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Optimizing Timing and Preventive Maintenance Activities of Distribution Feeders

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ABSTRACT

Today, one of the most important operating principles in the electricity industry and the electricity distribution network system is preventive maintenance of the network. Considering that most of the unwanted network shutdowns happen due to the lack of timely service of the network equipment and that the consequences of these shutdowns are very costly and troublesome, two issues have been analyzed and investigated in the follow-up: 1. Optimizing the activity maintenance and repair of distribution feeders according to available facilities, forces, and weather conditions. 2. Scheduling maintenance activities according to the importance of feeders. Due to the fact that the number of distribution feeders is large, maintenance costs are also high. In this article, a long-term maintenance plan for distribution feeders has been tried to be presented according to their importance, so that the cost is the total minimum. The proposed method is based on reliability indices to calculate the cost of repairs and maintenance. The proposed method can be a suitable tool for calculating the cost of repairs and maintenance.

1. Introduction

Today, the use of electrical energy has become one of the most basic needs of modern society, with the development of new electrical appliances, the need for power supply with high reliability has increased, hence the management of optimal planning of preventive maintenance activities that lead to Increasing the reliability and increasing the life of the equipment is of great importance. One of the important equipment in the distribution network is aerial feeders. Distribution feeders play an important role in increasing the reliability of the distribution network. In order to maintain the reliability of the distribution network, the inspection, repairs and maintenance of the feeders must be planned regularly and accurately. Risk-based preventive maintenance is an advanced activity of maintenance based on reliability. A series of information about the desired system is used to predict

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the probability of system error, maintenance and repairs using the Optimization results are obtained. Because the reduction in risk depends on the time when a repair and maintenance operation is implemented [1]. In the following, among the works performed in the field of preventive maintenance repairs, the following can be mentioned:

Moon *et al.*, [2] proposed a method to investigate the effects of maintenance strategies on reliability and total cost. This reliability-related method has benefited from the information related to component failures and maintenance methods. In a study by Abiri *et al.*, [3], a long-term airline maintenance planning model was developed based on risk management principles and independent risk factor modelling. The proposed model demonstrated improved computational efficiency compared to conventional dynamic programming approaches. An optimal preventive maintenance planning model based on risk management was proposed by Li *et al.*, [4]. The study addressed the problem using Lagrangian relaxation and dynamic programming techniques. In another study [5], a prioritization-based approach for preventive maintenance planning of transformers in the Gilan distribution network was presented. The proposed method utilized transformer condition data to establish maintenance and repair priorities. In a study by Moon *et al.*, [6], maintenance and repair planning for distribution networks and their equipment [7,8] were developed based on reliability analysis. The proposed approach employed the Markov model for the maintenance and repair of transformers and circuit breakers. In 2007 [9], a maintenance planning method for distribution networks was introduced. The proposed model was based on risk management and steady-state analysis using a tree-diagram approach. Studies by Rahimighazvini *et al.*, [10,11] investigated the application of artificial intelligence in power systems.

Asis *et al*. [12] investigated generation maintenance scheduling in a competitive electricity market. In a centralized environment, the system operator determines and enforces a maintenance scheduling plan for all producers to ensure system reliability while minimizing operational costs. However, such an approach is difficult to implement in a competitive market environment, where each producer aims to maximize its own profit, often conflicting with the operator's objective of maintaining system reliability.

To address preventive maintenance coordination in isolated distributed power systems with wind generation, Duarte *et al*. [13] proposed a risk-based approach. The proposed model coordinates preventive maintenance activities to minimize the probability of load loss within the power system. A sequential Markov Chain Monte Carlo (MCMC) simulation model was employed to quantify system risk. In addition, the nonlinear stochastic optimization problem associated with preventive maintenance scheduling (PMS) of generating units was effectively solved using Particle Swarm Optimization (PSO) and Genetic Algorithm (GA) techniques.

Papadimitrakis *et al*. [14] examined the application of metaheuristic search methods for optimal power flow (OPF), scheduling, and planning problems using a unified framework. The study highlighted the similarities among these optimization problems and comprehensively evaluated various metaheuristic techniques in terms of solution quality, multi-objective optimization performance, and computational complexity.

To model the interactive relationship between energy service providers (ESPs) and users, Huang et al. [15] proposed a two-stage energy management framework. The framework included a multi-objective optimization model for day-ahead scheduling and a Stackelberg game-based dynamic pricing model for real-time energy management. This approach incorporated source-load interaction optimization for hybrid energy systems [16,17] to improve both energy efficiency and operational economy.

