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Advanced Load Shedding Strategy Incorporating Voltage and Frequency Stability for Enhanced Grid Reliability

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***Abstract*—Power systems are frequently exposed to various disturbances and contingencies that can jeopardize grid stability. Some scenarios may require the hard line delegation of cutting a portion of the load in order to save the system from succumbing to a catastrophic position like a blackout. Throughout the world, a great many load shedding schemes are available, each one being quite contrastive to the others. This paper introduces an innovative approach to load shedding that integrates real-time frequency deviation and reactive power margin to ensure both voltage and frequency stability. The proposed methodology dynamically adjusts the amount of load shed based on system conditions, prioritizing non-critical loads while minimizing disruptions. Frequency excursions beyond system limits is prevented by taking advantage of the Rate of Change of Frequency (RoCoF) and reactive power margin in this method, safeguarding equipment and maintaining grid integrity. The performance of the methodology was validated through simulations on the North-Western power grid of Bangladesh, demonstrating superior performance in arresting frequency excursions while reducing the total load shed compared to traditional schemes. A satisfactory and convincing result is attained endorsing the efficaciousness of this adaptive load shedding strategy in enhancing grid stability and reliability.**

Keywords—UFLS, frequency response, RoCoF, load shedding, frequency nadir, reactive power margin, stability.

I. INTRODUCTION

The preeminent issue while connecting the whole world with electricity is to ensure the stability of the power supply. The main manifesto of a good power system is to build the system stable, which means the system parameters will return to the original value or very near of the original value in a rapid succession following a contingency [1]. The incredible demand increases at a dramatic rate as well as any fault or disturbance at any part of the vast system may result in the destabilization of the total network. To mitigate such a tribulation from prolonging, the grid operator may require to reduce load.

Load shedding is an artificial procedure of cutting an ample amount of load in order to restore and maintain the voltage and frequency stability of a power system under the threat of going astray to extremities of blackout as a concatenation of some contingency suffered by the system [2]. The process of load shedding diminishes stress on the grid and hold the system at safe position. The universal aim of a power system network is to maintain the balance of generation and demand. Any contingency may cause a disruption in this balance, typically reducing the generation. A decline in the load will help in reinstating the balance of generation-demand.

A lot many methods to perform load shedding have been introduced over the years. In [2], a load shedding scheme has been established on the basis of the reactive power margin of existing buses in a low inertia system. However, the amount of load shed is equal at all contingency since there is no consideration of RoCoF. A reactive power margin based zoning is performed in [3] and the shedding amount is computed constraining RoCoF as the indicator in a renewable source based system. A Particle Swarm Optimization (PSO) based solution is accomplished in [4] in order to discretize the amount of shedding. The idea of frequency and RoCoF is utilized in [5] attained from PMU detectors for a huge contingency. The proximity indicator for the amount of load to be shed in [6] is the lowest eigenvalue attained from the Jacobian matrix in the power flow. The ramping capacity of the Distributed Energy Resources (DER) in a microgrid is the key factor of shedding in [7]. The Phasor Measurement Units (PMU) of a system constantly provide voltage and frequency data that helps in formation of an adaptive centralized load shedding technique in [8] that simultaneously ensures both frequency and voltage stabilities. [9] introduces load shedding based on derivative on frequency change between two consecutive steps of shedding. Load is continuously shed in proportion to the frequency deviation in case of [10]. Linear optimization is applied in [11] for the emergency situation where load flow cannot be performed. The under-voltage that arose as a part of the post-fault situation is the base of load shedding in [12]. The magnitude of load to be shed in [13] is

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forecasted in accordance of the average magnitude of total load in a year. In [14], the frequency excursion is precisely detected and conforms to the Mixed-Integer Linear Programming based optimization framework. This algorithm does not prioritize any bus for load shedding. Load priority table and the intensity of a contingency are the key factors along with RoCoF in the determination of load shedding in [15]. In [16], optimal value of UFLS relay setting has been achieved using RoCoF to diminish the size of shedding as well as to sustain the security of the network. The discernible part of [2], [16] is that they mainly encompass an islanded microgrid or small separated smart grid or low inertia system or renewable integrated system rather than the main operational grid of the national system. Most of them either ensure voltage or frequency stability, but not both simultaneously. Only a few are optimized. The frequency excursion is free to be explored indefinitely.

