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Combination of Adaptive and Intelligent Load Shedding Techniques for Distribution Network

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***Abstract*— One of the challenge in islanding operation is to maintain frequency stability when generation is less than demand. This paper presents a new Under-Frequency Load shedding scheme for an islanded distribution network. The scheme is based on an adaptive and intelligent load shedding techniques. This proposed scheme is able to conserve power system collapse even for large disturbance and events in the system. The proposed scheme is evaluated through simulation in PSCAD/EMTDC software. A distribution network connected with mini-hydro generation in Malaysia is chosen for the test. Various test scenarios show the effectiveness of the proposed load shedding scheme to shed optimum load.**

***Index Terms*—Mini Hydro, Distributed Management System, Under-Frequency Load Shedding, Distributed Generation, Islanding.**

I. Introduction

NOWADAYS, Distributed Generation (DG) penetration is increasing in power system network. In Europe for example, almost 10% of the total electricity is generating from combine heat power-based DG [1]. DGs also can provide higher sustainability and reliability in the system [2]. Furthermore, utilization of renewable resources around the world for DGs is mainly because of the electricity generation process is free from pollution and also economical. Although, DGs provide a lot of benefits, its implementation into a network caused the networks and system configuration need to be changed.

The occurrences of intentionally islanding in the system is one technical issue caused by DGs [3]. This operation is inspired with the high penetration level of DG expected in the near future and it benefit could be offered. Accordingly, IEEE 1547 group has produced a series of guide referred as P1547.4 IEEE Guide for Design, Operation, and Integration of Distributed Resource Island System with Electric Power System [4]. It will serve as a guide for practicing an intentional islanding operation in electric power system.

The main challenge in islanding operation is the sudden change in power generation and demand when a network is disconnected from the grid. A large excess of load over local generation in the islanded system could result to a rapid frequency drop. The only way to prevent the response from becoming even worst and eventually collapse is to reject several loads in order to bring the frequency back to its nominal value. Load shedding helps to bring back the power balance in the system and prevent voltage and frequency decay. Under-Frequency Load Shedding (UFLS) must be performed quickly to arrest power system frequency decline by decreasing power system load to match available generating capacity.

Conventional load shedding scheme is a simple method to eliminate the over load effects in the system. Although the scheme is simple, it is widely known to be unreliable in shedding the right amount of load [5-7]. Thus, to improve its performance, an optimal load shedding scheme have been developed with adaptive load shedding technique in [7-8]. The frequency and the Rate of Change of Frequency (ROCOF) are estimated by the non-recursive Newton type algorithm for applying the adaptive under frequency load shedding in [6]. The response-based method is the adaptive load shedding and uses the swing equation for the calculation of the power imbalance in the system. Comparison between two centralized adaptive load shedding in response-based and combination of event-based and response-based is applied in [9-10]. An adaptive load shedding scheme was proposed, for typical UK distribution network in an islanded connected with DGs. It comprised of different type and size of loads and DGs [11]. The load shedding scheme for islanded power system based on dynamic prioritization is proposed for Navy shipboard power system in [12]. Load shedding scheme based on the frequency information, ROCOF, customers' willingness to pay and load histories is presented on islanded distribution network in [13].

This paper proposes a new strategy of load shedding scheme which will provide a solution for an islanded distribution system. The strategy utilizes a combination of adaptive and intelligent UFLS scheme adopting the event-based and response-based method to tackle those scenarios respectively. The proposed scheme is implemented to an intentional islanding operation considering existing Malaysia's distribution network. The islanding operation study is simulated using the PSCAD/EMTDC simulation tool.

II. Proposed UFLS Scheme to Protect Distribution Network

In this study, the distribution system is assumed to have reliable monitoring devices and fast communication system to transmit data. Real-time measurement unit and Remote Circuit Breakers (RCB) are facilitated at each of the load feeders. In this paper, Distributed Management system (DMS) will control and monitor the distribution network and DGs as illustrated in Fig. 1. It will decide the numbers of loads need to be shed in order to maintain frequency stability of the system.

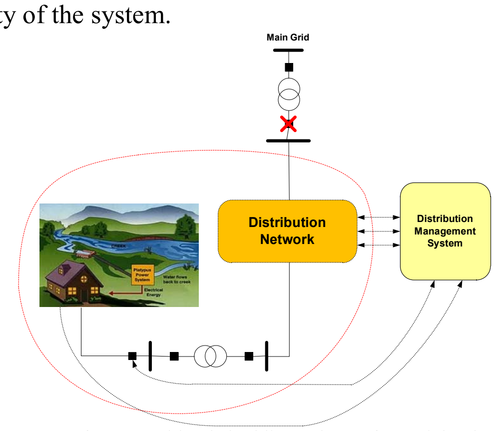

Fig. 1. concept of proposed load shedding scheme for an islanded network

The network is consists of two mini-hydro generators as shown in Fig. 1. The DMS will first check whether any of the generators is disconnected from the network. If this happens, the frequency of the network will follow to the frequency of the generator that is still in operation. Otherwise if both generators are still in operation, the frequency of the equivalent inertial center, f_c, is taken [14-15]. It can be calculated in (1).

$$f_c = \frac{\sum_{i=1}^{N} H_i f_i}{\sum_{i=1}^{N} H_i} \quad (1)$$

Where

N is the number of generators

H_i is inertia constant of each generator, seconds

f_i is the frequency of each generator, Hertz.