The main idea of this article is optimization in two parts, the first part is related to the optimization strategy of preventive maintenance activities of distribution feeders based on blackout and undistributed energy information and the prioritization of existing defects, and in the second part, the optimal scheduling strategy of preventive maintenance activities is based on prioritization of important feeders. Next, in the second part, the optimization strategy of preventive maintenance activities, results and analysis are given. In the third part, reliability indicators have been examined. In the fourth part, the importance and prioritization of feeders has been examined, in the sixth part, the optimal scheduling strategy of preventive maintenance activities has been examined, and in the fifth part, the simulation results of the optimal scheduling strategy of preventive maintenance activities have been discussed. And in the seventh and eighth sections, there are conclusions and references respectively. The data used about blackout and undistributed energy are related to the feeders of Baba Aman substation in Bojnord city in 2014.

At present, the preventive maintenance activities are based on visual inspections, cleaning of equipment, screwing of connections, and practical measurements to identify weak points and damage in distribution network equipment, so that preventive measures can be taken before an accident or error occurs. Nowadays, advanced equipment such as thermovision cameras are used for more accurate prediction of preventive maintenance activities in order to predict faults and errors in the distribution network, the visits made by thermovision cameras in North Khorasan is done periodically for the distribution network equipment and the results are as follows in the incident analysis software:

A) Distribution networks: looseness, corrosion, inappropriate connections, failure and current leakage in cables, failing capacitors, broken arresters, switches whose contacts are damaged or weak, points with excessive heat, overloads Wires that are breaking. b) Contactors and fuse switches: switches whose contacts are damaged, loose fuse switch blades, oxidation, load imbalance, overloads, hot contacts, hot communication cables. c) Transformers: loose shoes, weak connection of cable washers to heated bushings, load imbalance of transformer phases, clogged radiators, determining oil level in transformer.

Due to the fact that the visit of each feeder was done separately, information about the amount of blackout and undistributed energy was extracted from dispatching (event analysis software), then the feeders are visited according to a series of factors such as blackout, energy Not distributed and the importance of each feeder is prioritized. In the same way, 3 feeders were selected from the Baba Aman substation in Bojnord city and using the information obtained from the dispatching unit, including blackout and type of fault in 2014 (this information is related to the visit and service for each feeder separately), it was tried Planning for preventive maintenance activities should be carried out optimally. Figure 1 shows the blackout rate based on the type of Mehnan feeder fault, from Baba Aman substation in 2014.

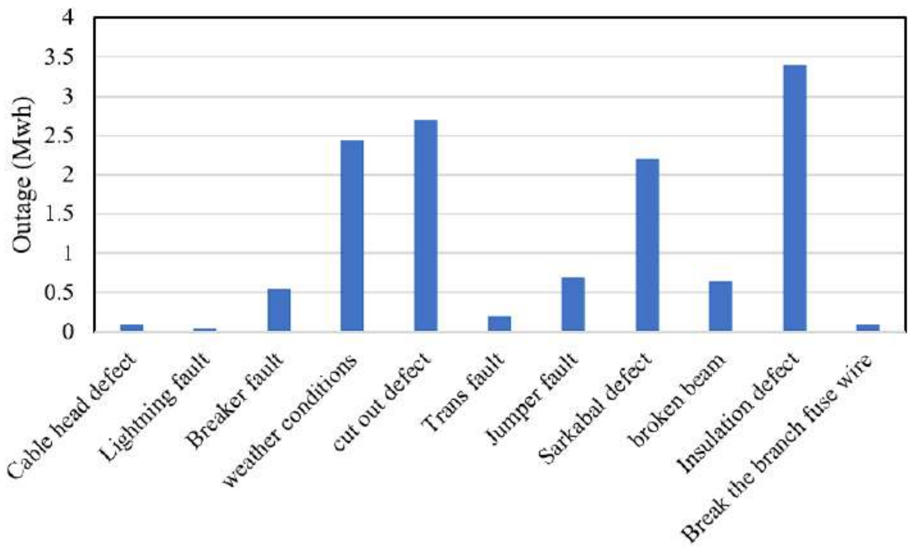

Fig. 1. Diagram of the blackout rate based on the type of fault in Mohnan feeder in 2014

Figures 2 and 3 show the number of outages based on the type of fault of Mehmansara and Sisab feeders from Baba Aman substation in 2014.