To this end, the paper puts forward a novel technique of load shedding for the operating national power grid in order to sustain the voltage and frequency stability at all times despite the appearance of any disturbance or contingency, be it large or small. The system's load buses are ranked in accordance with their reactive power margin. A bus with lower margin is identified as a weaker bus and subject to higher load shedding since it is more prone to suffer stability issues under distress. The RoCoF is also incorporated into calculating the shedding magnitude after assessing the frequency excursion pattern for the first few stages. The amount of load shedding will be different at different buses and vary according to the contingency that occurs. The power grid connects a different dimension of load that may suffer under a certain threshold of frequency. The generation, transmission and distribution may also go through significant stress due to very low frequency. The paper evaluates this predicament and proposes a path to place a frequency nadir above the threshold of frequency.

II. METHODOLOGY

The main parameters to determine the load amount that needs to be shed are Reactive Power Margin and RoCoF.

A. Reactive Power Margin

The surplus capacity of reactive power available in the system beyond the current demand denotes the reactive power margin [17]. The reactive power (in MVAR) is an element of the electrical power that oscillates between the source and load without performing any real work. It plays a crucial role in maintaining voltage levels and ensuring the stability of power systems.

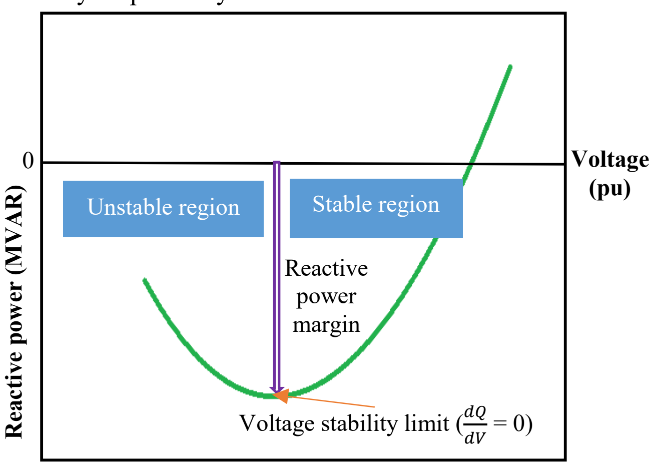


Fig. 1. Sample QV curve.

Reactive Power Margin acts as a safety buffer, providing additional capacity beyond what is currently required. This surplus reactive power can be rapidly injected into the system or absorbed as needed to counteract changes in demand or unexpected events. Maintaining an adequate Reactive Power Margin is crucial for preventing voltage instability, ensuring voltage support, and preventing potential cascading failures in the power grid.

The MVAR gap between the lowest point and the voltage axis of the QV plot at the load bus (PQ bus) is interpreted as the reactive power margin [18]. The rock-bottom point on the QV curve represents the point where the voltage of the system collapses [19]. The bus with the smallest margin of the reactive power indicates the corresponding bus to be the weakest in the network [20]. A Q-V curve with all the noticeable regions is shown in fig. 1.

B. Rate of Change of Frequency (RoCoF)

The national power grid while performing may suffer various levels of disturbance and contingencies, each one being quite in contrast to the other. The frequency deviation does in effect be variant to such severity. Measurement of RoCoF is the only way to perceive how treacherous is the contingency. A change in frequency over a variable amount of time is RoCoF [3]. When the contingency is quite serious like a generator failure or a large load disconnection, a stanchion decline of frequency is discerned. Frequency falls down in a magnanimous amount within a short period of time, in the process causing a massive damage to the electrical components attached to the system. In contrast, the small disturbance like minor load fluctuation mayhap results in a ramped up fall of frequency. The steady frequency fall makes a small deviation over a long period of time.

A greater RoCoF requires a higher load shed to return the system to its stable state readily since the situation is very volatile at this stage. So, RoCoF has a direct connection with the amount of load shedding.

C. Proposed Scheme

The first and foremost task is to evaluate the reactive power margin for all the existing PQ bus of a sample system. Standard load flow analysis along with varying reactive power injection and reactive power demand provides a QV curve of each load bus from where the reactive power margin can easily be attained.

As we intend to ensure the voltage and frequency stability for the total sample system, so we might reach to the point of performing load shedding. However, in contrast to the traditional scheme where an equal amount load is shed at all the existing buses, a greater magnitude of load will be shed in the relatively weaker bus in this scheme. The reactive power margin is the parameter to signify the strength of a bus as such the buses with lower reactive power margin are weaker.

