International Transactions on Electrical Engineering and Computer Science
Jaya et.al., Vol: 2, No: 3, pp: 128-138, Sep 2023

Optimal Location Settings for UPFC Using Ant Colony Optimization for Improving Power System Security Under Single Contingencies

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Abstract: Devices referred to as FACTS are utilized extensively in the process of making power system more secure. The UPFC, which contains both shunt and series correction, is one of the FACTS devices that is considered to be among the most successful. The placement of the FACTS device and the values that are selected for its parameters both have a role in determining how successful the device is in reducing security risks. In this study, the ACO approach is presented as a means of optimally positioning UPFC in order to improve the consistency of the power system in the occurrence of single contingencies, also known as an N-1 contingency. In order to guarantee the integrity of the system, the simulation is run on test systems based on the IEEE 6 bus and the IEEE 14 bus, taking into account line overloads and voltage destructions on the bus. This strategy has a two-pronged approach. In the beginning, a N-1 contingency test is carried out based on the severity ranking, and after that, an ACO algorithm is used to install UPFC in the ideal location in order to reduce the severity. In order to further verify the suggested method, the results are matched with the traditional NLP-IP method. This comparison reveals that the new strategy is better in terms of assuring the safety of power systems.

Keywords: Unified power flow controller, Ant colony optimization, Contingency analysis, Power flow analysis, Non linear load

1. Introduction

As a result of the drawbacks associated with the use of fossil fuels, there has been an increase in the need for energy supplies that come from renewable sources.

This element has a considerable influence on the overall security of the power network [1-3]. As a result of the problems that they pose with power quality, grid integration and islanding provide the reviewers with a challenging challenge. In addition, it is not possible to achieve these standards using conventional methods since it would be too expensive [4-6]. Because of this, engineers who work on power systems are always working to strengthen system security restrictions using contemporary methods [7]. Some examples of these constraints are the heat limitations of transmission network and the bus voltage variations that apply when N-1 incidents are present. Utilizing the various FACTS devices is one approach that may be used to resolve the issue described above. These devices not only increase the safety of the system, but they also have various uses in the power grid. Few of these applications include the reduction of oscillations, the improvement of system stability, and the reduction of transmission loss.

Article History
Received: 06-06-2023; Revised: 25-08-2023;
Accepted: 28-08-2023

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TCSC, SVC, STATCOM, and UPFC are just a few examples of the FACTS devices that are used on a regular basis [7]-[12]. The UPFC device is the one with the highest potential among these FACTS apparatus [9]. It is potential to manage voltage variations, reactive power flow, active power flow or any combination of these things, or to control none of them given that no operational restrictions are exceeded, which is the primary benefit of UPFC in comparison to other FACTS devices [14]. This is the primary advantage of UPFC. The efficiency of these devices is determined not only by their placement but also by the parameters they are set to. If these FACTS devices are appropriately situated and calibrated, they have the potential to redistribute the flow of power in the line, which ultimately outcomes in an increase in system security [15], [16].

Combinatorial analysis is used to determine optimum values for parameters as well as appropriate locations. In the recent past, a enormous count of academics have put a variety of different optimization algorithms through their paces in an effort to reduce power system issues utilizing FACTS. Utilizing metaheuristic optimization algorithms such as DE [15], [18], PSO [7], [11], GA [7], [19], Evolutionary programming [17], and ACO [20] is the strategy that is going to prove to be the most effective when dealing with issues of this kind. ACO has the benefit, in compared to the other meta-heuristic algorithms, that if the input varies rapidly, it can run constantly and familiarize to the variations in actual time. This gives it a distinct competitive edge. It has been shown that the ACO procedure is efficient when used to a wide range of challenging combinatorial struggles [21]. ACO is a population dependent technique that was motivated by the hunting behaviour of ants and their innate talent to attain the express route from a food basis to their nest. Ants have an innate capacity to locate the simple way among a source of food and their shell. This method of building is mathematically directed by heuristic intelligence on the given problem occurrence as well as by a collective memory that included encounter collected by the ants in previous iterations [22]-[24]. The basis method that underpins ACO is an iterative technique in which residents of small agents continuously create contestant results. It is clear from the various types of publications that are now accessible that very few study efforts that are cantered on the reduction of power network security by using UPFC with ACO procedures have been documented. Although ACO for UPFC in improving system security is documented in [25], the aim is only stated with loadability constraints in mind and does not take voltage violations into account. Therefore, the determination of this paper is to offer an submission of the ACO approach that seeks to discover the optimum position and tuning of UPFC in order to improve network security restrictions such as the temperature parameters of transmission system and the bus voltage limitations under N-1 different eventualities. The strategy that has been suggested has a dual approach. At the outset, a severity ranking is developed after an N-1 contingency test has been carried out. After that, the ACS algorithm is used to position the UPFC at the best possible location in order to reduce the severity. The technique that has been suggested has been evaluated using the IEEE 6 and IEEE 14 bus test systems. In order to further confirm the findings, it is matched with the traditional NLP-IR approach, which is capable of managing both big issues with sparse information and small problems with a high density of information. At each and every iteration, the algorithm is successful in meeting the limits. The procedure is able to make use of specialized strategies when dealing with issues of a significant magnitude [26].

