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Load shedding scheme based on frequency and voltage stability for an islanding operation of a distribution network connected to mini-hydro generation

Norazliani Md SAPARI[1,2], **Hazlie MOKHLIS**[1,3,*], **Javed AHMED LAGHARI**[4],
Halim ABU BAKAR[3], **Hasmaini MOHAMAD**[5], **Mohd Rohaimi MOHD DAHALAN**[6]
[1]Department of Electrical Engineering, Faculty of Engineering, University of Malaya, Kuala Lumpur, Malaysia
[2]Faculty of Technology, Universiti Malaysia Pahang, Pahang, Malaysia
[3]UM Power Energy Dedicated Advanced Centre, University of Malaya, Kuala Lumpur, Malaysia
[4]Department of Electrical Engineering, Quaid-e-Awam University of Engineering Science and Technology, Nawabshah, Pakistan
[5]Faculty of Electrical Engineering, University of Technology Mara, Selangor, Malaysia
[6]Marine Electrical and Electronics Technology Section, Universiti Kuala Lumpur Malaysian Institute of Marine Engineering Technology, Perak, Malaysia

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Abstract: This paper presents a load shedding scheme (LSS) based on system frequency and voltage stability (VS). In the proposed scheme, the amount of power imbalance is determined using a rate of change of frequency, and the load shedding priority is carried out based on a VS index. The load with the highest tendency for voltage collapse (based on the index value) is given first priority to be shed. Thus, by shedding the most sensitive load, the distribution system can be saved from power collapse and then the system can return to its nominal state after load shedding. The proposed LSS is validated through simulation using PSCAD/EMTDC software on a Malaysian distribution network that consists of two mini-hydro generators. The simulation results show that the proposed scheme manages to shed the optimal amount of load when compared to conventional and adaptive frequency LSS. Moreover, apart from frequency stability, the proposed scheme also shows a significant improvement in the voltage profile of the islanded system.

Key words: Underfrequency load shedding, islanding, voltage stability index, load prioritization, distributed generation, renewable energy

1. Introduction

In recent years, there has been global interest in distributed generations (DGs) based on renewable energy sources. Integrating DGs into the distribution system enables the load to incur smaller losses, reduces fossil fuel consumption, and contributes to an improvement of power quality [1,2]. Despite these advantages, there are technical issues associated with the integration of DGs into the distribution system. One of the major issues is the possibility of islanding occurrence [3]. During an islanding operation, the isolation of the distribution system from the utility grid causes a sudden power imbalance between total generation and load demands. As a result, the system frequency and voltage will drop significantly when the load demand is greater than the generation. During these incidents, the response of the DGs could be slow or unable to increase the generation above maximum capacity, which is the only possible way to conduct load shedding during these conditions [4,5]. Various research studies, which have been conducted to make islanding operations a reality, can be found in

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*Correspondence: hazli@um.edu.my

[6–9]. In [6], the authors proposed an analytical technique to access the reliability of an islanded system that has renewable-based DGs. The authors in [7,9] presented a control strategy for grid-connected and islanded-mode operations of the system. A proper islanding scenario was created to separate the bulk power system into several stable subsystems in [8].

In practice, the most commonly applied load shedding scheme (LSS) for islanded distribution systems is the underfrequency load shedding (UFLS) scheme [1,2,10–14]. In [2], the authors presented an analysis of the frequency gradient in the load-shedding process. In addition, an interest in obtaining the optimal load-shedding value was highlighted in [1,10]. In [12], the authors proposed to estimate the power deficit using the frequency first derivative. Multistage UFLS for an islanded microgrid was introduced in [13] with the use of the equivalent inertia constant. In addition, the application to estimate a disturbance magnitude based on the rate of change of frequency (ROCOF) can be found in [11,14]. However, the above-mentioned studies only highlight system frequency as the main factor in the process of load shedding.