The reactive power margin of all the load buses of the system are inverted and then normalized. These normalized values are termed as Reactive Margin Factor. Suppose, there are M load buses in the power system to be considered. Also suppose, the inverse value Q_1, Q_2, …, Q_M of the margins of reactive power of the PQ buses 1, 2, …, M respectively. Hence, the Reactive Margin Factor for the bus number n (r_n) might be computed by the help of (1).

$$r_n = \frac{Q_n}{Q_1+Q_2+\cdots+Q_M} = \frac{Q_n}{\sum_{i=1}^{M} Q_i} \quad (1)$$

The load shedding is performed at multiple stages keeping an eye on the excursion of the frequency curve. The stages of load shedding come into play when the system frequency crosses some threshold magnitude. A Pascal's Triangle based Binomial Expansion method is adopted to determine the shedding amount. Pascal's Triangle, an arrangement of numbers in triangular array, has the starting and ending of each row with a 1 and the other numbers are the sum of the two numbers straight above it in the previous row [21]. It represents the binomial coefficients.

By the application of binomial expansion, the load shedding amount at the very first stage for n-th load bus ($LS_{n,1}$) is determined as below.

$$LS_{n,1} = r_n \times L_n \quad (2)$$

Here, L_n is the amount of total load of the n-th load bus.

As some of the load is already shed, the second stage of load shedding will take it into account and the required amount ($LS_{n,2}$) can be obtained from (3).

$$LS_{n,2} = (1 - r_n) \times r_n \times L_n = (r_n - r_n^2) \times L_n \quad (3)$$

In the same way, the third stage of load shedding will compute the required amount ($LS_{n,3}$) by (4).

$$LS_{n,3} = \{1 - r_n - (r_n - r_n^2)\} \times r_n \times L_n = (1 - r_n)^2 \times r_n \times L_n \quad (4)$$

The stages of load shedding can be continued as long as required until frequency excursion is arrested by simply following Pascal's Triangle [21].

However, there is a little bump in this. The considered test system is a region of Bangladesh. The nominal system frequency of Bangladesh Power System is 50 Hz. The system is believed to be maintaining the frequency stability at a tolerance level of ± 0.5 Hz, which means in between 49.5 Hz and 50.5 Hz. The complexity arises when the system frequency crosses a threshold of 49 Hz, which results in malfunctioning and damage of electrical machinery and system components.

To topple the situation, the shed amount of load needs to be of such magnitude that the frequency nadir can be lower than 49 Hz. For that, a consideration of RoCoF is required. By considering threshold frequency for load shedding of the first stage at 49.5 Hz, the second stage at 49.3 Hz and the third stage at 49.1 Hz, RoCoF of the previous stages needs to be combined at the third stage along with the usual equation found by binomial expansion.

RoCoF can be calculated by measuring the frequency deviation over the time taken for that deviation to take place.

$$RoCoF = \frac{\Delta f}{\Delta t} \quad (5)$$

where Δf is the change in frequency over the time Δt. From the current frequency, the difference to reach the target frequency of 49 Hz (Δf_{target}) can be obtained from (6).

$$\Delta f_{target} = f_{current} - f_{target} = f_{current} - 49 \quad (6)$$

where $f_{current}$ is the system frequency at the present stage. Considering a linear interpolation, further frequency drop can be estimated by (7)

$$\Delta f_{expected} = \text{RoCoF} \times \Delta t \quad (7)$$

where $\Delta f_{expected}$ is how much further the frequency could drop over next Δt time if no load shedding was applied. In order to ensure the frequency does not drop below 49 Hz, the additional load that needs be shed to compensate for the expected frequency drop is computed from (8).

$$\Delta P = \frac{\Delta f_{target}}{\Delta f_{expected}} \times P_{shed} = \frac{\Delta f_{target}}{RoCoF \times \Delta t} \times P_{shed} \quad (8)$$

where P_{shed} is the power shed in the previous stages. This term scales the load shedding based on how much additional load needs to be shed so as the frequency does not drop below the level of 49 Hz.