The following parts of the paper are structured as follows: In the second part, we will take a high-level look at the UPFC and ACO algorithms. The framing of the network security challenge is what Section 3 is all about. The use of ACO for UPFC in the process of improving the safety of the power system is described in Section 4. The fifth section contains both the results and the debates. In the last portion, number 6, conclusions are discussed.

2. Overview of the UPFC and ACO algorithm

The suggested ACO procedure is responsible for determining the ideal position of the UPFC in the integrated system network as well as the optimal parameter settings for it. This is done with the intention of mitigating overloaded lines as well as bus voltage violations caused by N-1 different contingencies. As a result, this part of the article discusses the power flow example of the UPFC and provides a summary of the ACO procedure.

2.1 Power flow model of UPFC

When it comes to the control of power flow and voltage in a transmission line, the UPFC is the FACTS controller that offers the greatest flexibility. Both [13] and [27] published articles that discussed its modeling and integration for power flow research. The analogous circuit and schematic diagram of the UPFC, which may be found in [27-33], have been reprinted here for your convenience in Fig. 1 and Fig. 2, respectively. As can be seen in Fig. 1, it is made up of two VSC, one of which is associated in a shunt, while the another one is attached in a series. Both of these converters share a single capacitor.

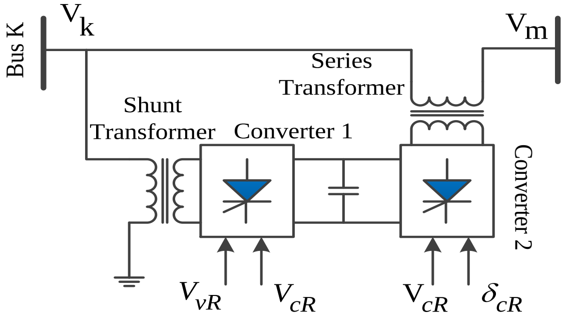

Fig. 1: Schematic diagram of UPFC

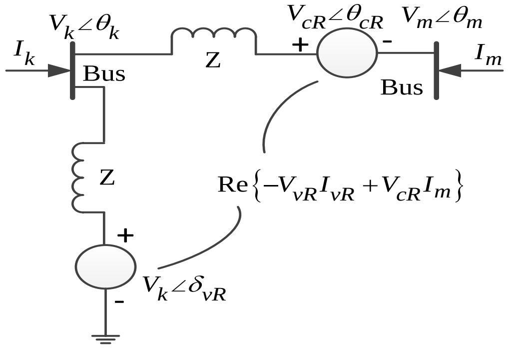

Fig. 2: UPFC equivalent circuit model

The voltage sources are

$$\left.\begin{aligned} E_{vR} &= V_{vR}(\cos\delta_{vR} + j\sin\delta_{vR}) \\ E_{cR} &= V_{cR}(\cos\delta_{cR} + j\sin\delta_{cR}) \end{aligned}\right\} \tag{1}$$

The manner in which the regulation of power flow is carried out is decided upon by the value of δ_{cR}. If there is a need to control the terminal voltage, then δ_{cR} should be in phase with the nodal voltage angle that is measured as θ_k. If there is a 90-degree phase angle variance among δ_{cR} and θ_k, then this variable acts as a phase shifter and regulates active power. It functions as a variable series compensator if, and only if, δ_{cR} makes an angle of 90 degrees with the angle of line current. On the other hand, the quantity of power flow that may be regulated is determined by the size of V_{cR}.

2.2 Overview of ACO algorithm

ACO [22]-[24] is a technique that takes its cues from the natural behaviors of ant colonies, which are communities of ants that live together. For stochastic combinatorial optimization, this strategy is one of the possible methods that may be used. Distributed computing, positive feedback and the use of a beneficial keen heuristic are the three elements that stand out most prominently in this paradigm. The following is an example of a simple ACO algorithm that may be used to determine the path that will result in the least total travel time.

Initialization

The quantity of nodes '$n_{AS'}$', total number of Ants 'm_{AS}', counters for time 't_{AS}' and number of cycles 'NC_{AS}', initial pheromone value 'τ_{ij}' at every edge '*i-j*' and variation in pheromone '$\Delta\tau_{ij}$' is initialized. Then compute the visibility factor *ij*. Later all the ants are randomly placed at every node creating a tabu list.

