IJE TRANSACTIONS A: Basics Vol. 36 No. 07, (July 2023) 1230-1238

International Journal of Engineering

Journal Homepage: www.ije.ir

Optimal Load Shedding for Voltage Collapse Prevention Following Overloads in Distribution System

S. Sundarajoo*, D. M. Soomro

Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia (UTHM), Parit Raja, Batu Pahat, Johor, Malaysia

PAPER INFO

Paper history:
Received 27 July 2022
Received in revised form 23 February 2023
Accepted 06 March 2023

Keywords:
Blackout
Under Voltage Load Shedding
Voltage Stability
Artificial Neural Networks
Distribution Network

ABSTRACT

Load shedding is generally regarded as the final option to evade voltage collapse and blackout following major overloads. The traditional method of load shedding curtails random loads regardless of their importance until the system's voltage is improved. Shedding random loads without considering their priority will lead to power interruption in vital infrastructures. Hence, to improve the existing power system protection scheme, development of a more effective and efficient load shedding method is necessary. In this paper, an optimal under voltage load shedding (UVLS) method is proposed for optimum prediction of amount of load shed and the best location for load curtailment. Moreover, the proposed method is designed to maintain the vital loads in the system during the load shedding process. In this work, the stability index (SI) and feed-forward backpropagation neural network (FFBPNN) were adopted to avoid voltage collapse and blackout by mitigating voltage instability following overloads in distribution system. The performance of the proposed method to several overload scenarios is investigated. Case studies performed on the IEEE 33-bus system exposed significant robustness and performance of the recommended technique. Compared to other approaches, the proposed approach is efficient in counteracting under-shedding occurrence, enhancing the voltage profile, and improving the stability of the system, whilst maintaining vital loads in the system during load shedding.

doi: *10.5829/ije.2023.36.07a.04*

1. INTRODUCTION

In the past several decades, many large-scale blackout incidents have occurred [1]. These incidents are not acceptable because they result in massive catastrophes to society's economic and social advancement. Protection measure via under voltage load shedding (UVLS) is the final and effective option to counteract a voltage instability situation [2]. Moreover, UVLS is used to prevent voltage collapse and power blackouts [3].

Various UVLS methodologies have been used to maintain system stability [4]. The trend of recent studies reflects the development of load shedding methodologies using computational intelligence (CI) methods. Using CI methods, nonlinear problems can be solved effortlessly. Consequently, many researchers have utilized CI methods in order to optimize the load shedding algorithm by minimizing the voltage drop and fulfilling all the constraints [5].

Singh et al. [6] optimized a load shedding problem based on voltage dependent load model, considering the stability constraints using black hole (BH) optimization. A metaheuristic algorithm known as moth swarm algorithm (MSA) was used by sayed et al. [7] to optimally solve a load shedding problem by minimizing the amount of load shed, reducing real power loss, and improving voltage profile. Another metaheuristic algorithm known as, improved moth flame optimization (IMFO), was applied by Sayed et al. [8] to lower the load shedding amount, enhanced the loadability of the network and prevent voltage collapse. Another UVLS method was proposed by Modarresi et al. [9] which has estimateds the load shedding amount based on the local measurements employing an adaptive neuro-fuzzy inference system (ANFIS).

A hybrid technique incorporating genetic algorithm (GA) and particle swarm optimization (PSO) to obtain the optimum amount of load to be shed for overloaded

*Corresponding Author Institutional Email: *he190076@siswa.uthm.edu.my* (S. Sundarajoo)

Please cite this article as: S. Sundarajoo, D. M. Soomro, Optimal Load Shedding for Voltage Collapse Prevention Following Overloads in Distribution System, ***International Journal of Engineering, Transactions A: Basics***, Vol. 36, No. 07, (2023), 1230-1238

systems was presented by Larik et al. [10]. To sum up, the major shared disadvantages of the aforementioned CI based load shedding frameworks were high computational time and pre-mature convergence. These drawbacks can result in non-optimal load shedding.

Cruz et al. [11], applied a reliability index, the system average interruption duration index, known as SAIDI, during load shedding optimization along with PSO to improve the reliability of distribution systems. Javadi and Amraee [12] presented a mixed integer programming (MIP), and loading margin based UVLS model to minimize the amount of load shedding. Tian and Mou [13] proposed a system analysis-based dispersed load curtailment framework in order to prevent voltage collapse by adopting a segmentation technique utilizing voltage control sensitivity. However, these papers did not consider the priority of load (i.e., vital, semi-vital, and non-vital) while applying the load shedding strategy. Thus, the performance of the aforementioned UVLS algorithms may not be adequate.

In order to address this issue, Sarwar et al. [14] used a mixed integer linear programming (MILP) method while considering the load priority and load ranking using voltage stability index. Similarly, by considering the load priority, a method to predict the minimum load shedding amount was reported by Mansouri et al. [15]. However, in the abovementioned papers, overload problems in the distribution system are ignored. Therefore, the effectiveness of these UVLS methods to prevent voltage collapse following overloads in distribution system may not be satisfactory.