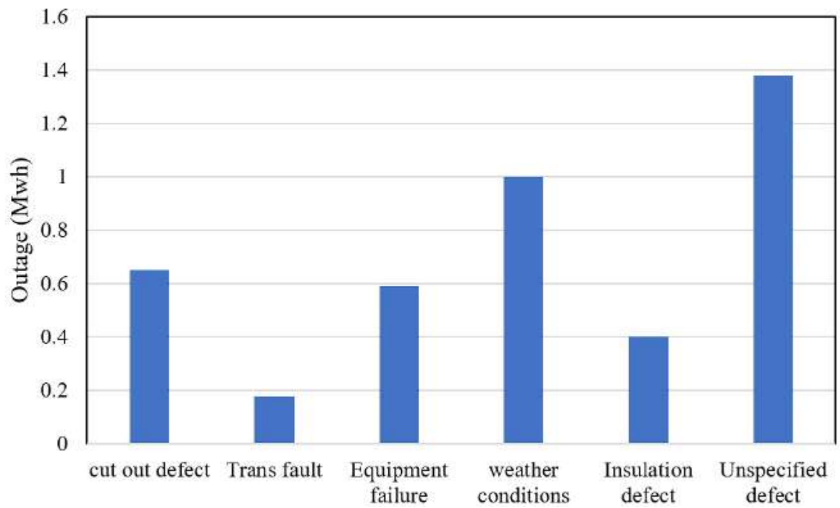

Fig. 2. Diagram of the number of outages based on the type of fault in the guest house feeder in 2014

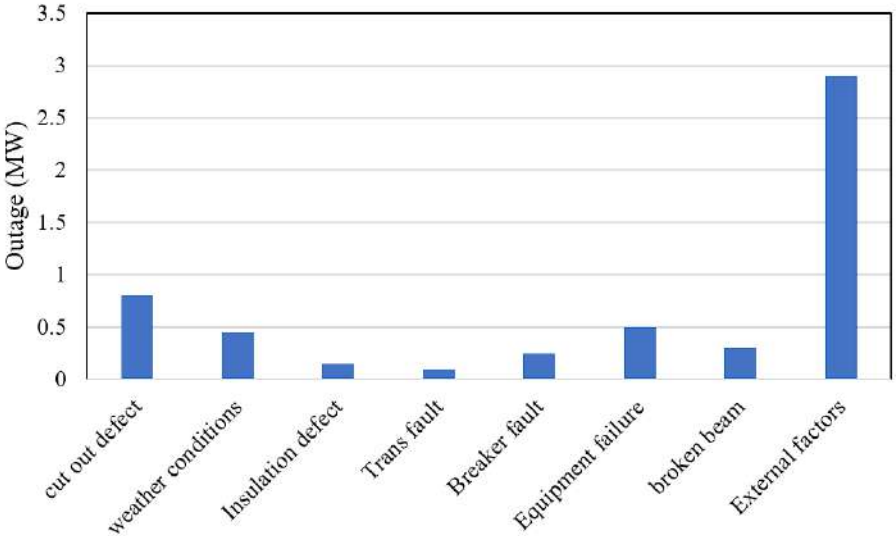

Fig. 3. Diagram of the blackout rate based on the type of fault in Sisab feeder in 2014

After collecting the information related to the number of outages and the type of faults for 9 feeders of Baba Aman substation in Bojnord city, the failures that cause the most outages and are prioritized for preventive maintenance planning are as follows. Loose connections have the greatest impact on outages and undistributed energy, and are a priority for service and maintenance. After loose connections, the most outage statistics are related to broken and cracked insulators in the network, which is placed in the next priority and repair and maintenance service should be taken. In the next prioritization, service and maintenance should be done for disconnecting switches (breaker-sectioners), cut-outs, and arresters, and finally, service and maintenance should be done for transformers, which have a lower shutdown rate than the previous factors. In the visit and periodic service program, the degree of importance of feeders for preventive repairs is different. Some factors determine the importance of important feeders, such as the type of feeder in terms of urban and rural, feeder load, the number of subscribers of each feeder, the length of the feeder. Cities and feeders that supply electricity to very important centers (such as petrochemical, cement factories) are in first priority, and then feeders that feed industrial load centers such as (industrial towns) are in priority. They are placed next, and at the end, the priority is the maintenance program with rural feeders.