Ant Cycle

Transfer every ant from the subsequent node 'i' to node 'j' with the chances of $P^k_{ASij}(t)$ as given in (2)

$$P^k_{ASij}(t) = \left\{ \frac{[\tau_{ij}(t)]^{\alpha}[\eta_{ij}(t)]^{\beta}}{\sum k\varepsilon \text{ allowed } k[\tau_{ij}(t)]^{\alpha}[\eta_{ij}(t)]^{\beta}} \right. \tag{2}$$

Where 'α' and 'β' are the considerations that governor the virtual position of provisional versus testing. Keep the point 'j' in tabu list and duplicate this procedure for (n_{AS} -*1*) points. Duplicate the same procedure and fulfil the tabu list for all 'm_{AS}' ants.

Pheromone Updating

Estimate the distance of the circuit illustrated by individual agents. Later renew the variation in pheromone level at each edge *'i-j'* with the tour designated by the k^{th} ant i.e *'L_k'* as follows

$$\Delta\tau_{ij}^{k} = \begin{cases} \dfrac{Q}{L_k} & if\ (i,j)\ \hat{I}\ tour\ described\ by\ tabu_k \\ 0 & otherwise \end{cases} \quad (3)$$

where *' Q '* is the constant and hence $\Delta\tau_{ij} = \Delta\tau_{ij} + \Delta\tau_{ij}^{k}$

For every edge compute the new pheromone level using the formula

$$\tau_{ij}(t_{AS}+n) = \rho.\tau_{ij}(t_{AS}) + \Delta\tau_{ij} \quad (4)$$

where *' ρ '* is the evaporation constantt. Therefore the suggestion of ants is rationalized and the same procedure is duplicated for $'NC_{AS}'$ cycles later draining the tabu list. The best route at the end of $'NC_{AS}'$ cycles is the shortest route.

3. Power system security with UPFC using ACO

This article addresses the issue of power network security by focusing on the prevention of transmission lines being overloaded as well as the maintenance of voltage variations that are kept within acceptable parameters under N-1 different types of emergency scenarios. As a result, the objective function derived from [24] is as described below.

$$Min(F) = W_{t1}\sum_{tl=1}^{NL}\left(\frac{s_{tl}}{s_{tl,max}}\right) + W_v \sum_{i=1}^{Nbus}\left(\Delta V_i\right)^2 \quad (5)$$

$$\Delta V_i = \begin{cases} \dfrac{Vref,\min - Vi}{Vref,\min} & if\ \ Vi < \ Vref,\min \\ 0 \quad\ if\ \ Vref,\min < \ Vi \ < \ Vref,\max \\ \dfrac{Vi - Vref,\max}{Vref,\max} & if\ \ Vref,\min < \ Vi \end{cases}$$

Subject to Equality Constraints

$$\left.\begin{array}{l} P_{Gi} - P_{Di} - |V_i| \sum\limits_{j=1}^{N_{bus}} |Y_{ij}||V_j|\cos(\theta_{ij} - \delta_i + \delta_j) = 0 \\ for\ i = 1,2,3,...,N_{bus};\ i \neq slack\ bus \end{array}\right\} \quad (6)$$

$$\left.\begin{array}{l} Q_{Gi} - Q_{Di} - \left[- |V_i| \sum\limits_{j=1}^{N_{bus}} |Y_{ij}||V_j|\sin(\theta_{ij} - \delta_i + \delta_j) \right] = 0 \\ for\ i = 1,2,3,...,N_{bus};\ i \neq slack\ bus; i \neq P\text{-}V\ bus \end{array}\right\} \quad (7)$$

Eq (6) and (7) is effective for all buses excluding for buses involving lines in which UPFC is fitted. The similarity restraints for the line in which UPFC is associated are given in [18]. Additionallyr, the inequality parameters for all the power network sections containing UPFC is given below from eq. (8) – (14). The inequality constraints are as follows