From the discussion above, it can be noted that considerable efforts are accomplished to propose new UVLS frameworks. However, a substantial number of past works on load shedding schemes are developed for transmission systems, and only a scant number of past works are reported for distribution systems. Similarly, the voltage stability issues are ignored in most of the previous studies. It is worth noting that the distribution system is close to the electricity users [16]. Thus, distribution system needs utmost attention and robustness. Moreover, distribution system interacts with oversensitive consumers such as health care, industrial and digital loads. The most important aim of the present distribution system is to offer valuable and continuous electricity to the users [16]. Likewise, the electricity users expect the least number of blackouts [17]. Also, the present distribution systems are more severely overloaded to meet the growing load demand. Therefore, the distribution system's stability and protection should be improved.

To satisfy the aforesaid crucial but unaddressed inadequacies, this paper develops an UVLS scheme by adopting stability index (SI) and artificial neural network (ANN) to tackle overloaded situations and prevent voltage collapse in distribution systems. The proposed UVLS technique is applied on a well-known benchmark system, the IEEE 33-bus system with different overload scenarios. The main contributions of this work are three-fold:

- A comparatively minor fraction of the past studies adopted SI as an indicator to determine the stability of buses in the system. Similarly, meager interest has been given to ANN based approaches for UVLS. Therefore, SI and ANN are incorporated for the first time to be applied for a load shedding strategy. By doing so, the computational time is fast, and the result obtained is optimal. Also, this study may assist future works to implement SI and ANN for various optimal load shedding strategies.
- The proposed load shedding framework consists of three main modules, namely SI module (SIM), system load priority module (SLPM), and ANN module (ANNM), to perform optimal load shedding following overloads in the distribution system. By employing these modules, the proposed method can optimally determine the adequate load curtailment amount and the best location for load curtailment whilst preventing under-shedding.
- The proposed algorithm considers the priority of the loads in the system (vital, semi-vital, and non-vital) to avoid power interruption in critical infrastructures such as healthcare facilities during load shedding. This is achieved by using the load priority limit data of the network.

The rest of this article consists of the following sections: Section 2 concisely demonstrates the proposed strategy. Section 3 discusses the efficacy of the proposed technique by simulations on the IEEE 33-bus system. Lastly, section 4 concludes the research paper.

2. PROPOSED METHOD

In this work, the fundamental objectives in designing an optimal UVLS methodology are: (1) to enhance the voltage profile of the system by shedding an optimum amount of load, (2) to find the optimum location to shed the load, and (3) to prevent the vital loads in the system from being shed during the UVLS process. The outline of the suggested UVLS procedure is presented in a block diagram, as exhibited in Figure 1. The details of the modules used in this work are described in the following subsections.

2. 1. Stability Index Module Generally, SI is used to assess the stability condition of the buses in a system [18]. SI will receive real-time voltage of sending and receiving bus, active and reactive power of receiving bus, and the resistance and reactance values of each line from the distribution system data and load flow analysis.

Accordingly, SI can be applied as an indicator in this work to determine the weak buses in the system that could lead to voltage collapse following overloads. By doing so, the optimum locations to shed the loads in the system can be determined. Hence, this paper incorporates the SI as a module known as SIM.

SI is derived from a standard two-bus distribution network, as presented in Figure 2. The equation of SI is stated in Equation (1):

$$SI_r = |V_s|^4 - \left[4\left(P_r x_{ij} - Q_s r_{ij}\right)^2 - 4\left(P_r r_{ij} - Q_s x_{ij}\right)^2\right]|V_s|^2 \quad (1)$$

where, SI_r is the receiving bus's SI value, the sending end bus voltage is V_s, the real power at the receiving bus and the reactive power at the sending bus are P_r and Q_s, respectively. The resistance and reactance of line i – j are r_{ij} and x_{ij}.

Note that larger SI value is required for buses in the system to be stable against voltage instability and prevent voltage collapse when the load demand increases. As a rule of thumb, voltage collapse is expected to occur as the SI value approaches to zero. In order to improve the SI value to a satisfactory value, the system's loading must be reduced. This can be achieved by shedding some loads from certain buses in the system. The total amount of load to be curtailed from the optimum locations identified by the SIM should be determined by applying an appropriate technique. As mentioned earlier, ANN is used as the tool to find the optimum load shedding amount in this work.