2. Reliability indices in the distributed network

The indicators defined in this section include the average system power outage frequency index (SAIFI) and the average system power outage duration index (SAIDI), which are introduced as subscriber-based indicators in the distribution network. In the following, we will introduce each of the indicators [18]:

$$SAIFI = \frac{\sum_i \lambda_i N_i}{N_i} \quad (1)$$

In the above relationship, λ_i is the failure rate of the i-th subscriber and N_i is the total number of subscribers, this index shows how many times each subscriber is disconnected in the time period on average.

$$SAIDI = \frac{\sum_i u_i N_i}{N_i} \tag{2}$$

3. Preventive maintenance activity scheduling strategy

In order to minimize the costs of the objective function, the planning of repairs and maintenance of the objective function and various restrictions and considering the importance of the feeders obtained from the previous section are described as follows:
The objective function is written as equation (3) and consists of two parts, the first part related to maintenance cost and a binary decision variable, which is one if maintenance is done and zero otherwise. The second part of the relationship related to the repair cost multiplied by the failure rate of feeder i in period t.

$$\sum_{t=1}^{T}\sum_{i=1}^{NF}\sum_{n=1}^{Ndf}\left(\left(MC_i^n(t)\times I_i^n(t)+FC_i^n(t)\times \lambda_i^n(t)\right)\times(1+dr)^{-t}\right) \tag{3}$$

dr: decline rate, $MC^n_i(t)$: total cost associated with nth maintenance on feeder i in period t, FC^n_i: total cost associated with nth fault occurring on feeder i in period t. T: long-term repair and maintenance plan period, NF: number of feeders considered for long-term planning.
Equation (4) shows the budget limitations in maintenance planning.

$$\sum_{i=1}^{NF}\sum_{n=1}^{Ndf}\left(MC_i^n(t)\times I_i^n(t)+FC_i^n(t)\times \lambda_i^n(t)\right)\le MB(t) \tag{4}$$

Ndf: number of affected subscribers, MB (t): budget allocated to maintenance in period t.
Another stipulation is related to the scheduling of maintenance activities of all feeders, all maintenance activities of feeders must be done within a specific period of time (5-year period is considered in this article).

Reliability limits for important and non-important feeders are defined separately, to determine the appropriate interval of repairs and preventive maintenance considering the importance of feeders, SAIFI and SAIDI reliability index for high-priority feeders have a lower value. is, according to relations (5 and 6), the reliability constraints are expressed for important and non-important feeders.

$$\sum_{i=1}^{N_{imp}}\sum_{n=1}^{Ndf}\left(\frac{NC_j^{n,M}}{NC}\times I_j^n(t)+\frac{NC_j^{n,f}}{NC}\times \lambda_j^n(t)\right)\le SAIFI_{imp}(t) \tag{5}$$

$$\sum_{i=1}^{N_{uimp}}\sum_{n=1}^{Ndf}\left(\frac{NC_z^{n,M}}{NC}\times I_z^n(t)+\frac{NC_z^{n,f}}{NC}\times \lambda_z^n(t)\right)\le SAIFI_{uimp}(t) \tag{6}$$

$NC^{n,M}_j$: the number of affected subscribers according to the nth maintenance activity on parameter j. $NC^{n,f}_j$: the number of affected subscribers according to the nth maintenance activity on parameter j. The same parameters are repeated with the same concepts in relation (7) but for non-important feeders. NC: total subscribers.

In the particle community algorithm, each particle is a potential answer to the optimization problem. The particles reach the best location in the search space with the two factors of the best previous experience and the best individual of the group [19]. The position of each particle is determined by two vectors in the search space. Let the position vector X = [x_1, x_2, ..., x_n] and the velocity vector V = [v_1, v_2, ..., v_n]. In this method, each particle corrects its position by means of its current speed, previous experience and the experience of neighboring particles. PB = [pb_1, pb_2, ..., pb_n] is the best position of the i-th particle found so far and GB = [gb_1, gb_2, ..., gb_n] is the best position among all particles. In each iteration, the velocity and position of each particle of sample i is updated using the relation (7 and 8).