$$P_{Gi}^{\min} \le P_{Gi} \le P_{Gi}^{\max} \quad (8)$$

$$Q_{Gi}^{\min} \le Q_{Gi} \le Q_{Gi}^{\max} \quad (9)$$

$$T_k^{\min} \le T_k \le T_k^{\max} \quad (10)$$

$$V_{vR}^{\min} \le V_{vR} \le V_{vR}^{\max} \quad (11)$$

$$V_{cR}^{\min} \le V_{cR} \le V_{cR}^{\max} \quad (12)$$

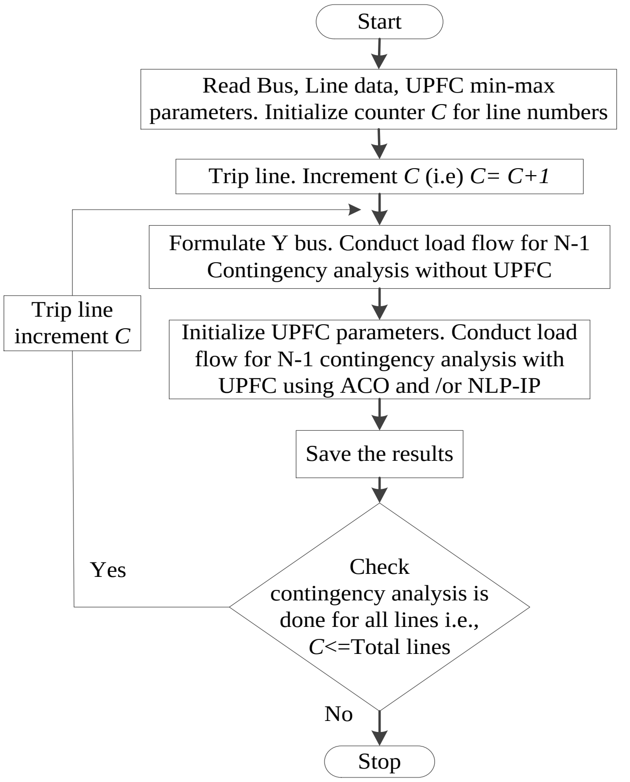

Fig. 3: Flow chart with ACO and UPFC for security improvement

$$\delta_{vR}^{\min} \leq \delta_{vR} \leq \delta_{vR}^{\max} \qquad (13)$$

$$\delta_{cR}^{\min} \leq \delta_{cR} \leq \delta_{cR}^{\max} \qquad (14)$$

4. Implementation of ACO for UPFC to enhance Power system security

Fig. 3 presents the flow chart for the suggested method of ACO for optimum placement and parameter setup of UPFC to increase power system security. This algorithm aims to improve power system reliability. It is clear from looking at the figure that all of the data, including bus and line UPFC parameters, constraints, and so on, are provided at the beginning as input. Then, in order to minimize the objective function (1), the basic case—that is, the situation in which UPFC is not used—as well as the security-enhanced case that is, the case in which UPFC is used—are both conducted for each line outage. The findings are then kept, and the procedure is repeated for each transmission line.

5. Simulation results and Discussion

This section provides an overview of the findings from the study on the Enhancement of Power System Security using UPFC utilizing the ACO method. The suggested methodology is evaluated using the IEEE 6 and IEEE 14 bus test systems. In order to verify the accuracy of the findings, a comparison is made between the results acquired via the use of the NLP-IP approach and the current results. The data pertaining to the IEEE 6 and IEEE 14 bus systems have been obtained from references [28] and [29-37] respectively. The execution of load flow algorithms in MATLAB is facilitated by the use of MATPOWER coding [31-35]. This procedure is carried out on an INTEL Core 2 Duo CPU T5500@ 1.66 GHz processor, running inside the Windows XP Professional operating system. The ACO algorithm's control parameter values include: the number of ants, which is set to 50; the number of cycles, which is set to 300; the pheromone update constant, which is set to 20; the exploration constant, which is set to 1; the global pheromone decay rate, which is set to 0.9; the local pheromone decay rate, which is set to 0.5; the pheromone sensitivity, which is set to 1; and the visibility sensitivity, which is set to 5. The simulation findings for the test systems are categorized into two distinct categories. The first case under consideration is the IEEE 6 bus system, whereas the second case pertains to the IEEE 14 bus system.

5.1 Case 1: IEEE 6 bus system

There are three generators and eleven transmission lines that make up the IEEE 6 bus system. There are eleven different N-1 possibilities. Table 1 displays the outcomes of the performance index and ranking based on bus voltage violations and overloaded lines for all N-1 possible scenarios.

Table 1: Rank for N-1 contingency analysis of Case 1

Outage line	Lines		OLL		VV		PI =	Rank
	From Bus	To Bus	Line No.	Total	Bus No.	Total	OLL+VV	
1	1	2	2,3	2	-	0	2	3
2	1	4	1,3,5	3	-	0	3	2
3	1	5	1,2,6	3	-	0	3	2
4	2	3	-	-	-	0	0	-
5	2	4	2,6	2	4	1	3	2
6	2	5	3,5	2	-	0	2	3
7	2	6	3,9	2	-	0	2	3
8	3	5	3,5,6,9	4	-	0	4	1
9	3	6	3,5,6	3	6	1	4	1
10	4	5	-	0	-	0	0	-
11	5	6	-	0	-	0	0	-

Legend: OLL: Over Load Line, **VV**: Voltage Violation, **PI**: Performance Index

Table. 3: Rank for N-1 contingency analysis of Case 2.