2. 2. System Load Priority Module The SLPM is implemented to identify the type of loads in each bus of the system. As mentioned before, the proposed method curtails loads from the non-vital loads at first. Therefore, the type of loads (vital, semi-vital, and non-vital) are required to be known. This is done to prevent the proposed method from shedding vital loads in the network. The type of loads in each bus of the system is categorized according to the importance of the loads. The loads include residential loads, industrial loads, commercial loads, and uninterruptible loads. Uninterruptible loads include health care, navigation, military, and public service loads. The uninterruptible loads are vital loads and should be served without any disconnection. For those purposes, the proposed load shedding method will shed loads in each bus of the system according to the load priority category rather than shedding random loads in each bus. This will ensure the vital loads in each bus of the system to operate without any interruption.

2. 3. Artificial Neural Network Module ANN commences computations to imitate the learning procedures of the human brain [19]. ANN is one of the CI techniques that can be employed as a tool to achieve the optimal solution. As reported by Qiao et al. [20], ANN is the most capable algorithm to curtail loads, which are optimum. For that capability, ANN is implemented to find the optimum load shedding amount in this paper.

The ANNM implemented in this paper retrieves the load priority data from the SLPM. The ANNM plays a significant part in predicting the optimal amount of load to be curtailed from the optimum locations determined by the SIM. Input, hidden, and output layers are the three composition layers required to model a feed forward neural network with error backpropagation learning (FFBPNN).

The input layer is the first layer, the output layer is the last layer, and the layer in the middle of the input and output layer is the hidden layer. Every neuron in a particular layer is linked to each neuron in the following layer. In this paper, the type of training used to train the neural network is known as backpropagation.

Backpropagation is a type of supervised training. The FFBPNN model is designed with two inputs in the input layer and one output in the output layer. The inputs of the

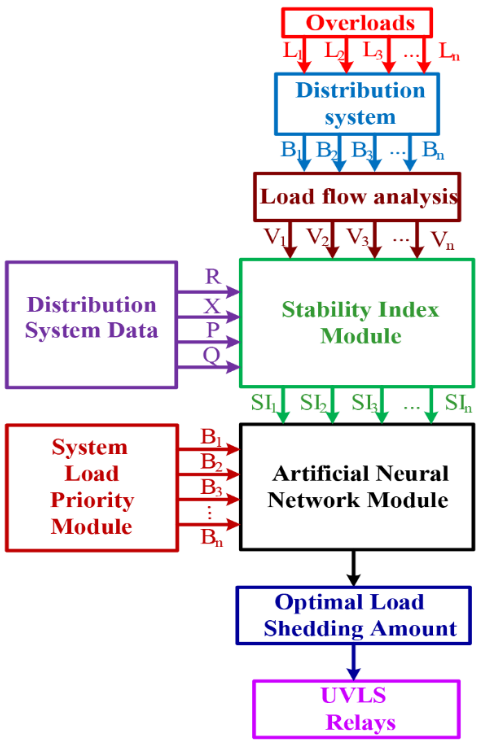

Figure 1. Proposed load shedding scheme outline

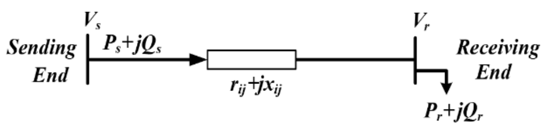

Figure 2. Two-bus system

FFBPNN model are comprised of post-overload active load demand at bus *i*, signified as P_i, and percentage of vital load requirement at bus *i*, represented as X_i. The hidden layers are comprised of one layer of nodes between input and output layers. The output layer of the network consists of one output which is the amount of load to be shed, denoted as P_{shed}. The neural network model used in this module is presented in Figure 3.

The Levenberg-Marquardt (LM) algorithm is utilized to solve the optimization problem in FFBPNN. LM algorithm is one of the most efficient algorithms for fast convergence rate and least error [13, 20]. The training data set is divided into three portions; 70% utilization for training, 15% for validation to decrease overfitting, and 15% for testing to achieve a decisive result. At times, the output of the network may distinguish from the targets after training, especially when the data set varies. Hence, stochastic gradient descent is employed in backpropagation to reduce the error in order to obtain a suitable network output.

The cross-validation methodology is adopted to achieve the finest training. By doing so, the most efficient FFBPNN is stimulated. One hidden layer is kept permanent, while the number of neurons is varied in each trial to obtain the minimum value of the mean square error (MSE). Throughout the procedure of determining the suitable total neurons in the hidden layer, approximately 50 tests were conducted starting from 1 to 50 neurons. Finally, the network with the minimum value of MSE is chosen to be used to obtain the optimal load shedding amount. Figure 4 represents the overall framework of the ANNM for the proposed method. The comprehensive methodology of the recommended approach is shown in the flowchart as presented in Figure 5.