Hence, a total load which is required to be cut-off in the third stage combines (4) and (8).

$$LS_{n,3} = (1 - r_n)^2 \times r_n \times L_n + \frac{\Delta f_{target}}{RoCoF \times \Delta t} \times P_{shed} \quad (9)$$

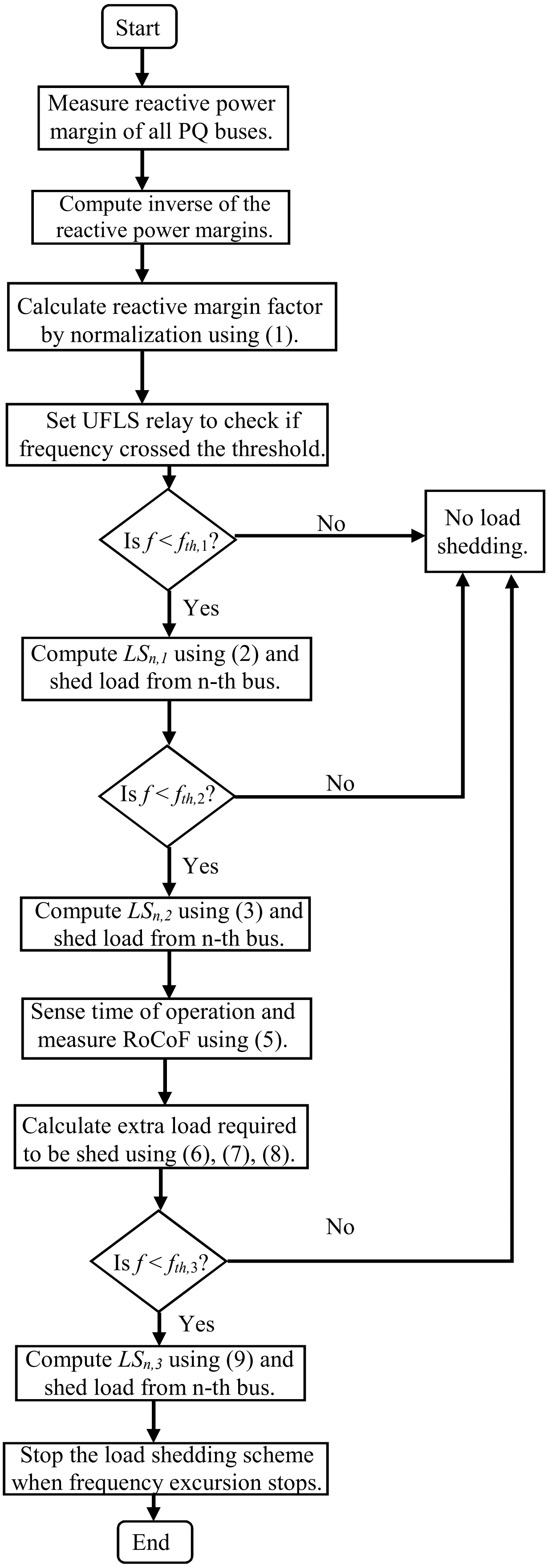
The normalization in the calculation of Reactive Margin Factor contributes to the fact that the variation in load will not have a significant impact, since load increase may result in the decreased reactive power margin.

III. Implementation

Both online and offline implementation of the proposed scheme can be performed. The system parameters and required data can be attained by simulation of the system in software. The UFLS relays of the system can perceive the system frequency and can adapt to shed load according to the proposed scheme. A step by step method for the scheme to run is provided below.

Step 1: Measure the reactive power margin of all the available load bus (PQ bus) of the system.
Step 2: Find the inverse of all the Q-margins measured.
Step 3: Normalize the inverse of the Q-margins to determine reactive margin factor using (1).
Step 4: Set the under-frequency relay to sense whether the system frequency has crossed the first UFLS threshold frequency ($f_{th,1}$). If yes, then shed a load of amount ($LS_{n,1}$) determined from (2) for n-th PQ bus. Otherwise do not shed any amount of load.
Step 5: Similarly, set the under-frequency relay to sense if the system frequency has crossed the second UFLS threshold frequency ($f_{th,2}$). If yes, then shed a load of amount ($LS_{n,2}$) determined from (3) for n-th PQ bus. Otherwise do not shed any amount of load.
Step 6: Measure the time taken to reach this frequency deviation and from there, find RoCoF using (5).
Step 7: Use (6), (7) and (8) to compute the extra load that is required to be shed so as the system frequency might not violate 49 Hz limit.
Step 8: Finally, set the under-frequency relay to sense if the system frequency has crossed the third UFLS threshold frequency ($f_{th,3}$). As a precaution for the system frequency not to cross the 49 Hz limit for safety, a load of amount ($LS_{n,3}$) will be shed that can be calculated from (9) for n-th PQ bus. Otherwise do not shed any amount of load.
Step 9: The load shedding stops as soon as frequency excursion quits.

A flow chart is established below for the ease of application in the software for automation purposes.