Outage line	Lines		OLL		VV		PI =	Rank
	From Bus	To Bus	Line No.	Total	Bus No.	Total	OLL+ VV	
1	1	2	2,5,7	3	12	1	4	1
2	1	5	1,5	2	12	1	3	2
3	2	3	5,6,7	3	12	1	4	1
4	2	4	5	1	12	1	2	3
5	2	5	-	0	12	1	1	4
6	3	4	-	0	12	1	1	4
7	4	5	-	0	12	1	1	4
8	4	7	-	0	12	1	1	4
9	4	9	-	0	12	1	1	4
10	5	6	7	1	7,12	2	3	2
11	6	11	-	0	12	1	1	4
12	6	12	-	0	-	0	-	-
13	6	13	-	0	-	0	-	-
14	7	8	No feasible solution					
15	7	9	-	0	7	1	1	4
16	9	10	-	0	12	1	1	4
17	9	14	-	0	12	1	1	4
18	10	11	-	0	11,12	2	2	3
19	12	13	-	0	12	1	1	4
20	13	14	-	0	12,13	2	2	3

Number of overloaded lines (OLL) and number of voltage violation buses (VV) are the two components that go into the calculation of the performance index (PI). Outages on lines 8, 9, and 2, 3, 5 are rated first, second, and third, respectively, while outages on lines 1, 6, and 7 are placed third. The results of the basic case (that is, without UPFC) and the security-enhanced scenario (that is, with UPFC) with optimum placement and parameter settings for crucial contingencies are summarized in Table 2. The base case was run without UPFC. It is clear from looking at Table 2 that for line outage 8, without UPFC, the lines 3,5,6 and 9 that are overloaded are those lines. However, with UPFC, the only line that is overloaded is line 3, but it has a lower proportion of overflow. In a similar vein, when it comes to other line outages, UPFC makes it such that the number of overloaded lines and the percentage of overloading are both lower than they would be in the absence of UPFC. In order to demonstrate that the suggested ACO-based security upgrade is effective, it is evaluated using the NLP-IP approach, which is included in Table 2 as well. When compared to the conventional NLP-IP technique, the results achieved by the suggested method are, in every instance, superior to those obtained by the latter. Fig. 4 is an example of the convergence graph for instance 1, which uses ACO and NLP-IP. This particular instance has line 8 as the outage.

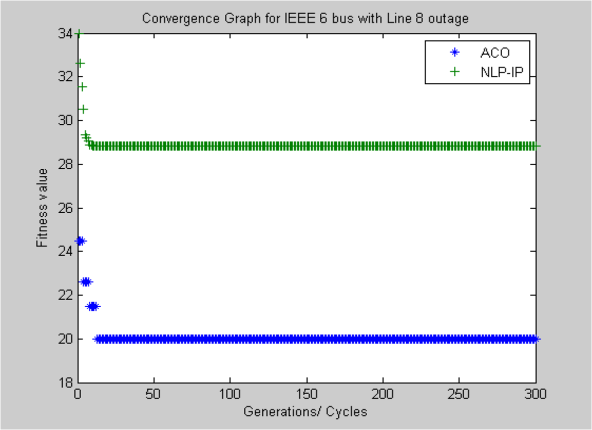

Fig. 4: Convergence Graph for Case 1 IEEE 6 bus with line 8 outage

Table 2: Security enhancement analysis of Case 1.

Without UPFC				**With UPFC**									
				ACO					**NLP-IP**				
Outage Line	**OLL**	**% LL**	**VV**	**UPFC location**	**UPFC settings**	**OLL**	**% LL**	**VV**	**UPFC location**	**UPFC settings**	**OLL**	**%LL**	**VV**
8	3	112.57	-	Line 10	Vvr=1.0493	3	100.47	-	Line 5	Vvr=1.001	2	115.3	-
	5	103.49			Vcr=0.001					Vcr=0.001	3	127.1	
	6	110.83									9	129.6	
	9	106.45											
9	3	106.59	Bus 6	Line 10	Vvr=1.0341	7	117.68	Bus 6	Line 6	Vvr=1.039	2	103.7	Bus6
	5	100.74			Vcr=0.1254					Vcr=0.001	3	133.4	
	6	101.11											
2	1	163.53	-	Line 9	Vvr=1.0543	1	158.39	-	Line 7	Vvr=1.054	1	165.3	-
	3	138.72			Vcr=0.1254	3	135.15			Vcr=0.012	3	148.8	
	5	162.97				5	116.71				5	173.8	
3	1	137.57	-	Line 10	Vvr=1.0500	1	133.51	-	Line 5	Vvr=0.989	1	129	-
	2	108.32			Vcr=0.001	2	105.68			Vcr=0.001	2	121	
	6	117.21											
5	2	155.48	Bus 4	Line 9	Vvr=1.0500	2	113.08	-	Line 2	Vvr=1.181	2	133.7	Bus4
	6	102.34			Vcr=0.001					Vcr=0.067	6	130	
1	2	105.4	-	Line 9	Vvr=1.0500	2	101.7	-	Line 3	Vvr=0.949	2	117.1	-
	3	121.82			Vcr=0.001	3	118.01			Vcr=0.001	3	127.9	
6	3	111.12	-	Line 10	Vvr=1.0500	3	102.62	-	Line 7	Vvr=0.990	3	133.9	-
	5	101.79			Vcr=0.001					Vcr=0.001	5	111.8	
7	3	105.66	-	Line 10	Vvr=1.0274	3	101.55	-	Line 10	Vvr=0.997	3	109.8	-
	9	125.36			Vcr=0.001	9	120.37			Vcr=0.001	9	131.7	

Table 4: Security enhancement analysis of Case 2.