Other studies consider VS in the load-shedding process [15–19]. The load shedding proposed in [15] focuses on the restoration of power flow solvability and improvement of the VS margin. In [16], a load-shedding algorithm is presented that considers the minimization of the sum of total load and VS as a multiobjective problem that can be solved using a weighted sum genetic algorithm. A line VS index was proposed in [17] to shed the load to avoid the maximum loading point. The authors in [18] used a modification of the L-indicator index to achieve optimal load shedding. Meanwhile, [19] considered the load margin as the VS index for load shedding. From the literature review, it can be observed that LSS is designed and based on either frequency or VS. Since UFLS takes into account only the frequency of the system as a main criterion for load shedding, it may contribute to unanticipated or adverse consequences of system voltage. On the other hand, LSS based on VS alone may also affect the frequency stability. There has been no attempt to consider frequency and VS together as LSS for an islanded distribution system. The only paper that considered frequency and VS in LSS was [20], but the proposed algorithm is for a transmission system only.

Considering the need of ensuring frequency and voltage within the allowable limits, this paper presents LSS that considers frequency and voltage stability in the selection of the load to be shed. In the proposed scheme, ROCOF is used to estimate the power imbalance while a VS index is used to prioritize load shedding. The VS is identified through an online VS index that detects the stability status of each bus in the system during dynamic condition. Critical buses indicating the weakest buses in the system are given priority for shedding in order to avoid voltage collapse in the whole system. The proposed scheme is tested through PSCAD/EMTDC simulation using real Malaysian distribution systems consisting of two mini-hydro generators (MHGs).

2. Methodology of the proposed scheme

Figure 1 illustrates the overall concept of the proposed LSS for the islanding operation of the distribution network. In general, the proposed scheme consists of three main modules: 1) a frequency monitoring controller (FMC) 2) a stability index controller (SIC), and 3) a load shedding controller (LSC). A detailed description of these modules is presented in Sections 2.1 to 2.3. In the proposed scheme, it is assumed that all information required from the distribution system is provided through an efficient communication link to transmit the signal.

2.1. Frequency monitoring controller

The FMC is designed to continuously monitor the system frequency f_{grid}.The occurrence of islanding or sudden load variation in the system would cause deviation in the system frequency. In the case that the system frequency

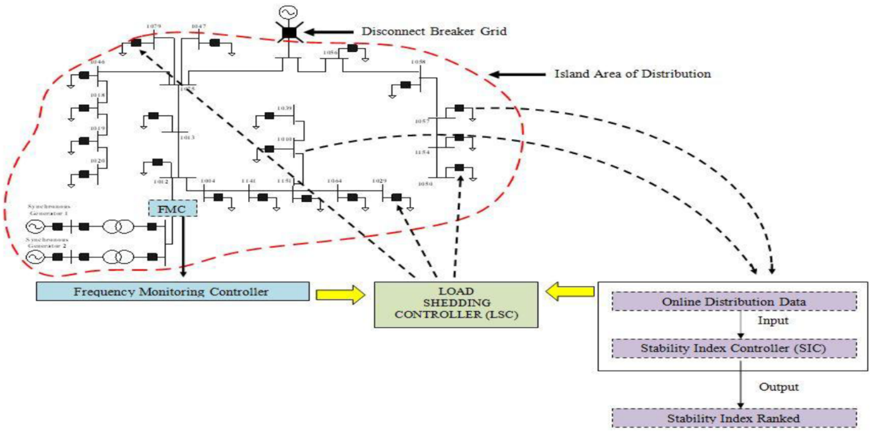

Figure 1. Layout of the proposed scheme.

declines below the limit, a certain load may need to be shed to restore the system frequency. In this paper, to secure the operation of the islanded distribution network, $f_{setlimit}$ is set to 49.5 Hz, which is commonly used in Malaysia. The FMC will send a signal to the LSC in order to disconnect the load immediately after the frequency drops below $f_{setlimit}$. For multiple MHGs, the FMC calculates the center of inertia frequency (COIF)as follows [21]:

$$f_{COI} = \frac{\sum_{i=1}^{N} H_i f_i}{\sum_{i=1}^{N} H_i}, \tag{1}$$

where f_{COI} is COIF (Hz), H_i is the inertia constant of the ith generator (seconds), f_i is the frequency of the ith generator (Hz), and N is the number of DGs.