IV. Result and Analysis

A. Targeted Area

For this paper, we have been using Power System data from the North-Western region of Bangladesh. The area includes 16 districts of Rajshahi and Rangpur divisions. This system consists of 22 buses, 11 generators, 10 transformers and transmission lines. Baghabari bus is considered as the slack bus of the system. We are considering 230 kV and 132 kV transmission lines only due to technical limitations. All the system parameters are procured from Power Grid Company of Bangladesh (PGCB) and Bangladesh Power Development Board (BPDB) for accurately representing the national power grid while performing simulations [22], [23]. PSSE®E, PSAF and MATLAB software have been used to analyze the system. Fig. 2 is the single line diagram of the total test system under consideration.

There are eight load buses in the system. They are Palshbari, Bogura, Naogaon, Chapai Nawabganj, Amnura, Rajshahi, Natore and Sherpur.

B. Reactive Power Margin

A details view of The Q-margins of the PQ buses are furnished in Table I.

Amnura bus has the lowest value of reactive power margin among all the PQ buses, which means that Amnura is the weakest bus. This bus is the most susceptible to voltage instability and may face potential cascading failure. In order to prevent such a calamity, Amnura bus will suffer the largest percentage of cut-off of the load in comparison to the remaining buses. Natore bus has the maximum reactive power margin. That means, it is the strongest bus. Hence, the smallest percentage of load shedding will be faced by the Natore bus. All other buses fall among these two buses in accordance with rank based on their reactive power margin.

TABLE I. Reactive Power Margin

Bus Name	**Reactive Power Margin**
Palashbari	398.13 MVA
Bogura	509.17 MVA
Naogaon	435.69 MVA
Chapai Nawabganj	479.00 MVA
Amnura	397.28 MVA
Rajshahi	508.63 MVA
Natore	558.36 MVA
Sherpur	424.00 MVA

C. Load Shedding Amount

The amount of load shedding at different stages is calculated using relevant equations from the previous section. A comparative study is placed in Table II in between the proposed scheme of load shedding (in MW) and the traditional UFLS scheme considering a constant 20% load shed at every stage.

A gradual decline can be visualized in the amount of load shedding from the first stage to the second stage. The trend to remain similar could be predicted for the third stage too.

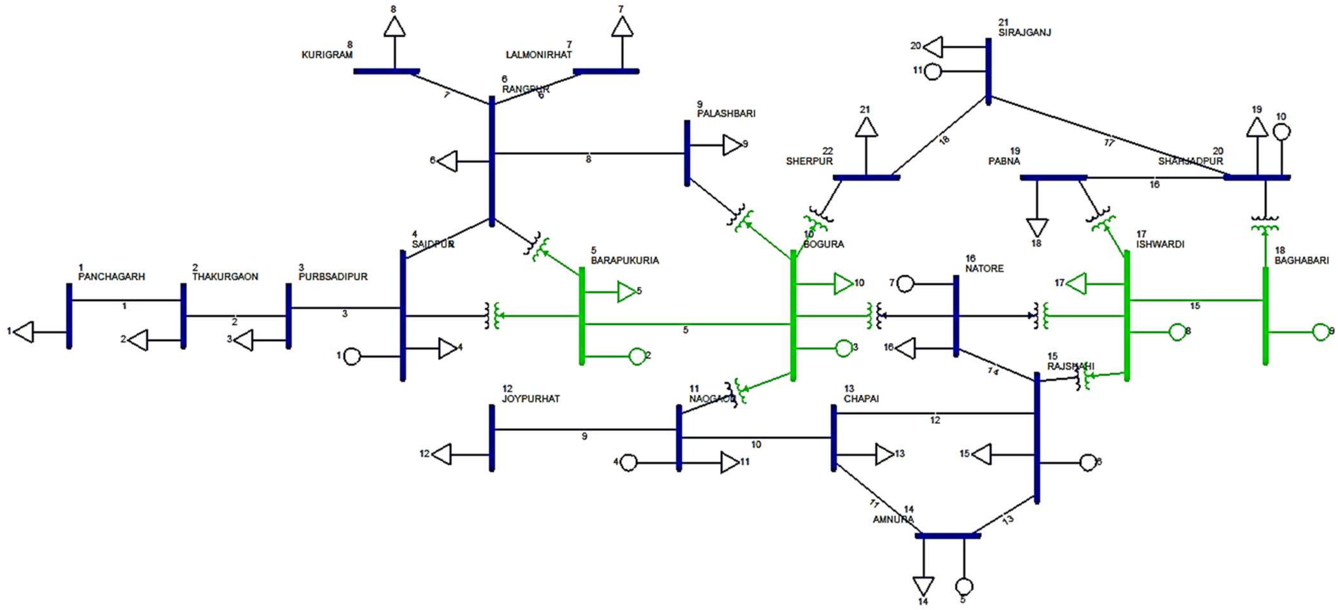


Fig. 2. Single line diagram of the system.