Without UPFC				With UPFC									
				ACO					NLP-IP				
Outage Line	OLL	% LL	VV	UPFC location	UPFC settings	OLL	% LL	VV	UPFC location	UPFC settings	OLL	%LL	VV
1	2	264.82	Bus 12	Line 9	Vvr=1.020	2	263.11	Bus12	Line 9	Vvr=1.020	2	263.1	Bus12
	5	108.32146.68			Vcr=0.001	5	100.12			Vcr=0.001	5	100.1	
	7					7	148.59				7	148.6	
3	5	138.65	Bus 12	Line 6	Vvr=0.984	4	114.76	Bus12	Line 7	Vvr=0.985Vcr=0.001	5	139.6	Bus12
	6	106.37			Vcr=0.001	5	115.65				6	108.5	
	7	103.13				6	108.52				7	100.3	
2	1	121.51	Bus 12	Line 10	Vvr=1.003	1	121.59	-	Line 10	Vvr=0.978Vcr=0.001	1	121.6	-
	5	156.75			Vcr=0.001	5	157.37				5	157.4	
10	7	100.13	Bus7	Line 10	Vvr=1.059	-	-	-	Line 10	Vvr=0.984Vcr=0.001	-	-	-
			Bus12		Vcr=0.001								
4	5	134.3	Bus 12	Line 6	Vvr=0.995	3	103.73	Bus 12	Line 5	Vvr=0.978Vcr=0.001	5	133.9	Bus12
					Vcr=0.001	5	119.47						
18	-	-	Bus11	Line 7	Vvr=0.977	-	-	Bus 11	Line 11	Vvr=1.091Vcr=0.001	-	-	-
			Bus12		Vcr=0.001			Bus 12					
20	-	-	Bus12	Line 7	Vvr=0.951	-	-	Bus 12	Line 7	Vvr=1.050Vcr=0.001	-	-	-
			Bus13		Vcr=0.001								

5.2 Case 2: IEEE 14 bus system

The IEEE 14 bus system has a total of five generators and twenty transmission lines. There are twenty N-1 possible outcomes. Table.3 contains the outcomes of the performance index and ranking based on bus voltage violations and overloaded lines for all N-1 possible outcomes. It may be deduced from Table 3 that there are two scenarios that rank 1 and two that rank 2, and that there are three contingencies that rank 3. Therefore, for Case 2 of the IEEE 14 bus system, the augmentation of security using UPFC is performed only for ranks 1, 2, and 3, and the results are listed in Table 4. Based on the results shown in Table 4, it is clear that for line outage 1, without UPFC, the lines 2,5, and 7 are the ones that are overloaded. With UPFC, the same lines are overloaded, but the overall overflow % is lower. In this particular scenario, the optimum points may be obtained using either the new technique ACO or the more traditional NLP-IP. For line outage 3, the overloaded lines without UPFC are 5,6 and 7, whereas the overcrowded lines with UPFC utilizing ACO are 4,5 and 6, and the overloaded lines using NLP-IP are 5,6 and 7. When compared to NLP-IP, the suggested solution results in much reduced overall overloading. This is likewise the case in the previous scenario. The convergence graph for Case 2, an IEEE 14 bus system with line 4 outage, is shown in Figure 5 as an example case. This case involves ACO and NLP-IP.