2.2. Online stability index controller

The SIC is developed by adopting the power stability index (PSI) proposed in [22] to identify the critical buses through the VS index. The index is chosen since it is formulated based on a distribution system characteristic in which the R/X ratio is high. Furthermore, the DG consideration in the formulation also makes the index suitable in assessing VS for distribution systems connected to DGs. This index has been proven to work well in determining the optimization of DG placement [12]. Mathematically, the PSI is given as:

$$PSI_{N,N=j-1} = \frac{4r_{ij}\left(P_{Lj}\right)}{\left[|V_i| \times \cos\left(\theta - \delta\right)\right]^2}, \tag{2}$$

where r_{ij} is the line resistance in pu, i is the sending bus, j is the receiving bus, P_{Lj} is the real power load, V_i is the voltage at the sending end, $\theta$is the receiving end angle, and $\delta$is the sending end angle.

The VS index of all buses in the distribution system is calculated by using Eq. (2). The SIC ranks PSI in descending order. The bus with an index value close to 1 represents the most critical bus in the distribution system. Critical buses with high volatility will be shed first in the system. It should be noted that the SIC controller algorithm is designed in such a way that it keeps updating the status of each bus and VS index values for ranking the load buses in the system during system disturbances. After identifying the critical load buses, the SIC controller sends the signal to the LSC to disconnect the loads.

2.3. Load shedding controller

The LSC is the controller that sheds the load based on the developed load-shedding algorithm. The algorithm is activated when it receives the signal of the main circuit breaker on the islanding formation. Continuous input signals received from the FMC and SIC prompt the LSC to make the decision to shed the load. The LSC will disconnect the loads that have critical VS values.

The amount of load to be shed is determined based on the amount of power imbalance resulting from islanding. There are 2 strategies used to determine power imbalances: event-based and response-based strategies. An event-based strategy is applied when a part of the distribution network is islanded. The LSC is initiated to determine the power imbalance to secure the islanding operation as given in Eq. (3):

$$\Delta P = (P_{grid} + P_{DG}) - P_{Load}, \tag{3}$$

where $\Delta P = P_{DG} P_{Load} \Delta P$ is the power mismatch between DG and total load demand, P_{grid} is the grid power generation, P_{DG} is the power dispatched by DG, and P_{Load} is the total load demand. The LSC uses the response-based strategy in the case of load increment to estimate the power imbalance. The mismatch in power is calculated by using the power swing equation. Mathematically, the total power imbalance due to load variation for N generators can be computed by using Eq. (4):

$$\Delta P = ((2 \times \sum_{i=1}^{N} H_i / f_n) \times df_C / dt), \tag{4}$$

where H_i is the inertia constant of the ith generator (in seconds), df_C/dt is the rate of change of COIF (H/s), f_n is the rated frequency (Hz), N is the number of DGs, and ΔP is the power imbalance.

3. Test system and load-shedding modeling

The test system in Figure 2 was modeled using PSCAD/EMTDC software. The system is an 11-kV distribution network composed of 25 buses and 20 lumped loads. There are 2 MHG units connected to the system. Each is rated at a capacity of 2 MVA with a maximum power dispatch of 1.8 MW and operates at a voltage level of 3.3 kV. These MHGs are connected to 2-MVA transformers to increase the voltage level to 11 kV. The transmission grid is connected to the distribution system via two units of step-down transformers (132 kV/11 kV), rated at 30 MVA each. The base and peak load of the system is 2.269 MW and 3.5872 MW, respectively.

Both MHGs units are synchronous generator types equipped with a governor, a hydraulic turbine with all the necessary valves to control water flows, and an excitation controller. A standard model of the exciter, governor, and hydraulic turbine components in the PSCAD/EMTDC library was used. For load modeling, the static load-type component was used. This type of load model considers the active and reactive power separately and is represented as [23] follows:

$$P = P_0 \left(1 + K_{fp} \Delta f + K_{vp} \Delta V\right), \tag{5}$$

$$Q = Q_0 \left(1 + K_{fq} \Delta f + K_{vq} \Delta V\right), \tag{6}$$

where P and Q are active and reactive power at the new voltage and frequency, P_0 and Q_0 are active and reactive power at base voltage and frequency, K_{fp} and K_{fq} are the coefficients of active and reactive power load dependency on frequency, K_{vp} and K_{vq} are the coefficients of active and reactive power load dependency on voltage, Δf is the frequency deviation, and ΔV represents voltage deviation.