3. SIMULATION RESULTS

To prove the efficacy of the suggested technique, the IEEE 33-bus system, a well-known distribution system,

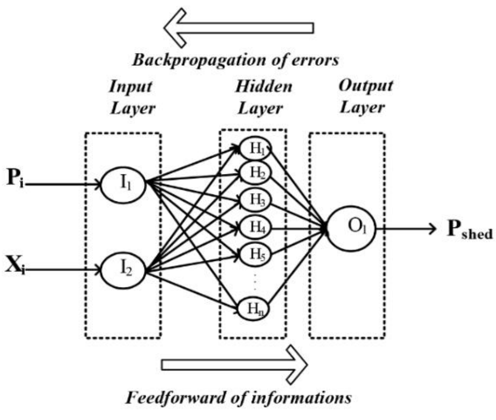

Figure 3. Neural-network model used in ANNM

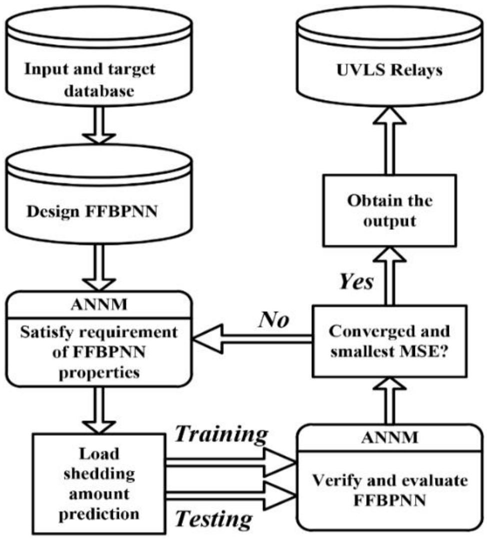

Figure 4. Overall framework of the ANNM

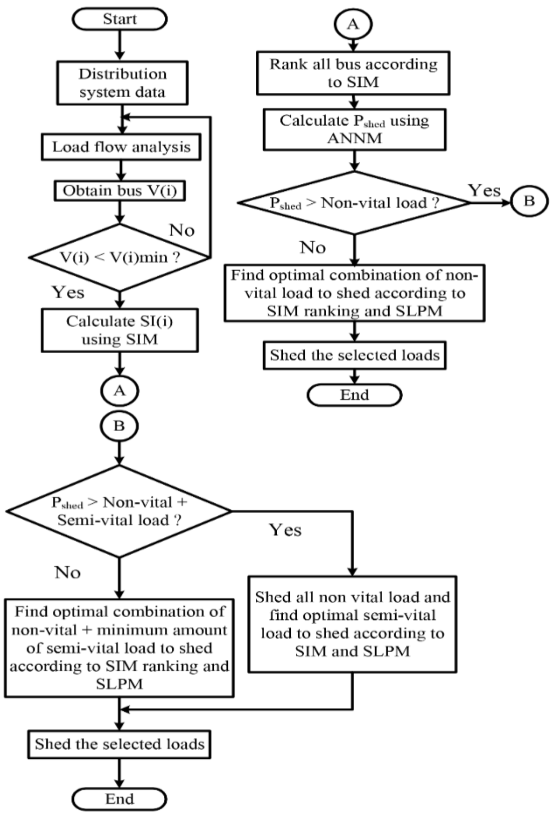

Figure 5. Flowchart of proposed method

is used, as shown in Figure 6. Baran and Wu [21] established the IEEE 33-bus system. The test network comprised 33 buses, 32 branches, and 33 constant loads. The 33-bus system operates at a rated voltage of 12.66kV. The bus data and line data of the 33-bus system were obtained from Montoya et al. [22]. In the original case, the total power demand of the system is 3.715MW and 2.3Mvar. The load priority limits comprising the percentage of vital loads in each bus are listed in Table 1.

To assess the robustness of the proposed method following overloads, three scenarios, namely without overload, 25% overload, and 50% overload, are stimulated. Additionally, four case studies were conducted comprising the aforementioned scenarios to examine the system's response to the proposed load shedding method. The details of the case studies are listed in Table 2. Additionally, the proposed method will be compared with the conventional and PSO based load shedding method to verify the efficacy of the proposed technique at the end of this section.

The simulations are performed in MATLAB environment in a 64-bit computer with i7-4720 2.60GHz CPU and 8.0GB RAM.

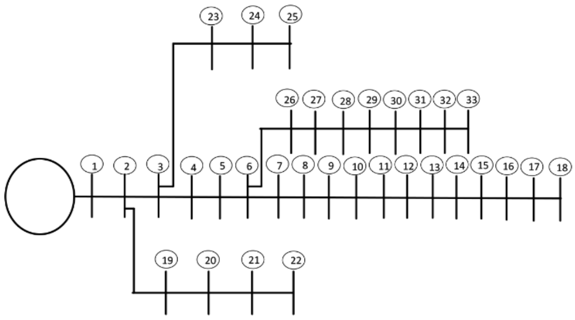

Figure 6. One line diagram of IEEE 33-bus system

TABLE 1. Vital load percentage for IEEE 33-bus

Bus	Percentage (%)	Bus	Percentage (%)
1	0	18	34
2	34	19	60
3	23	20	53
4	64	21	20
5	15	22	50
6	43	23	4
7	35	24	15
8	21	25	10
9	5	26	59
10	21	27	2
11	0	28	28
12	52	29	15
13	11	30	55
14	47	31	25
15	57	32	30
16	61	33	3
17	37		