However, the real scenario is quite different since an extra amount of load needs to be shed to arrest the frequency excursion above the 49 Hz threshold limit. The total amount of load shed in all three stages is lower in this proposed scheme in comparison to the traditional scheme. The total load shed in conventional scheme is 414.6 MW, whereas the proposed scheme sheds 236.79 MW which almost 60% of the traditional scheme.

TABLE II. LOAD SHEDDING AMOUNT

Bus Name	**1st Stage**		**2nd Stage**		**3rd Stage**	
	Propo-sed	***Tradi-tional***	***Propo-sed***	***Tradi-tional***	***Propo-sed***	***Tradi-tional***
Amnura	7.20	10.0	6.16	10.0	6.38	10.0
Palashbari	13.21	18.4	11.31	18.4	11.57	18.4
Sherpur	7.28	10.8	6.30	10.8	6.73	10.8
Naogaon	13.52	20.6	11.74	20.6	12.10	20.6
Chapai Nawabganj	7.16	12.0	6.31	12.0	6.74	12.0
Rajshahi	13.15	23.4	11.67	23.4	12.55	23.4
Bogura	12.91	23.0	11.46	23.0	12.21	23.0
Natore	10.24	20.0	9.19	20.0	9.67	20.0
Total	84.67	138.2	74.17	138.2	77.95	138.2

D. *Test Case with Contingencies*

1) Generator trip: A test case is analyzed by performing a generator outage of capacity 188 MW at the Sirajganj bus. The resultant frequency response curve is shown in fig. 3.

The plot of fig. 3. notifies a frequency nadir while applying the proposed scheme is 49.077465 Hz in comparison to the traditional scheme with 48.930568 Hz. The improvement of the frequency nadir is evident in the presented scheme. The frequency nadir remains within the safety threshold of 49 Hz in the propose scheme.

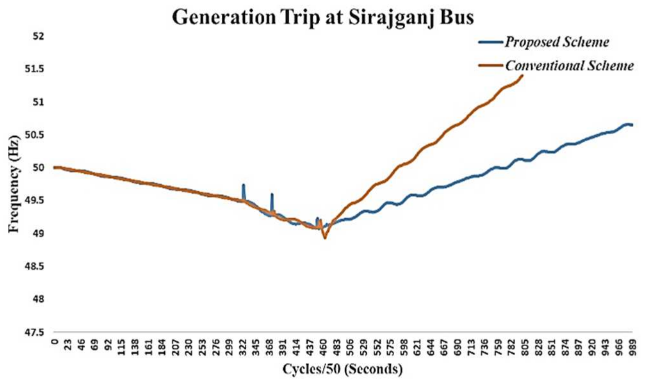


Fig. 3. Frequency response curve of generator outage.

2) Line trip: The second analyzed test case would be the tripping of a transmission line in between the buses Saidpur and Rangpur of 41.5 km length and 768 MVA rating. Fig. 4 is the frequency response to the contingency.

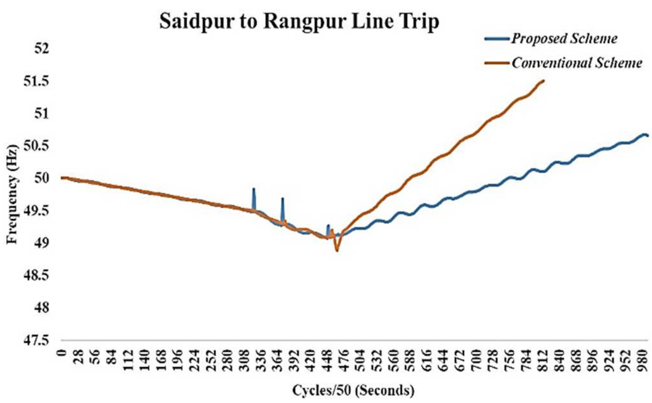


Fig. 4. Frequency response curve of line trip.