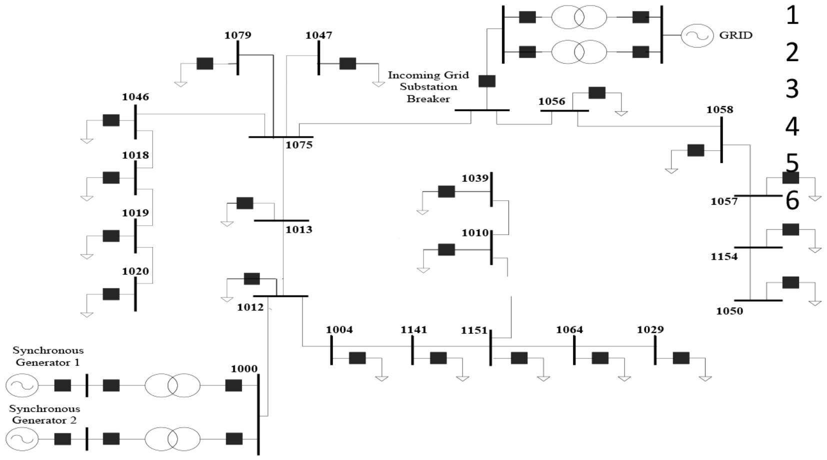

Figure 2. Test system.

The value of a load at particular buses in the test system is shown in Table 1. In this study, the distribution system is operated under peak load conditions. The performance of the proposed scheme is analyzed for an islanding operation at peak load with the various events simulated and presented in Section 4.1. As previously mentioned, the proposed load-shedding scheme will be compared with conventional and adaptive load-shedding techniques.

Table 1. Total load consumption in the distribution network.

Bus ranking	Bus no.	P (MW)	Q (Mvar)	Load priority	Bus ranking	Bus no.	P (MW)	Q (Mvar)	Load priority
1	1047	0.0615	0.0195	Nonvital	11	1064	0.1398	0.0867	Semivital
2	1013	0.0684	0.0423	Nonvital	12	1018	0.1743	0.1080	Semivital
3	1141	0.0796	0.0495	Nonvital	13	1154	0.2097	0.1275	Semivital
4	1012	0.0800	0.0495	Nonvital	14	1004	0.2121	0.1314	Semivital
5	1039	0.1040	0.0423	Nonvital	15	1046	0.2551	0.1578	Semivital
6	1050	0.1095	0.0576	Nonvital	16	1020	0.2767	0.1716	Semivital
7	1079	0.1179	0.0597	Nonvital	17	1029	0.3468	0.2148	Semivital
8	1010	0.1300	0.0678	Nonvital	18	1019	0.1601	0.0990	Vital
9	1057	0.1890	0.1152	Nonvital	19	1151	0.1608	0.0966	Vital
10	1058	0.1980	0.1230	Nonvital	20	1056	0.5139	0.3282	Vital

3.1. Modeling of the conventional UFLS scheme

The conventional UFLS scheme is modeled with 9 stages of load shedding, as shown in Table 2. The load is ranked according to the lowest amount of active load value without considering the load priority of the system. The conventional UFLS is initiated when the system frequency falls below 49.5 Hz. The load will be shed at every frequency threshold according to the defined stages and will stop once frequency is restored to its normal value. The main drawback of this scheme is that there is a possibility that extra load could be shed.

3.2. Modeling of the adaptive UFLS scheme

The modeling of the adaptive UFLS scheme is slightly different than that of the conventional UFLS scheme in that the total load to be shed is based on a calculated power imbalance. As in a conventional UFLS scheme,

Table 2. The 9 stages of the conventional UFLS scheme.

UFLS stage	Bus no.	Load (MW)	Frequency threshold (Hz)	UFLS stage	Bus no.	Load (MW)	Frequency threshold (Hz)
1	1047	0.0615		5	1151	0.1608	49.1
	1013	0.0684	49.5		1018	0.1743	
	1141	0.0796		6	1057	0.1890	49.0
2	1012	0.0800	49.4		1058	0.1980	
	1039	0.1040		7	1154	0.2097	48.9
3	1050	0.1095	49.3		1004	0.2121	
	1079	0.1179		8	1046	0.2551	48.8
4	1010	0.1300	49.2		1020	0.2767	
	1064	0.1398		9	1029	0.3468	48.7
5	1019	0.1601	49.1		1056	0.5139	

the system controller will check whenever the frequency limit reaches 49.5 Hz. Following system disturbances, the controller will determine the amount of power imbalance by using a swing equation, as shown in Eq. (4). After estimating the power imbalance, the load is shed according to the priority of load categories. These are presented in Table 1. The loads are categorized as vital, semivital, and nonvital and are ranked according to load prioritization. As reported in [14], nonvital loads, such as residential loads, are given priority to be shed first before vital loads (e.g., hospital or factory loads) during system disturbances.