TABLE 2. Case studies

Case	Description
1	Without load shedding
2	With proposed load shedding technique
3	With conventional load shedding technique
4	With PSO based load shedding technique

3. 1. Case 1: Without Load Shedding The first case for the overload scenarios is without any load shedding method. As the system is exposed to massive overloads, the voltage profile and the SI values of every bus reduce, as shown in Figure 7. In this situation, the voltage profile of the system falls below the allowable limit (0.9 pu) for scenarios with an overload of 25% and 50%. Hence, it is clear that the network requires a load curtailment strategy to prevent voltage collapse and instability.

3. 2. Case 2: With Proposed Method In this case, the proposed method is simulated. The ANN structure used in the proposed method is as presented in Table 3. The proposed method allows shedding of loads at weak buses according to the SIM, while the vital loads in every bus of the system are maintained according to the SLPM. The summary of the proposed UVLS results are presented in Table 4.

Furthermore, Figure 8 shows the voltage profile, the SI values, the percentage of load shed, and the amount of load shed. According to Figure 8, the system's voltage profile is guaranteed for every overload scenario, where the computed voltage of every bus in the system is above 0.92 pu, which is higher than the permissible voltage of 0.9 pu.

3. 3. Case 3: With Conventional Method In this case, the conventional UVLS method was simulated using the voltage levels and the amount of load to be shed for every voltage level as listed in Table 5.

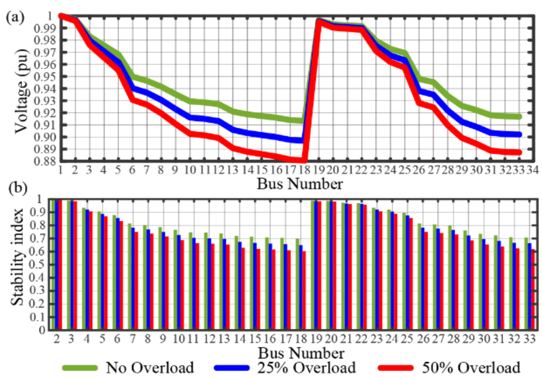

Figure 7. Without load shedding: (a) System voltage profile (b) System SI values

TABLE 3. Neural network training parameters

Parameter	Descriptions
Input layer	1
Input layer neurons	2
Hidden layers	1
Hidden layer neurons	10
Output layer	1
Output layer neurons	1
Layer 1 activation function	Tansig
Layer 2 activation function	Purelin
Performance function	Mean squared error (MSE)
Maximum epoch	1000
Maximum validation checks	6

TABLE 4. Proposed method results summary

Overload scenarios (%)	0%	25%	50%
Total load shed amount (MW)	0	1.18	2.10
Total load shed percentage (%)	0	0.25	0.38
Minimum voltage (pu)	0.91	0.92	0.921

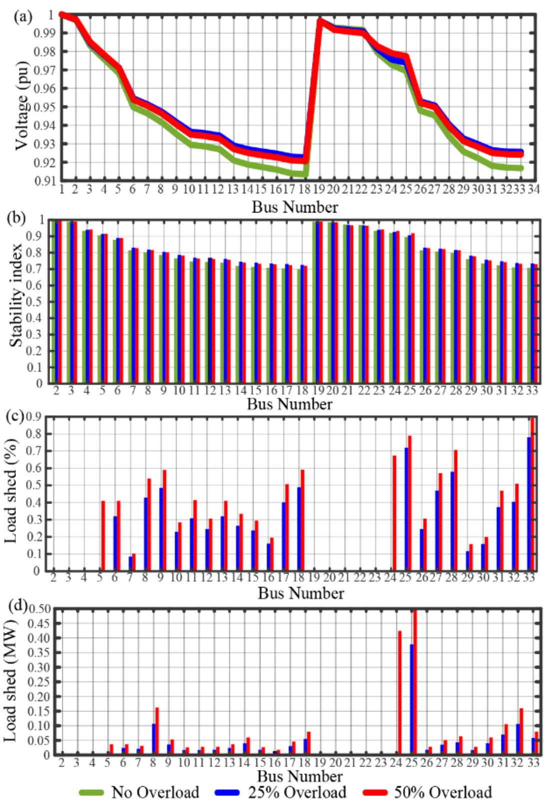

Figure 8. With proposed load shedding method: (a) System voltage profile (b) System SI values (c) Load shed percentage (d) Load shed amount

TABLE 5. Conventional load shedding stages

Stage	Voltage Threshold (pu)	Load Shedding Value (%)
1	0.9	20
2	0.88	20
3	0.86	10

The voltage profile, percentage of load shed, and the amount of load shed with the conventional method are shown in Figure 9, whereas Table 6 summarizes the results obtained using the conventional UVLS method. It is evident from Table 6 that the conventional method shed insufficient amount of load for each overload scenario. This condition is known as under-shedding, which leads to instability of the system and may result in voltage collapse and cascaded blackouts.