$$v_i^{k+1} = \omega v_i^k + c_1 r_1 \left(pb_i^k - x_i^k \right) + c_2 r_2 \left(gb_i^k - x_i^k \right) \tag{7}$$

$$x_i^{k+1} = x_i^k + v_i^{k+1} \tag{8}$$

c_1 and c_2 are the acceleration coefficients and random values with normal distribution in the interval (1 and 0), W is the inertia coefficient, usually in the implementation of the algorithm, it usually decreases linearly from one to values close to zero. In this article, the particle assembly algorithm for the problem of optimal scheduling of repairs and preventive maintenance of distribution feeders is implemented as follows:
First step: determining the parameters of the algorithm, then an initial population of particles with priority positions is generated, which includes the initial maintenance schedule for feeders in 5 years. The repetition index is (k=0).
Second step: by calculating the objective function for the initial population, the fitness of each particle is determined. The objective function for the optimal maintenance scheduling problem is according to equation (3) which is given in section 3.
Third step: in each iteration, the fitness value of each particle is compared with the best fitness of the particle. If the current fitness value of each particle is lower than the value of the best fitness of the particle, that value is set as the current pbest of that particle (minimization problem).
Fourth step: the particle corresponding to the best individual fitness pbest among all particles is selected and is set as the current global best gbest.
Fifth step: The new position of the particles is updated using relations (7 and 8).
Sixth step: If the stop condition is met (the maximum number of iterations), the algorithm ends, otherwise the iteration index is set to k=k+1 and the algorithm continues from the second step.

After the completion of the algorithm, the optimal solution of the problem (the best position of the particle) indicates the optimal timing of the maintenance of the feeders of the distribution network, the corresponding fitness value is the value of the lowest total cost.

4. Simulation results

The studied network is related to Bojnord city and Baba Aman post, which has 9 feeders, at the beginning of the work, they are prioritized according to the method mentioned in the article and is as follows. Feeders are classified based on the points mentioned. For a period of five years, the optimal strategy for scheduling repairs and preventive maintenance for the studied network has been simulated. SAIFI values are considered according to blackout information and undistributed energy for important feeders and 1.5 for non-important feeders. The information related to the maintenance cost for each feeder per kilometer is calculated, then the total cost related to Repairs and maintenance for each feeder is calculated in Rials according to its length and converted into dollars. The sum of the common factors between the three feeders on blackout is shown in Figure 4.

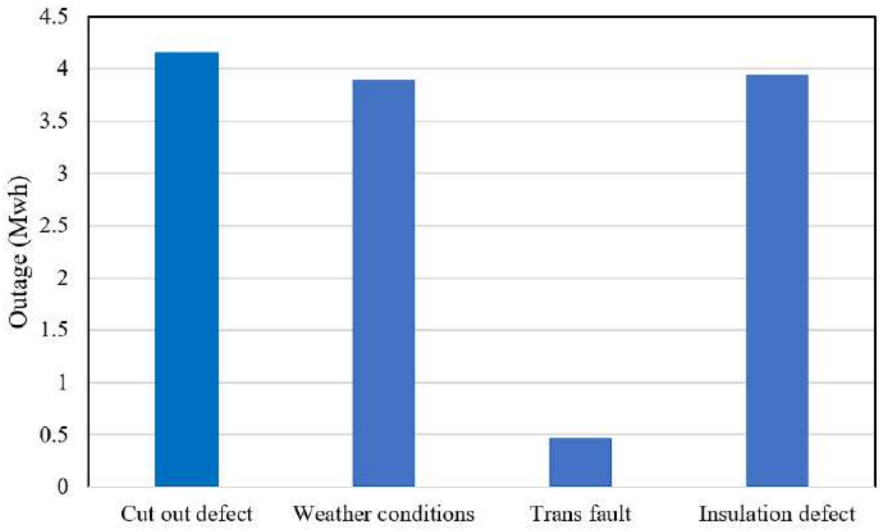

Fig. 4. Sum of the common factors on the blackout of feeders

Figure 5 shows the convergence characteristics of the particle community algorithm.

