye, T. J. (2012). Optimal wind farm collector system topology design considering total trenching length. IEEE Transactions on Sustainable Energy, 3(3), 339–348. https://doi.org/10.1109/TSTE.2012.2185817

[4] Dutta, S., & Overbye, T. (2013). A graph-theoretic approach for addressing trenching constraints in wind farm collector system design. In 2013 IEEE Power and Energy Conference at Illinois (PECI) (pp. 48–52). IEEE. https://doi.org/10.1109/PECI.2013.6506033

[5] Rehman, S., & Ali, S. S. A. (2015). Wind farm layout design using modified particle swarm optimization algorithm. In IREC2015 The Sixth International Renewable Energy Congress (pp. 1–6). IEEE. https://doi.org/10.1109/IREC.2015.7110915

[6] Cerveira, A., de Sousa, A., Pires, E. J. S., & Baptista, J. (2016). Optimal cable design of wind farms: The infrastructure and losses cost minimization case. IEEE Transactions on Power Systems, 31(6), 4319–4329. https://doi.org/10.1109/TPWRS.2016.2521700

[7] Lin, L., Chen, Y., & Wang, N. (2012). Clustering wind turbines for a large wind farm using spectral clustering approach based on diffusion mapping theory. In 2012 IEEE International Conference on Power System Technology (POWERCON) (pp. 1–6). IEEE. https://doi.org/10.1109/PowerCon.2012.6401298

[8] Lin, L., Wang, S., Zhu, C., Li, W., Liu, X., & Xu, L. (2012). Investigation of active power coordination control strategy of wind farm cluster using hierarchical principle. In 2012 IEEE PES Innovative Smart Grid

Technologies (pp. 1–6). IEEE. https://doi.org/10.1109/ISGT-Asia.2012.6303163

[9] Li, D., Wang, S., Lei, W., Tian, C., Yang, H., & Xu, G. (2015). Method for wind farm cluster active power optimal dispatch under restricted output condition. In 2015 5th International Conference on Electric Utility Deregulation and Restructuring and Power Technologies (DRPT) (pp. 1981–1986). IEEE. https://doi.org/10.1109/DRPT.2015.7432563

[10] García-Sánchez, T., Gómez-Lázaro, E., Muljadi, E., Kessler, M., & Molina-García, A. (2016). Statistical and clustering analysis for disturbances: A case study of voltage dips in wind farms. IEEE Transactions on Power Delivery, 31(6), 2530–2537. https://doi.org/10.1109/TPWRD.2016.2522946

[11] Albasri, F. A., Sidhu, T. S., & Varma, R. K. (2007). Performance comparison of distance protection schemes for shunt-FACTS compensated transmission lines. IEEE Transactions on Power Delivery, 22(4), 2116–2125. https://doi.org/10.1109/TPWRD.2007.900283

[12] Abande, G. B., Satarkar, M. F. A. R., Rawoot, M. H., Thakre, M., & Kale, V. S. (2014). Impact of STATCOM on distance relay. In 2014 International Conference on Circuits, Power and Computing Technologies (ICCPCT) (pp. 809–813). IEEE. https://doi.org/10.1109/ICCPCT.2014.7055010

[13] Salemnia, A., Khederzadeh, M., & Ghorbani, A. (2009). Impact of static synchronous compensator (STATCOM) on performance of distance relay. In 2009 IEEE Bucharest PowerTech (pp. 1–8). IEEE. https://doi.org/10.1109/PTC.2009.5282187

[14] Bapiraju, J. V. V. N., Shenoy, J. U., Sheshadri, K. G., Khincha, H. P., & Thukaram, D. (2004). Implementation of DSP based relaying with particular reference to effect of STATCOM on transmission line protection. In 2004 International Conference on Power System Technology, 2004. PowerCon 2004 (Vol. 2, pp. 1381–1385). IEEE. https://doi.org/10.1109/ICPST.2004.1460217

[15] Abbas, A. Y. M., Kalcon, G. O. A., & Sidahmed, A. H. (2014). Impact of static synchronous compensator on performance of distance protection of transmission lines. SUST Journal of Engineering and Computer Science (JECS), 15(1).

[16] Dubey, R., Samantaray, S. R., Panigrahi, B. K., & Venkoparao, G. V. (2015). Adaptive distance relay setting for parallel transmission network connecting wind farms and UPFC. International Journal of Electrical Power & Energy Systems, 15, 113–123. https://doi.org/10.1016/j.ijepes.2014.09.033

[17] Wu, Y.-K., Su, Y.-S., Su, P.-E., & Wu, T.-Y. (2017). Economics- and reliability-based design for an offshore wind farm. In 2017 IEEE/IAS 53rd Industrial and Commercial Power Systems Technical Conference (I&CPS) (pp. 1–9). IEEE. https://doi.org/10.1109/ICPS.2017.7945091