Fig. 4 identifies a frequency nadir of 49.078251 Hz in case of the proposed scheme. On the contrary, the conventional scheme provides a frequency nadir of 48.884798 Hz which is not only lower than the proposed way but also violates the safety limits of 49 Hz.

3) Load increase: As the third test contingency, the load at Rajshahi bus suddenly jumps to 300 MW from the original condition of 117 MW. The frequency response to the situation is established in fig. 5.

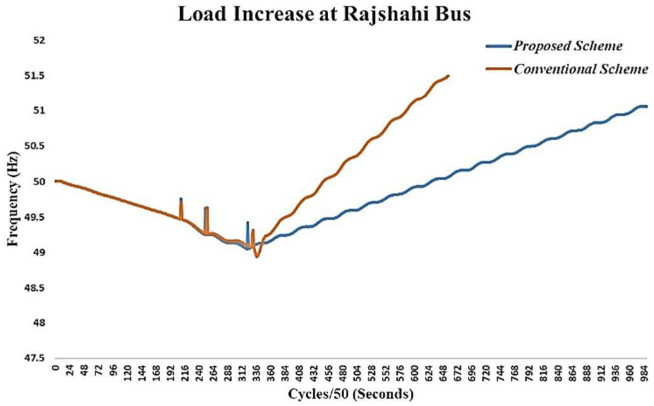


Fig. 6. Frequency response curve of load increasing.

A better frequency nadir, 49.049587 Hz, is attained from fig. 5 in contrast to the conventional UFLS scheme, 48.937215 Hz.

V. Conclusion

The main focus of this paper is to introduce a scheme that will retain the voltage and frequency stability with the shortest amount of load shedding possible and maintain frequency within a limited value. The simulation plot indicates a higher frequency nadir in comparison to the traditional scheme in all three contingencies tested. Moreover, the frequency nadir does not exceed the 49 Hz limit causing the system to be stress free and provides support to the machineries connected to the system. The total amount of load shed is 40% lower than the conventional scheme. An unequal shedding is registered for different load buses guaranteeing the lowest possible shed in each of the buses.

Due to certain limitations of the software, only the transmission level is used in simulation. However, a more detailed view of generation and distribution level might give a clearer and realistic view of the system. Moreover, implementation of Load Frequency Relief (LFR) would further improve the frequency response curve. Inclusion of these few factors will contribute to the formation of an optimized and efficient load shedding scheme that can confer the national power grid to be far more reliable and resilient.

References

[1] P. Kundur *et al*., "Definition and classification of power system stability IEEE/CIGRE joint task force on stability terms and definitions," in *IEEE Transactions on Power Systems*, vol. 19, no. 3, pp. 1387-1401, Aug. 2004, doi: 10.1109/TPWRS.2004.82598.

[2] Nahid-Al-Masood, M. N. H. Shazon, S. R. Deeba and S. R. Modak, "A Frequency and Voltage Stability-Based Load Shedding Technique for Low Inertia Power Systems," in *IEEE Access*, vol. 9, pp. 78947-78961, 2021, doi: 10.1109/ACCESS.2021.3084457.

[3] Nahid-Al- Masood, Atik Jawad, Satyaki Banik, "A RoCoF-constrained underfrequency load shedding scheme with static voltage stability-based zoning approach," Sustainable Energy, Grids and Networks, Volume 35, 2023, 101080, ISSN 2352-4677.

[4] S. Debbarma, K. Roy, P. P. Singh and S. Kumar, "Distributed Generation and RoCoF Relay Integrated Multi-Stage Under Frequency Load Shedding Scheme in Power Systems," *2023 11th National Power Electronics Conference (NPEC)*, Guwahati, India, 2023, pp. 1-5, doi: 10.1109/NPEC57805.2023.10384945.

[5] A. Derviškadić, Y. Zuo, G. Frigo and M. Paolone, "Under Frequency Load Shedding based on PMU Estimates of Frequency and ROCOF," *2018 IEEE PES Innovative Smart Grid Technologies Conference Europe (ISGT-Europe)*, Sarajevo, Bosnia and Herzegovina, 2018, pp. 1-6, doi: 10.1109/ISGTEurope.2018.8571481.

[6] L.D. Arya, V.S. Pande, D.P. Kothari, "A technique for load-shedding based on voltage stability consideration," International Journal of Electrical Power & Energy Systems, Volume 27, Issue 7, 2005, Pages 506-517, ISSN 0142-0615.