4. Results and discussion

The performance of the proposed scheme will now be tested for islanding and in cases of load increment. Following this, the response of the system frequency and the voltage profile of the proposed scheme will be compared with the conventional and adaptive UFLS schemes.

4.1. Case I: islanding operation

This scenario is simulated to achieve an intentional islanding operation of the distribution network. The grid breaker trips at 3.5 s. After islanding, an excess of load that needs to be supplied by the MHGs causes a system frequency decline. The bus voltage magnitude also decreases, and this is shown in Figure 3 (i.e. in bus numbers 1012, 1050, and 1039).

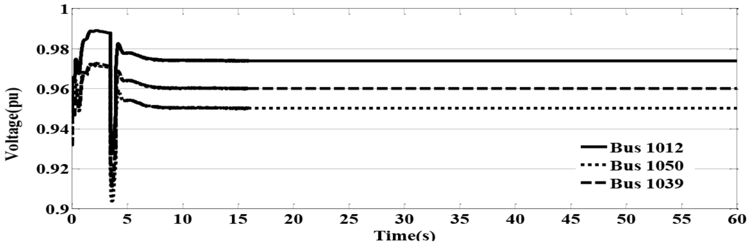

Figure 3. Voltage responses for various buses in the distribution network.

Prior to islanding, the MHGs supply 3.16 MW to the load (3.6613 MW) while the remaining supply is taken from the grid (0.5422 MW). Losing the main grid forces the MHGs to take over the generation from the grid. Considering the spinning reserve, the MHGs can only generate a maximum of 3.6 MW. Thus, to ensure the stability of the islanded area, excess loads need to be shed. In this scenario, the SIC continuously updates the VS index. Table 3 shows the ranked VS index of the PSI throughout the simulation. In the beginning, the VS index is evaluated using the SIC during the steady state. This initial process is important to recognize the critical buses in the test system. In terms of VS, the highest PSI value indicates the weakest bus in the system that has the highest possibility of collapsing. During the disconnection of the grid breaker, the VS index for buses 1151, 1141, 1064, 1039, and 1012 increases, as shown in Figure 4. During this time, the synchronous generator needs to maintain its stability without reaching the maximum reactive power limit. Without any control action, the voltage might drop and cause the generator to trip. If this occurs, VS is another critical issue to consider simultaneously along with system frequency in the load-shedding process. The LSC is then initiated and the event-based strategy is adopted to determine the power imbalance value (i.e. 0.39 MW). By implementing the proposed technique, the most critical buses, namely 1151, 1141, and 1064 (the highest values of PSI in the SIR), will be given the priority to be shed, as presented in Table 3. Since the VS index value lies between two bus voltages, removing the critical buses could affect the whole system voltage performance. Different approaches towards load shedding include the traditional (mentioned in Section 3.1) and adaptive (mentioned in Section 3.2) techniques. Both of these techniques do not consider VS as the primary concern in the load-shedding process. Thus, the most critical bus, 1151, still remains in the system. This critical point can create heavy stress on the system that can propagate to the whole network and affect overall system performance.

Table 3. Analysis of VS index ranking for Case I.