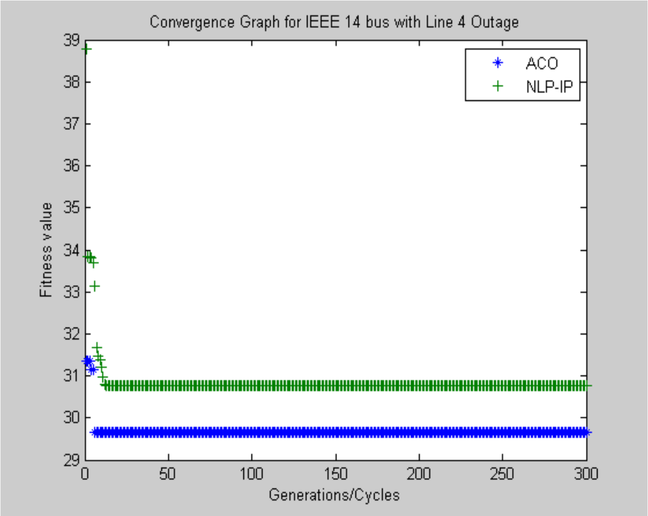

Fig. 5: Convergence Graph for Case 2, IEEE 14 bus with Line 4 outage

6. Conclusion

In this article, the ACO procedure is offered as a method for increasing the safety of power systems by using UPFC. The suggested technique demonstrates the capability of finding ideal parameters for UPFC placement and settings in order to reduce the severity of the power system security issue. The simulation tests that were conducted on both the IEEE 6 bus and the IEEE 14 bus demonstrate that the suggested technique, in most situations, addresses the issue of line overloading and bus voltage violation, and in some cases, reduces the percentage level of overloading in the lines. These studies were carried out using the IEEE 6 bus and the IEEE 14 bus. It has been compared to the traditional NLP-IP approach in order to validate the ability of the proposed method, and the findings suggest that the proposed method is better in all instances. Validating the ability of the proposed method was accomplished via this comparison. The work that has to be done in the future includes determining the best place to put several FACTS devices based on single and multiple-case scenario analyses using a variety of optimization methods.

Conflict of Interest

The authors declare “No conflict of interest”

References

[1] B. Stott, O. Alsac, A. J. Monticelli. “Security Analysis and Optimization”, *Proceedings of the IEEE*, Vol. 75, No. 12, pp. 1623-1644, December 1987.

[2] J. A. Huang, A. Valette, M. Beaudoin, K. Morison, A. Moshref, M. Provencher, J. Sun. “An Intelligent System for Advanced Dynamic Security Assessment”, *Proceedings of the IEEE Power Con 2002, International conference on power system technology*, pp. 220-224, 2002.

[3] Ch. R. Reddy, and K. H. Reddy. "Islanding Detection Techniques for Grid Integrated DG–A Review." *International Journal of Renewable Energy Research (IJRER)*, Vol. 9, No. 2, pp. 960-977, 2002.

[4] Ch. R. Reddy, and K. H. Reddy "A New Passive Islanding Detection Technique for Integrated Distributed Generation System Using Rate of

Change of Regulator Voltage over Reactive Power at Balanced Islanding." *Journal of Electrical Engineering & Technology*, Vol 14, No. 2, pp. 527-534, 2019.

[5] Ch. R. Reddy and K. H. Reddy. "Islanding detection for inverter based distributed generation with Low frequency current harmonic injection through Q controller and ROCOF analysis." *Journal of Electrical Systems*, Vol. 14, No. 2, pp. 179-191, 2018.

[6] J. Zhang, D. Guo, F. Wang, Y. Zuo, H. Zhang "Research on energy management strategy for islanded microgrid based on hybrid storage device." *2013 International Conference on Renewable Energy Research and Applications*, pp. 91-96, 2013.

[7] G. I. Rashed, H.I.S habeen and S. J. Cheng, "Optimal location and parameter setting of TCSC by both Genetic Algorithm and Particle Swarm optimization", *Proc. Of 2nd IEEE Conference on Industrial Electronics and Applications*, pp. 1141-1147, 2007.

[8] F. H. Gandoman, A. Ahmadi, A.M.Sharaf, P. Siano, J. Pou, B. Hredzak, V. G. Agelidis "Review of FACTS technologies and applications for power quality in smart grids with renewable energy systems." *Renewable and sustainable energy reviews*, Vol. 82, pp. 502-514, 2018.

[9] S. K. Behera, N. K. Mohanty "Social welfare maximization with thyristors controlled series compensator using grey wolf optimization algorithm", *International Journal of Electrical Engineering Education*, Vol. 58, No. 2, pp. 209-222, 2019.

[10] K. Bhattacharjee, M. Pant "Hybrid particle swarm optimization-genetic algorithm trained multi-layer perceptron for classification of human glioma from molecular brain neoplasia data", *Cognitive Systems Research*, Vol. 58, pp. 173-194, 2019.

[11] H. Shayeghia, H.A. Shayanfarb, S. Jalilzadehc, A. Safari, "A PSO based unified power flow controller for damping of power system oscillations", *Energy Conversion and Management*, Vol. 50, No. 10, pp. 2583–2592, 2009.

[12] M. Mathur and R.K.Varma "Thyrisor Based FACTS Controllers for Electrical Transmission Systems", *IEEE Press Series on Power Engineering, John Willy & Sons*, New York, 2002.

[13] S. Li, T. Wang, H. Zhang, L. Wang, Y. Jiang, J. Xue "Sensitivity-based coordination to controllable ranges of UPFCs to avoid active power loop flows", *International Journal of Electrical Power & Energy Systems*, Vol. 144, art.no. 105383, 2020.