3. 4. Case 4: With PSO Method In this case, one of the most employed and well-known CI methods, the PSO algorithm has been utilized for load shedding procedure. The PSO is used to obtain the optimal load shed amount. Minimization of load shedding amount is taken as the objective of the optimization model. By doing so, the

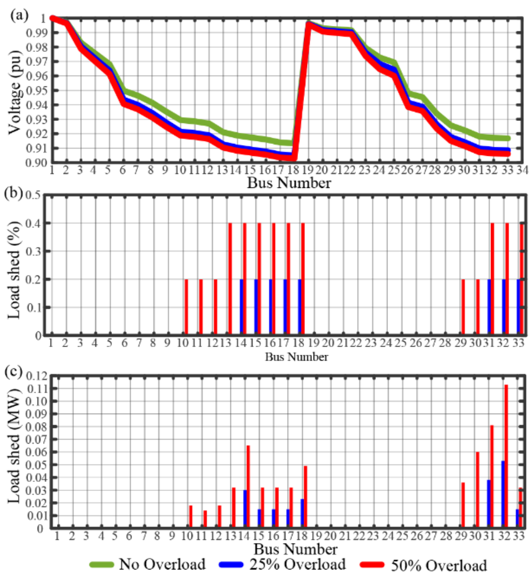

Figure 9. With conventional UVLS method: (a) System voltage profile (b) Load shed percentage (c) Load shed amount

TABLE 6. Conventional UVLS results summary

Overload scenarios (%)	0%	25%	50%
Total load shed amount (MW)	0	0.20	0.62
Total load shed percentage (%)	0	0.04	0.11
Minimum voltage (pu)	0.91	0.905	0.903

PSO based optimal load shedding method is simulated to be compared with the results achieved by the proposed approach for further validation. The voltage profile, load curtailment percentage, and the amount of load shedding obtained utilizing PSO based load shedding method are given in Figure 10. Table 7 summarizes the results obtained using that method. It can be noticed from Table 7 that the PSO based method also resulted in under-shedding and it failed to improve the voltage profile above the acceptable limit.

3. 5. Comparative Study Results A feasible UVLS method should be capable of curtailing the mismatch amount of load and preserving the system voltage to prevent voltage collapse and blackout. The three different methods examined in this paper for scenarios of 25% overload and 50% overload are compared in this section as shown in Table 8.

It can be noticed from Table 8 that the amount of load shed by the conventional technique and the PSO technique are lower than the amount of power imbalance. This creates an under-shedding event due to the inadequate load shedding performed for the overload events. On the contrary, the proposed method does not suffer from under-shedding in every overload scenario. This is due to the ability of the proposed technique to find the load curtailment amount, optimally.

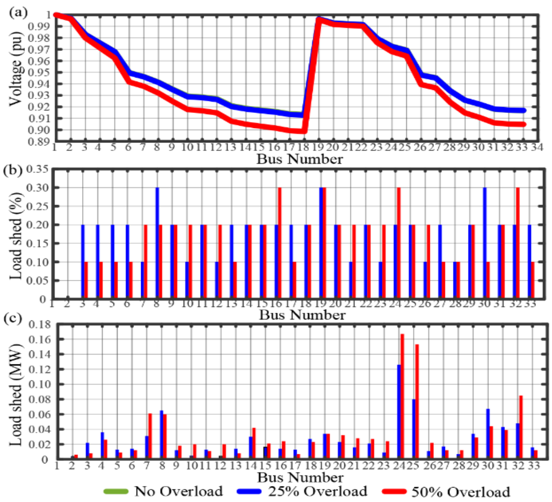

Figure 10. With PSO based load shedding method: (a) System voltage profile (b) Load shed percentage (c) Load shed amount

TABLE 7. PSO-UVLS results summary

Overload scenarios (%)	0%	25%	50%
Total load shed amount (MW)	0	0.89	1.10
Total load shed percentage (%)	0	0.19	0.20
Minimum voltage (pu)	0.91	0.913	0.89

TABLE 8. Comparative study results

Overload	Parameter	Proposed	PSO	Conventional
25%	Power imbalance (MW)	0.92	0.92	0.92
	Amount of load shed (MW)	1.18	0.89	0.20
	Under-shedding (MW)	-	0.03	0.72
	Minimum voltage (pu)	0.92	0.913	0.905
50%	Power imbalance (MW)	1.85	1.85	1.85
	Amount of load shed (MW)	2.10	1.10	0.62
	Under-shedding (MW)	-	0.75	1.23
	Minimum voltage (pu)	0.921	0.89	0.903