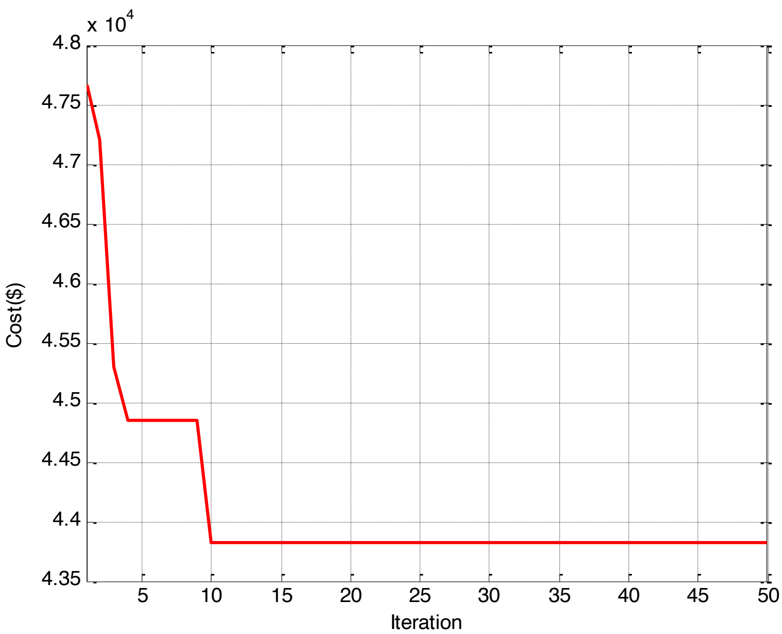

Fig. 5. Convergence characteristic of particle community algorithm

Table 2 shows the results of maintenance activities, including partial and general repairs, and for a period of five years. The cost of preventive maintenance activity strategy is 43816.1653 dollars.

Table 1
Optimum scheduling of maintenance of dams in a 5-year study

Year	Feeder								
	F1	F2	F3	F4	F5	F6	F7	F8	F9
1	1	0	1	0	0	1	0	0	0
2	1	0	0	0	0	0	1	1	0
3	0	0	0	0	1	0	0	0	1
4	0	1	0	0	0	0	0	0	0
5	0	0	0	1	0	0	0	0	0

According to Table 1, it can be seen that all the feeders have been subjected to preventive repairs and maintenance during the study period (5 years), on the other hand, the value of the objective function has been minimized for this planning. In the following, the effect of reliability indicators on the total cost will be examined. In the first part, the value of SAIFI for important feeders was changed from 1 to 1.5 and for non-important feeders from 1.5 to 2, the total cost amount was 43625.3201 dollars. Figure 6 shows the total cost reduction compared to the initial cost.

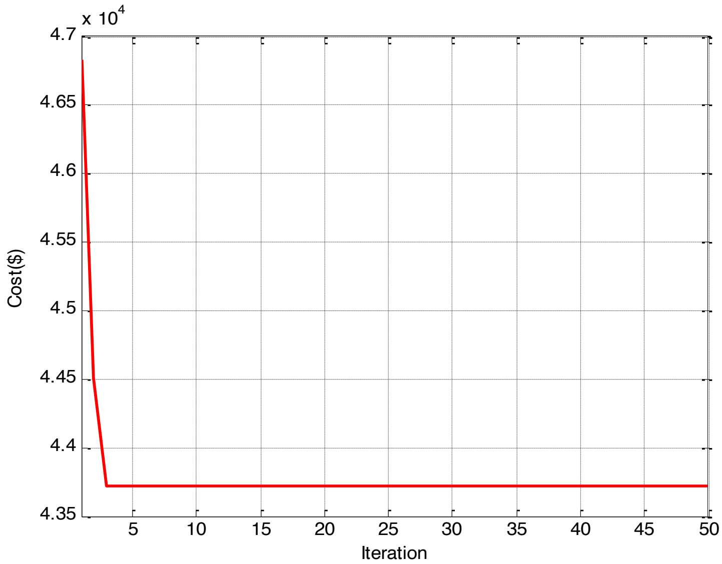

Fig. 6. Convergence characteristic of particle community algorithm

In the second part, the value of SAIFI for important feeders was changed from 1 to 0.5 and for non-important feeders it was changed from 1.5 to 1, the total cost amount was 43982.3512 dollars. Figure 7 shows the cost increase compared to the initial cost.