[14] S. Morsli, O. Bekhechi and A. Chaker "A Fuzzy Tuned Adaptive PI Controller Based UPFC to Improve Power Oscillations Damping in Multi Machine Power System", *International Review on Modelling and Simulations,* Vol. 8, No. 3, pp. 307-314, 2015.

[15] G.I. Rashed, Y. Sun; K.A. Rashed, H.I. Shaheen "Optimal location of unified power flow controller by differential evolution algorithm considering transmission loss reduction", *IEEE International Conference on Power System Technology*, pp. 1 – 6, 2012.

[16] E. Ghahremani and I. Kamwa, "Optimal Placement of Multiple-Type FACTS Devices to Maximize Power System Loadability Using a Generic Graphical User Interface", *IEEE Trans. Power System*, Vol. 28, No. 2, pp 764-778, 2013.

[17] H.I. Shaheen, G. I. Rashed, S.J. Cheng, "Optimal Location and Parameters Setting of Unified Power Flow Controller Based on Evolutionary Optimization Techniques", *IEEE Power Engineering Society General Meeting*, pp. 1 – 8, 2007.

[18] B. Bhattacharyya, V. K. Gupta and S. Kumar "UPFC with series and shunt FACTS controllers for the economic operation of a power system" *Ain Shams Engineering Journal,* Vol. 5, No. 3, pp. 775–787, 2014.

[19] D. Arabkhaburi, A. Kazemi, M. Yari and J. Aghaei, "Optimal Placement of UPFC in Power Systems Using Genetic Algorithm", *IEEE International Conference on Industrial Technology,* pp.1694 – 1699, 2006.

[20] Z. Hamid, I. Musirin, M.M. Othman, and M.R. Khalil, "Optimum tuning of Unified Power Flow Controller via Ant Colony Optimization technique", *4th International Power Engineering and Optimization Conference,* pp.170 – 177, 2010.

[21] C. Erik, and H. Sossa "A comparison of nature inspired algorithms for multi-threshold image

segmentation." *Expert Systems with Applications*, Vol. 40, No. 4, pp. 1213-1219, 2014.

[22] D. Marco, V. Maniezzo, and A. Colorni. "Ant system: optimization by a colony of cooperating agents." *IEEE transactions on systems, man, and cybernetics, part b (cybernetics)*, Vol. 26, No. 1, pp. 29-41, 1996.

[23] M. Dorigo and L. M. Gambardella, "Ant Colony System: A cooperative learning approach to the traveling salesman problem", *IEEE Transaction on Evolutionary Computation*, Vol 6, No.4, pp. 317-365, 1997.

[24] D. Marco and G.D. Caro "Ant colony optimization: a new meta-heuristic." *Proceedings of the 1999 congress on evolutionary computation*, Vol. 2, pp. 1470-1477, 1999.

[25] B. P. Gajanan. "Optimal Location of FACTS Device on Enhancing System Security." *International Journal of Electrical and Computer Engineering*, Vol. 2, No. 3, pp. 309, 2012.

[26] F. A. Porta and S. J. Wright "Interior point methods," *Journal of Computational and Applied Mathematics*, Vol. 124, No. 1-2, pp. 281–302, 2000.

[27] A. N. Niaki and M.R. Iravani "Steady-state and Dynamic Models of Unified Power Flow Controller (UPFC) for Power System Studies", *IEEE Transactions on Power Systems*, Vol. 11, No. 4, pp. 1937–1943, 1996.

[28] Mehrdad Tarafdar Hagh, Manijeh Alipour, Saeed Teimourzadeh, "Application of HGSO to security based optimal placement and parameter setting of UPFC", *Energy Conversion and Management*, Vol. 86, July 2014, pp. 873–885.

[29] S. Dutta, P. Mukhopadhyay, P.K. Roy, D. Nandi "Unified power flow controller based reactive power dispatch using oppositional krill herd algorithm", *International Journal of Electrical Power & Energy Systems*, Vol. 80, pp. 10-25, 2016.

[30] S. Kalyani and K. S. Swarup, " Study of Neural Network Models for Security Assessment in Power Systems", *International Journal of Research and Reviews in Applied Sciences*, Vol. 1, No. 2, pp. 104-117, 2009.

[31] T. Hagh, M. Alipour, and S. Teimourzadeh. "Application of HGSO to security based optimal placement and parameter setting of UPFC", *Energy Conversion and Management*, Vol. 86, pp. 873-885, 2014.

[32] M. Saleh, Y. Esa, N. Onuorah, A. A. Mohamed "Optimal microgrids placement in electric distribution systems using complex network framework." *2017 IEEE 6th International Conference on Renewable Energy Research and Applications*, pp. 1036-1040, 2017.

[33] M. Dávid, M. Kajanová, and P. Braciník "The Impact of Embedded Generation on Distribution Grid Operation." *2018 7th International Conference on Renewable Energy Research and Applications*, pp. 360 -364, 2018.

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