4. CONCLUSION

This paper proposed an optimal UVLS method to mitigate voltage collapse following overloads in distribution network. Some of the prominent features of the proposed method include, managing power imbalances, preventing under-shedding, and improving load shedding efficiency by maintaining vital loads during load shedding. The proposed method can determine the best location for load shedding using SIM. Furthermore, an intelligent FFBPNN-based method is designed to predict load curtailment amount efficiently using ANNM. On the other hand, the vital loads in the system were maintained according to the SLPM. The proposed approach was tested on the IEEE 33-bus test network and the results were compared with other approaches. The results from simulation unveiled that the proposed method can significantly prevent voltage collapse following overloads in distribution system.

5. ACKNOWLEDGEMENTS

This research was supported by Universiti Tun Hussein Onn Malaysia (UTHM) through GPPS (vot H626).

6. REFERENCES

1. Sundarajoo, S., and Soomro, D. M. “Under voltage load shedding and penetration of renewable energy sources in distribution systems: a review.” ***International Journal of Modelling and Simulation***, (2022), 1-19. https://doi.org/10.1080/02286203.2022.2143191

2. Nemouchi, H., Tiguercha, A., and Ladjici, A. A. “An adaptive

decentralized under voltage load shedding in distribution networks." ***International Transactions on Electrical Energy Systems***, Vol. 30, No. 11, (2020), e12592. https://doi.org/10.1002/2050-7038.12592

3. Maresch, K., Marchesan, G., Junior, G. C., and Borges, A. "An underfrequency load shedding scheme for high dependability and security tolerant to induction motors dynamics." ***Electric Power Systems Research***, Vol. 196, (2021), 107217. https://doi.org/10.1016/j.epsr.2021.107217
4. Khamis, A., Khatib, T., Aishah, N. M., and Ridzuan, R. "A novel research clustering scheme using bibliometric analysis : A case study of global trend in electrical power system load shedding." ***Iranian Journal of Science and Technology, Transactions of Electrical Engineering***, (2021). https://doi.org/10.1007/s40998-021-00430-z
5. Dreidy, M., Mokhlis, H., and Mekhilef, S. "Application of meta-heuristic techniques for optimal load shedding in islanded distribution network with high penetration of solar PV Generation." ***Energies***, Vol. 10, No. 2, (2017), 150. https://doi.org/10.3390/en10020150
6. Singh, P., Arya, R., Titare, L. S., and Arya, L. D. "Optimal load shedding to avoid risks of voltage collapse using black hole algorithm." ***Journal of The Institution of Engineers (India): Series B***, Vol. 102, (2021), 261-276. https://doi.org/10.1007/s40031-021-00543-3
7. Sayed, F., Kamel, S., Yu, J., and Jurado, F. "Optimal load shedding of power system including optimal TCSC allocation using moth swarm algorithm." ***Iranian Journal of Science and Technology, Transactions of Electrical Engineering***, Vol. 44, (2020), 741-765. https://doi.org/10.1007/s40998-019-00255-x
8. Sayed, F., Kamel, S., Taher, M. A., and Jurado, F. "Enhancing power system loadability and optimal load shedding based on TCSC allocation using improved moth flame optimization algorithm." ***Electrical Engineering***, Vol. 103, (2021), 205-225. https://doi.org/10.1007/s00202-020-01072-w
9. Modarresi, J., Gholipour, E., and Khodabakhshian, A. "New adaptive and centralised under-voltage load shedding to prevent short-term voltage instability." ***IET Generation, Transmission & Distribution***, Vol. 12, No. 11, (2018), 2530-2538. https://doi.org/10.1049/iet-gtd.2017.0783
10. Larik, R. M., Mustafa, M. W., Aman, M. N., Jumani, T. A., Sajid, S., and Panjwani, M. K. "An improved algorithm for optimal load shedding in power systems." ***Energies***, Vol. 11, No. 7, (2018), 1808. https://doi.org/10.3390/en11071808
11. Cruz, L. M., Alvarez, D. L., Al-Sumaiti, A. S., and Rivera, S. "Load curtailment optimization using the PSO algorithm for enhancing the reliability of distribution networks." ***Energies***, Vol. 13, No. 12, (2020), 3236. https://doi.org/10.3390/en13123236
12. Javadi, M., and Amraee, T. "Mixed integer linear formulation for undervoltage load shedding to provide voltage stability." ***IET Generation, Transmission & Distribution***, Vol. 12, No. 9, (2018), 2095–2104. https://doi.org/10.1049/iet-gtd.2017.1118
13. Tian, A., and Mou, X. "A network analysis-based distributed load shedding strategy for voltage collapse prevention." ***IEEE Access***, Vol. 7, (2019), 161375-161384.
14. Sarwar, S., Mokhlis, H., Othman, M., Muhammad, M. A., Laghari, J. A., Mansor, N. N., Mohamad, H., and Pourdaryaei, A. "A mixed integer linear programming based load shedding technique for improving the sustainability of islanded distribution systems." ***Sustainability (Switzerland)***, Vol. 12, No. 15, (2020). https://doi.org/10.3390/SU12156234
15. Mansouri, H. R., Mozafari, B., Soleymani, S., and Mohammadnezhad, H. "A new optimal distributed strategy to mitigate the phase imbalance in smart grids." ***International Journal of Engineering, Transactions C: Aspects***, Vol. 33, No. 12, (2020), 2489-2495. https://doi.org/10.5829/ije.2020.33.12c.08
16. Murty, V. V. S. N., and Kumar, A. "Voltage regulation and loss minimization in reconfigured distribution systems with capacitors and OLTC in the presence of PV penetration." ***Iranian Journal of Science and Technology, Transactions of Electrical Engineering***, Vol. 3, , (2020). https://doi.org/10.1007/s40998-020-00389-3
17. Zare, H., Khanalizadeh Eini, M., and Esmaeili, A. "Stabilization of voltage and current in the distribution networks using APF and TSC." ***International Journal of Engineering, Transactions B: Applications***, Vol. 35, No. 5, (2022), 1064-1073. https://doi.org/10.5829/IJE.2022.35.05B.21
18. Danish, M. S. S., Senjyu, T., Danish, S. M. S., Sabory, N. R., Narayanan, K., and Mandal, P. "A recap of voltage stability indices in the past three decades." ***Energies***, Vol. 12, No. 8, (2019), 1544. https://doi.org/10.3390/en12081544
19. Al-Ani, B. R. K., and Erkan, E. T. "A study of load demand forecasting models in electricity using artificial neural networks and fuzzy logic model." ***International Journal of Engineering, Transactions C: Aspects***, Vol. 35, No. 6, (2022), 1111-1118. https://doi.org/10.5829/ije.2022.35.06c.02
20. Qiao, J., Wang, L., Yang, C., and Gu, K. "Adaptive levenberg-marquardt algorithm based echo state network for chaotic time series prediction." ***IEEE Access***, Vol. 6, (2018), 10720-10732. https://doi.org/10.1109/ACCESS.2018.2810190
21. Baran, M. E., and Wu, F. F. "Network reconfiguration in distribution systems for loss reduction and load balancing." ***IEEE Power Engineering Review***, Vol. 9, No. 4, (1989), 101-102. https://doi.org/10.1109/MPER.1989.4310642
22. Montoya, O. D., Gil-González, W., and Grisales-Noreña, L. F. "An exact MINLP model for optimal location and sizing of DGs in distribution networks: A general algebraic modeling system approach." ***Ain Shams Engineering Journal***, Vol. 11, No. 2, (2020), 409-418. https://doi.org/10.1016/j.asej.2019.08.011