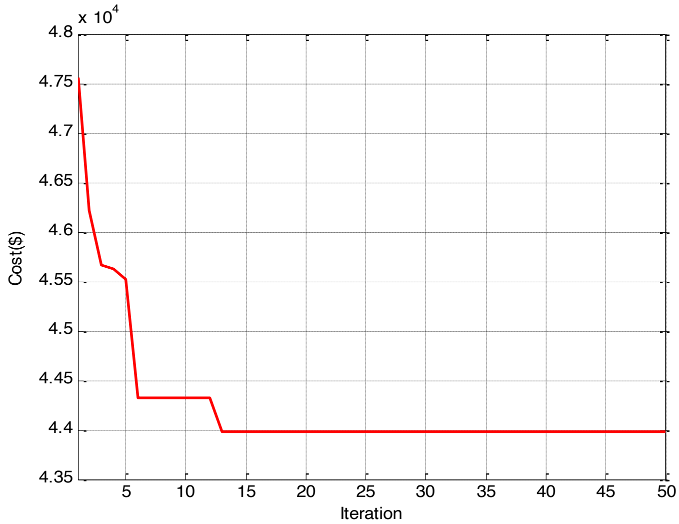

Fig. 7. Convergence characteristic of particle community algorithm

In Figure 8, the value of the cost function resulting from the particle community algorithm method in different scenarios is shown graphically. According to Figure 8 in the first case, the value of SAIFI is considered 1 for important feeders and 1.5 for non-important feeders, the value of the cost function is $43816.1653. In the case of the second study, the value of SAIFI is considered 1.5 for important feeders and 2 for non-important feeders, the value of the cost function is $43625.3201. Finally, in the third case, the value of SAIFI has been changed to 0.5 for important feeders and 1 for non-important feeders, the value of the cost function is $43982.3512.

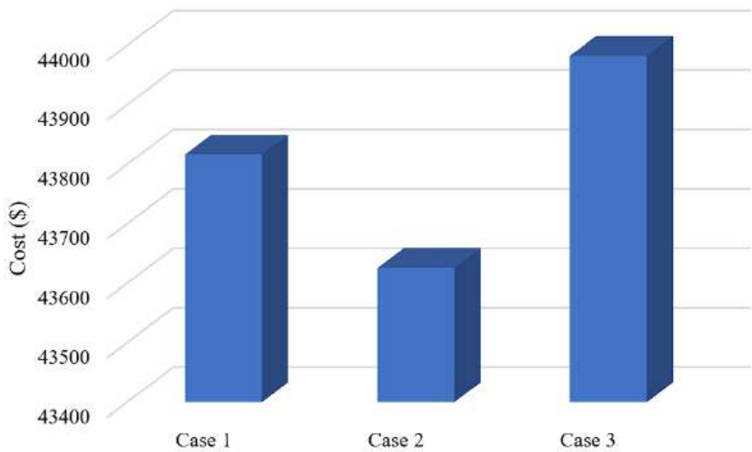

Fig. 8. Comparison of the cost function resulting from the particle community algorithm in different scenarios

5. Conclusion

One of the ways to increase reliability in the distribution network is to perform preventive maintenance activities. The purpose of this paper is to plan preventive maintenance activities for medium pressure feeders of Baba Aman substation in Bojnord city by minimizing the objective function. The objective function of the article includes the costs of repairs and maintenance of feeders. In this article, the feeders are prioritized and based on blackout and undistributed energy information, the value of SAIFI is considered for important and non-important feeders. Then, taking into account the limitations mentioned in the fifth part of the article, planning Long-term repairs and preventive maintenance for feeders have been done at the lowest cost. In the last part, the effect of changing reliability indicators for feeders in the objective function (total cost) has been investigated. The proposed method can be a suitable tool for calculating the cost of repairs and maintenance.

References

[1] Bertling, Lina, Ron Allan, and Roland Eriksson. "A reliability-centered asset maintenance method for assessing the impact of maintenance in power distribution systems." *IEEE Transactions on power systems* 20, no. 1 (2005): 75-82. https://doi.org/10.1109/TPWRS.2004.840433.

[2] Moon, Jong-Fil, Jea-Chul Kim, Hee-Tae Lee, Sang-Seung Lee, Yong Tae Yoon, and Kyung-Bin Song. "Time-varying failure rate extraction in electric power distribution equipment." In *2006 International Conference on Probabilistic Methods Applied to Power Systems*, pp. 1-6. IEEE, 2006. https://doi.org/10.1109/PMAPS.2006.360275.

[3] Abiri-Jahromi, A., M. Fotuhi-Firuzabad, and E. Abbasi. "An efficient mixed-integer linear formulation for long-term overhead lines maintenance scheduling in power distribution systems." *IEEE transactions on Power Delivery* 24, no. 4 (2009): 2043-2053. https://doi.org/10.1109/TPWRD.2009.2028785.

[4] Li, Yuan, S. Yeddanapudi, James D. McCalley, Ali A. Chowdhury, and Ward Jewell. "Resource management for distribution system maintenance using optimized risk reduction." In *2006 International Conference on Probabilistic Methods Applied to Power Systems*, pp. 1-6. IEEE, 2006. https://doi.org/10.1109/PMAPS.2006.360279.

[5] Honarmand, M. E., M. R. Haghifam, H. Dousti Barhagh, and R. Pormoozeh Noveiri. "Optimization of distribution transformers maintenance using the ranking method." In *2011 International Conference & Utility Exhibition on Power and Energy Systems: Issues and Prospects for Asia (ICUE)*, pp. 1-5. IEEE, 2011. https://doi.org/10.1109/ICUEPES.2011.6497708.