Bus number	Before load shed (3.5 s)		After load shed (40 s)		
	Steady state	Island	Proposed technique	Adaptive technique	Traditional technique
1151	0.5576	0.5892	0.0001	0.5636	0.5388
1141	0.2163	0.2288	0.0001	0.0001	0.0001
1064	0.1885	0.2002	0.0001	0.1915	0.0001
1039	0.1655	0.1760	0.1635	0.0001	0.0001
1012	0.1392	0.1605	0.1586	0.0001	0.0001
1046	0.0930	0.0994	0.0931	0.0951	0.0940
1010	0.0771	0.0819	0.0763	0.0783	0.0001
1029	0.0426	0.0452	0.0421	0.0432	0.0425
1020	0.0289	0.0309	0.0289	0.0296	0.0292
1004	0.0248	0.0263	0.0250	0.0254	0.0253
1056	0.0234	0.0251	0.0235	0.0240	0.0237
1057	0.0173	0.0185	0.0174	0.0177	0.0175
1018	0.0159	0.0170	0.0159	0.0162	0.0160
1019	0.0147	0.0157	0.0147	0.0150	0.0148
1154	0.0142	0.0152	0.0143	0.0145	0.0143
1058	0.0091	0.0098	0.0091	0.0093	0.0092
1050	0.0074	0.0080	0.0075	0.0076	0.0001
1079	0.0072	0.0078	0.0072	0.0074	0.0001
1013	0.0040	0.0042	0.0040	0.0001	0.0001
1047	0.0037	0.0040	0.0037	0.0001	0.0001

Therefore, to validate the novelty of the proposed scheme, the voltage response is compared with an adaptive UFLS scheme, as shown in Figure 5. It can be observed here that the proposed schemes provide the highest improvement in all bus voltages compared to the adaptive UFLS schemes. For conventional schemes,

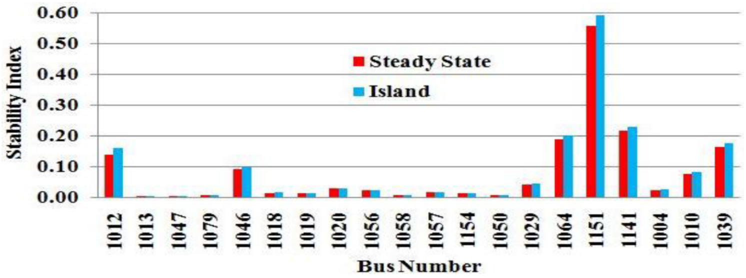

Figure 4. Comparison of VS index values during steady and islanding states.

the maximum and minimum bus voltage magnitude is 0.8374 pu and 0.7942 pu, respectively. These values show that the voltage magnitude is much lower than in the proposed scheme.

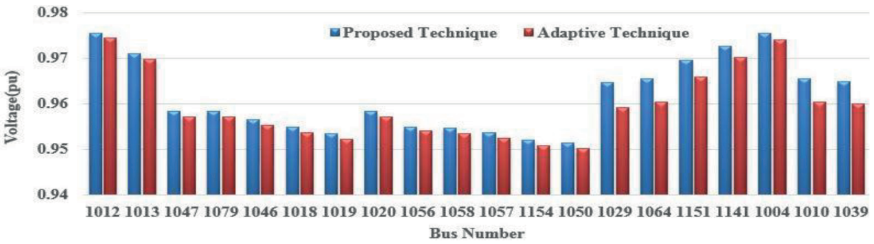

Figure 5. Voltage magnitudes for the proposed and adaptive schemes in Case I.

Further analysis of system frequency is shown in Figure 6. In this figure, the frequency response of the proposed scheme is compared with the conventional and adaptive UFLS schemes. To compare, the amount of load being shed and other parameters are shown in Table 4. Figure 6 shows that both the adaptive and conventional techniques have high levels of overshoot of 50.1 Hz and 50.5 Hz, respectively, compared to the proposed scheme. This is due to the extra load shedding as shown in Table 4. However, the proposed scheme response shows that it sheds the optimal amount of load and has a smooth response without any overshoot. Thus, the frequency and voltage response of the proposed scheme demonstrates that it successfully improves the voltage profile and stabilizes the system frequency by shedding lower amounts of load. Furthermore, the proposed scheme successfully eliminates critical buses from the system that may cause power collapse. Hence, the stability of the system is maintained.

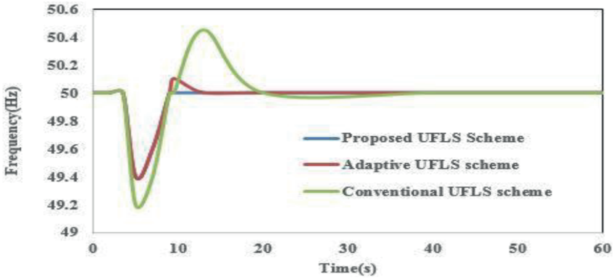

Figure 6. Frequency response for different load shedding techniques in islanding operation at 3.5 s.