Persian Abstract

چکیده

کاهش بار به طور کلی به عنوان گزینه نهایی برای جلوگیری از فروپاشی ولتاژ و خاموشی پس از اضافه بارهای عمده در نظر گرفته می شود. روش سنتی کاهش بار، بارهای تصادفی را بدون توجه به اهمیت آنها تا زمانی که ولتاژ سیستم بهبود یابد، محدود می کند. ریزش بارهای تصادفی بدون در نظر گرفتن اولویت آنها منجر به قطع برق در زیرساخت های حیاتی می شود. از این رو، برای بهبود طرح حفاظتی سیستم قدرت موجود، توسعه یک روش کاهش بار موثرتر و کارآمدتر ضروری است. در این مقاله، یک روش بهینه کاهش بار تحت ولتاژ (UVLS) برای پیش‌بینی بهینه مقدار بار ریخته‌شده و بهترین مکان برای کاهش بار پیشنهاد شده است. علاوه بر این، روش پیشنهادی برای حفظ بارهای حیاتی در سیستم در طول فرآیند کاهش بار طراحی شده است. در این کار، شاخص پایداری (SI) و شبکه عصبی پس انتشار پیش‌خور (FFBPNN) برای جلوگیری از فروپاشی و خاموشی ولتاژ با کاهش ناپایداری ولتاژ به دنبال اضافه‌بار در سیستم توزیع، اتخاذ شد. عملکرد روش پیشنهادی برای چندین سناریو اضافه بار بررسی شده است. مطالعات موردی انجام شده بر روی سیستم ۳۳ گذرگاهی IEEE استحکام و عملکرد قابل توجه تکنیک توصیه شده را نشان داد. در مقایسه با سایر روش‌ها، رویکرد پیشنهادی در مقابله با وقوع کم‌ریزش، افزایش پروفیل ولتاژ، و بهبود پایداری سیستم و در عین حال حفظ بارهای حیاتی در سیستم در طول ریزش بار، کارآمد است.