[7] Q. Hong *et al*., "A New Load Shedding Scheme With Consideration of Distributed Energy Resources' Active Power Ramping Capability," in *IEEE Transactions on Power Systems*, vol. 37, no. 1, pp. 81-93, Jan. 2022, doi: 10.1109/TPWRS.2021.3090268.

[8] J. Tang, J. Liu, F. Ponci and A. Monti, "Adaptive load shedding based on combined frequency and voltage stability assessment using synchrophasor measurements," in *IEEE Transactions on Power Systems*, vol. 28, no. 2, pp. 2035-2047, May 2013, doi: 10.1109/TPWRS.2013.2241794.

[9] Rudez, R.U. and Mihalic, R., 2012. Adaptive UFLS schemes in modern power systems-conceptual and simulation proved comparison. *Int. J. Energy Eng*, *3*, pp.100-107.

[10] Li, Changgang, Yanli Sun, and Yawei Yu. "An under-frequency load shedding scheme with continuous load control proportional to frequency deviation." In *IOP Conference Series: Materials Science and Engineering*, vol. 199, no. 1, p. 012074. IOP Publishing, 2017.

[11] X. Fu and X. Wang, "Load Shedding Scheme Ensuring Voltage Stability," *2007 IEEE Power Engineering Society General Meeting*, Tampa, FL, USA, 2007, pp. 1-6, doi: 10.1109/PES.2007.385850.

[12] H. Bai and V. Ajjarapu, "A Novel Online Load Shedding Strategy for Mitigating Fault-Induced Delayed Voltage Recovery," in *IEEE Transactions on Power Systems*, vol. 26, no. 1, pp. 294-304, Feb. 2011, doi: 10.1109/TPWRS.2010.2047279.

[13] Urban Rudez, Rafael Mihalic, "Predictive underfrequency load shedding scheme for islanded power systems with renewable generation," Electric Power Systems Research, Volume 126, 2015, Pages 21-28, ISSN 0378-7796.

[14] Ali Rafinia, Jamal Moshtagh, Navid Rezaei, "Stochastic optimal robust design of a new multi-stage under-frequency load shedding system considering renewable energy sources," International Journal of Electrical Power & Energy Systems, Volume 118, 2020, 105735, ISSN 0142-0615.

[15] Amin Mokari-Bolhasan, Heresh Seyedi, Behnam Mohammadi-ivatloo, Saeed Abapour, Saeed Ghasemzadeh, "Modified centralized ROCOF based load shedding scheme in an islanded distribution network," International Journal of Electrical Power & Energy Systems, Volume 62, 2014, Pages 806-815, ISSN 0142-0615.

[16] F. Elyasichamazkoti and S. Teimourzadeh, "Secure Under Frequency Load Shedding Scheme with Consideration of Rate of Change of Frequency," *2021 IEEE Green Technologies Conference (GreenTech)*, Denver, CO, USA, 2021, pp. 552-557, doi: 10.1109/GreenTech48523.2021.00092.

[17] Tareq Aziz, Nahid-Al Masood, Shohana Rahman Deeba, Wayes Tushar, Chau Yuen, "A methodology to prevent cascading contingencies using BESS in a renewable integrated microgrid," International Journal of Electrical Power & Energy Systems, Volume 110, 2019, Pages 737-746, ISSN 0142-0615.

[18] Zhenyu Huang, Lixin Bao, Wilsun Xu, "A method to measure QV curves and its applications in power systems," International Journal of Electrical Power & Energy Systems, Volume 29, Issue 2, 2007, Pages 147-154, ISSN 0142-0615.

[19] T. Amraee, A.M. Ranjbar, B. Mozafari, N. Sadati, "An enhanced under-voltage load-shedding scheme to provide voltage stability," Electric Power Systems Research, Volume 77, Issue 8, 2007, Pages 1038-1046, ISSN 0378-7796.

[20] T. Aziz, T. K. Saha and N. Mithulananthan, "Identification of the weakest bus in a distribution system with load uncertainties using reactive power margin," *2010 20th Australian Universities Power Engineering Conference*, Christchurch, New Zealand, 2010, pp. 1-6.

[21] Hilton, P. and Pedersen, J. (1987) 'Looking into Pascal's Triangle: Combinatorics, Arithmetic, and Geometry', *Mathematics Magazine*, 60(5), pp. 305–316. doi: 10.1080/0025570X.1987.11977330.

[22] *PGCB*, [online] Available: www.pgcb.gov.bd.

[23] *BPDB*, [online] Available: www.bpdb.gov.bd.