4.2. Case II: load increment of 0.5 MW in the islanded system

In this case, a sudden overload scenario is simulated in the islanded distribution system. The sudden load increment is simulated during peak load at feeders 1047, 1013, and 1079 with a total power output of 0.5 MW

Table 4. Total load shed amount in an islanding operation at 3.5 s.

Power imbalance: 0.39 MW				Power imbalance: -	
Proposed technique		Adaptive technique		Conventional technique	
Number of buses	Load value (MW)	Number of buses	Load value (MW)	Number of buses	Load value (MW)
1151	0.1608	1047	0.0615	1012	0.0800
1141	0.0796	1013	0.0684	1013	0.0684
1064	0.1398	1141	0.0796	1047	0.0615
		1012	0.0800	1079	0.1179
		1039	0.1040	1050	0.1095
				1064	0.1398
				1141	0.0796
				1010	0.1300
				1039	0.1040
Total shed	0.3802	Total shed	0.3935	Total shed	0.8907

and 0.063 MVAR at t = 60.0 s. In peak load conditions, the total load on the islanded area is 3.2793 MW. After load increment, the total load increases to 3.7793 MW, which exceeds the maximum capacity of MHG generation (3.6 MW). To prevent the system frequency from further decline, the LSC evaluates whether ROCOF is greater than the threshold max (maximum ROCOF). If it is greater, the response-based strategy is initiated to determine the amount of load to be shed.

The response of the two UFLS schemes is shown in Tables 5 and 6. It can be observed that the conventional UFLS scheme sheds extra load in the islanding case (Case I). Due to this, the generation has a sufficient amount

Table 5. VS index ranking for the proposed technique at a load increment of 0.5 MW.

Proposed technique				
During islanding		Due to sudden load increase		
Bus number	VS index value	New bus ranking	VS index value	After LSS
1039	0.1635	1039	0.1704	0.0001
1012	0.1586	1012	0.1446	0.0001
1046	0.0931	1046	0.0974	0.0977
1010	0.0763	1010	0.0794	0.0787
1029	0.0421	1029	0.0438	0.0426
1020	0.0289	1020	0.0302	0.0294
1004	0.0250	1004	0.0259	0.0256
1056	0.0235	1056	0.0245	0.0239
1057	0.0174	1057	0.0181	0.0176
1018	0.0159	1079	0.0170	0.0166
1019	0.0147	1018	0.0166	0.0161
1154	0.0143	1013	0.0160	0.0157
1058	0.0091	1019	0.0152	0.0149
1050	0.0075	1154	0.0148	0.0144
1079	0.0072	1047	0.0130	0.0127
1013	0.0040	1058	0.0095	0.0092
1047	0.0037	1050	0.0078	0.0076
1151	0.0001	1151	0.0001	0.0001
1141	0.0001	1141	0.0001	0.0001
1064	0.0001	1064	0.0001	0.0001

Bus numbers of 1039–1012 are shed in Case II

Top 2 critical buses become stable after load shed in proposed LSS

Bus numbers of 1151–1064 are shed in Case I

Table 6. VS index ranking for the adaptive technique at a load increment of 0.5 MW.

Adaptive technique				
During islanding		Due to sudden load increase		
Bus number	VS index value	New bus ranking	VS index value	After LSS
1151	0.5636	1151	0.5673	0.5573
1064	0.1915	1064	0.1918	0.1873
1046	0.0951	1046	0.0953	0.0934
1010	0.0783	1010	0.0783	0.0001
1029	0.0432	1029	0.0433	0.0422
1020	0.0296	1020	0.0296	0.0289
1004	0.0254	1004	0.0254	0.0250
1056	0.0240	1056	0.0241	0.0236
1057	0.0177	1057	0.0177	0.0173
1018	0.0162	1079	0.0169	0.0089
1019	0.0150	1018	0.0163	0.0159
1154	0.0145	1019	0.0150	0.0147
1058	0.0093	1154	0.0145	0.0142
1050	0.0076	1013	0.0119	0.0001
1079	0.0074	1058	0.0093	0.0001
1141	0.0001	1047	0.0093	0.0087
1039	0.0001	1050	0.0076	0.0079
1012	0.0001	1039	0.0001	0.0001
1013	0.0001	1141	0.0001	0.0001
1047	0.0001	1012	0.0001	0.0001

Critical bus remains in the system

Bus numbers of 1039–1012 are shed in Case I

of power to supply the remaining 3.2 MW in the conventional scheme. However, the difference in response between the proposed UFLS scheme and the adaptive UFLS scheme is noticeable in this case.