[6] Moon, Jong-Fil, Yong Tae Yoon, Sang-Seung Lee, Jae-Chul Kim, Hee-Tae Lee, and Geun-Pyo Park. "Reliability-centered maintenance model to managing power distribution system equipment." In *2006 IEEE Power Engineering Society General Meeting*, pp. 6-pp. IEEE, 2006. https://doi.org/10.1109/PES.2006.1709186.

[7] Aryanfar, Mohammad, Ghazal Rahmani-Sane, Milad Hadizadeh Masali, and Ali Mosallanejad. "Application of recovery techniques to enhance the resilience of power systems." In Future Modern Distribution Networks Resilience, pp. 195-213. Elsevier, 2024.

[8] Amini, Shiva, Salah Bahramara, Hêmin Golpîra, Bruno Francois, and João Soares. "Techno-economic analysis of renewable-energy-based micro-grids considering incentive policies." Energies 15, no. 21 (2022): 8285.

[9] Janjic, Aleksandar D., and Dragan S. Popovic. "Selective maintenance schedule of distribution networks based on risk management approach." *IEEE transactions on power systems* 22, no. 2 (2007): 597-604. https://doi.org/10.1109/TPWRS.2007.894863.

[10] Rahimighazvini, Hossein, Milad Hadizadeh Masali, Sahand Saeidi, and Reza Barzegaran. "Disaster impact prediction in the power grid using artificial intelligence based on Texas synthetic grid data replication." World Journal of Advanced Research and Reviews 21, no. 3 (2024): 1631-1641.

[11] Rahimighazvini, Hossein, Zeyad Khashroum, Maryam Bahrami, and Milad Hadizadeh Masali. "Power electronics anomaly detection and diagnosis with machine learning and deep learning methods: A survey." International Journal of Science and Research Archive 11, no. 2 (2024): 730-739.

[12] Assis, Fernando A., Armando M. Leite da Silva, Leonidas C. Resende, Rodolfo AR Moura, and Marco Aurelio O. Schroeder. "Generation maintenance scheduling with renewable sources based on production and reliability costs." *International Journal of Electrical Power & Energy Systems* 134 (2022): 107370. https://doi.org/10.1016/j.ijepes.2021.107370.

[13] Duarte, Yorlandys Salgado, Janusz Szpytko, and Alfredo M. del Castillo Serpa. "Monte Carlo simulation model to coordinate the preventive maintenance scheduling of generating units in isolated distributed Power Systems." *Electric Power Systems Research* 182 (2020): 106237. https://doi.org/10.1016/j.epsr.2020.106237.

[14] Papadimitrakis, M., N. Giamarelos, M. Stogiannos, E. N. Zois, NA-I. Livanos, and A. Alexandridis. "Metaheuristic search in smart grid: A review with emphasis on planning, scheduling and power flow optimization applications." *Renewable and Sustainable Energy Reviews* 145 (2021): 111072. https://doi.org/10.1016/j.rser.2021.111072.

[15] Huang, Yujing, Yudong Wang, and Nian Liu. "A two-stage energy management for heat-electricity integrated energy system considering dynamic pricing of Stackelberg game and operation strategy optimization." *Energy* 244 (2022): 122576. https://doi.org/10.1016/j.energy.2021.122576.

[16] Parsibenehkohal, Reza, Mohsin Jamil, and Ashraf Ali Khan. "A multi-stage framework for coordinated scheduling of networked microgrids in active distribution systems with hydrogen refueling and charging stations." International Journal of Hydrogen Energy 71 (2024): 1442-1455.

[17] Niaki, Ali Akbarzadeh, and Mohsin Jamil. "An efficient hydrogen-based water-power strategy to alleviate the number of transmission switching within smart grid." International Journal of Hydrogen Energy 70 (2024): 347-356.

[18] Yaser, F., A. Z. Azriyenni, and D. Y. Sukma. "Valuation of Reliability Index in Distribution Network 13.8 kV." *Assessment* 10 (2020): 11.

[19] Yu, Xin-mei, Xin-yin Xiong, and Yao-wu Wu. "A PSO-based approach to optimal capacitor placement with harmonic distortion consideration." *Electric Power Systems Research* 71, no. 1 (2004): 27-33. https://doi.org/10.1016/j.epsr.2004.01.002.