The VS index of buses before and after load increment is shown in Tables 5 and 6 for the proposed and adaptive UFLS schemes, respectively. As tabulated, it can be observed that the VS index of load buses 1079, 1013, and 1047 has changed due to overload. According to this analysis, the sudden changes in the system affect the VS of the buses in the network. By using the proposed scheme, the top 2 critical buses, namely 1039 and 1012, become stable (close to zero) after the load is shed based on the SIR (Table 5). However, in the adaptive UFLS scheme, bus number 1151 (the critical bus) still remains in the system, as shown in Table 6. Thus, the proposed scheme offers better stability compared to the adaptive technique. Furthermore, a significant improvement of the voltage profile has been achieved using the proposed scheme compared to the adaptive technique, as illustrated in Figure 7. The frequency response of the adaptive and proposed scheme is shown in Figure 8, and the load shed amount is shown in Table 7. It can be observed that the proposed scheme sheds a lower amount of load (0.1840 MW) than the adaptive technique (0.3574 MW). Furthermore, the frequency response of the proposed scheme recovers to a nominal value without overshoot. On the other hand, the adaptive technique has an overshoot of 50.5 Hz. Therefore, the performance of the proposed scheme for voltage and frequency stability is more effective.

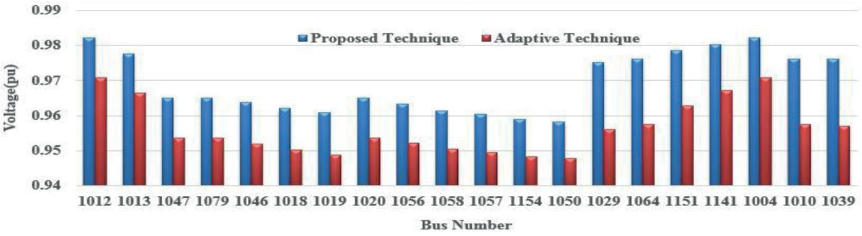

Figure 7. Voltage magnitude for proposed and adaptive schemes in Case II.

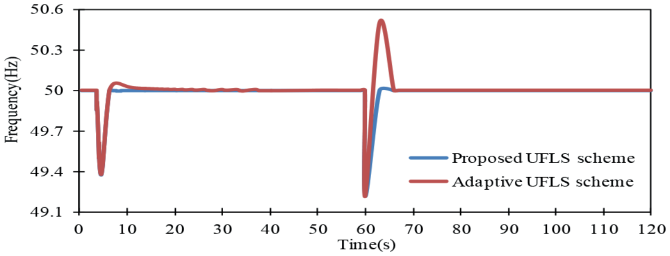

Figure 8. Frequency response for the proposed and adaptive techniques for a load increment of 0.5 MW.

Table 7. Total load shed amount in peak load for a load increment of 0.5 MW.

Power imbalance: 0.5 MW (overload)			
Proposed technique		Adaptive technique	
Number of (MW)	Load value (MW)	Number of buses	Load value (MW)
1039	0.1040	1050	0.1095
1012	0.0800	1079	0.1179
		1010	0.13
Total shed amount	0.1840	Total shed amount	0.3574

5. Conclusion

This paper has presented a new load-shedding scheme for an islanding operation of distribution networks connected with MHGs. The proposed scheme considered system frequency and voltage stability as the foundations of the load-shedding process. Because of this, both the voltage and frequency of the islanded distribution system can be restored to their nominal values following an event of unbalanced power between generations and loads. The proposed scheme was validated through simulation using PSCAD/EMTDC software on a Malaysian distribution network consisting of 2 MHGs. The simulation results proved that the proposed scheme resulted in a better voltage profile throughout the system, a smooth frequency response without overshoot, and the expulsion of buses with voltage stability problems from the system. Furthermore, a comparison with conventional and adaptive UFLS schemes also revealed that the proposed scheme is far better in terms of stabilizing the system.

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