This frequency is then compared to the frequency protection setting of each generator. If the frequency lies outside this setting, both generators will be tripped off, which in practice available to protect the generator. Otherwise, the frequency will be used to calculate the ROCOF. Then the load shedding scheme is executed into the DMS to shed optimal load in the network according to the disturbance magnitude. There are two methods to determine the amount of loads that are needed to be shed. These methods are 1) event-based method and 2) response-based method. The algorithm will have to decide the right strategies based on the ROCOF and breaker status at the network and generators.

Frequency is measured and ROCOF is calculated at every half cycle and controller checks the breaker status, continuously. To remove any small disturbances in the system, the magnitude of ROCOF is compared with $ROCOF_{max}$ (absolute value set in the DMS). If it is greater than $ROCOF_{max}$ then it might need to shed some loads. The magnitude of ROCOF is utilized to estimate the power imbalance. It is estimated by using the ith generators swing equation of the system with N machines derived from the swing equation which is expressed in (2):

$$\Delta P = \frac{2 * \sum_{i=1}^{N} H_i}{f_n} * \frac{df_c}{dt} \quad (2)$$

Where

f_n is the rated value of frequency, Hertz

ΔP is the imbalance power, per-unit.

Event-based strategy will be applied when one of the generators is tripped during islanded mode. The proposed strategy will intelligently make a decision to improve the system frequency response and also prevent the blackout in the system. If event-based occurs, the algorithm will calculate the total power imbalance between the generation and total load demand.

III. THE DISTRIBUTION SYSTEM MODEL WITH DGS

The test system is shown in Fig. 2. It consists of 23 buses, 20 lumped loads with 2 mini-hydro generators. The DMS can be controlled the system frequency by 16 RCBs. Both mini-hydro generators are connected on Main bus bar and supplies power to distribution network.

In this research, DG is comprised of two mini-hydro synchronous generator units having nominal terminal voltage of 3.3 kV. Each generator connected with transformer for stepping up to 11 kV for distribution network. The generators are driven by a hydraulic turbine for controlling the mechanical torque by water flow. The generators are also equipped with excitation control and this is an important requirement since the unit is expected to maintain voltage level on acceptable range in the system. The excitation system model chosen in this work is the IEEE type AC1A standard model and the Non-Elastic Water Column without Surge Tank model as a hydraulic turbine model.

Loads are ranked based on their priorities. Load look-up table is classified in 3 categories such as vital, semi-vital and non-vital. Table I shows the load classification and value of active power during the low, medium and peak load. The proposed load shedding technique will disconnect the load with lowest ranked firstly, according to the order of priority, and the load with high ranked at the last.

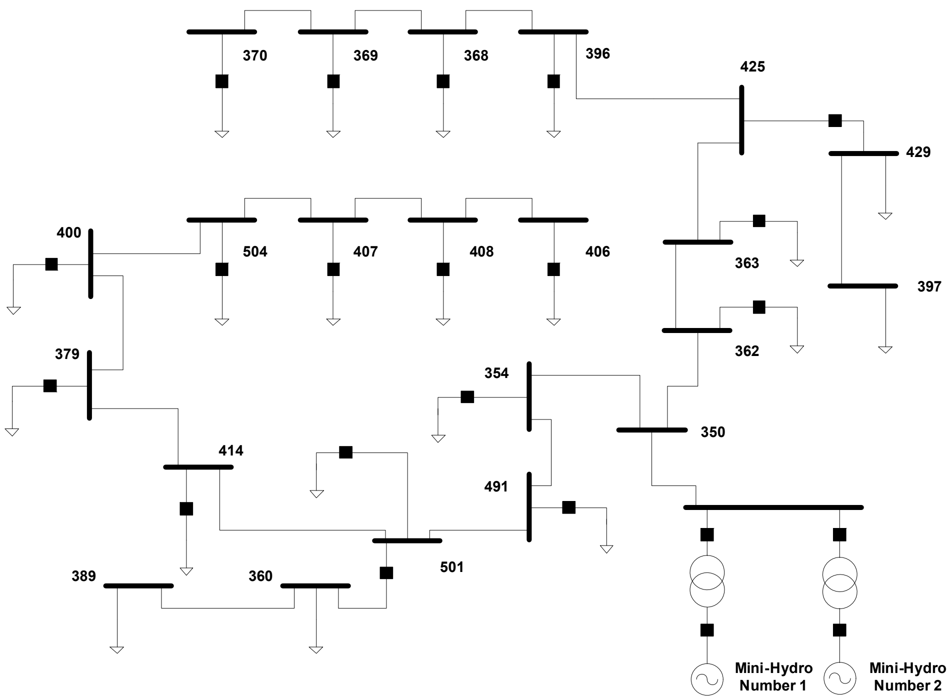

Fig. 2. test system

TABLE I
LOAD RANKING TABLE

Load Ranked	Bus Number	P (MW) Peak Load	P (MW) Medium Load	P (MW) Base Load
1	363	0.0456	0.03649	0.02739
2	491	0.0531	0.04255	0.03201
3	362	0.0531	0.04249	0.03189
4	400	0.063	0.0501	0.0372
5	397-429	0.11721	0.09831	0.07941
6	407	0.126	0.0816	0.0372
7	408	0.132	0.10564	0.07929
8	360-389	0.15009	0.12864	0.10719
9	368	0.11619	0.09294	0.06969
10	354	0.14151	0.09726	0.05301
11	370	0.1845	0.1476	0.1107
12	396	0.1701	0.1701	0.1701
13	504	0.1398	0.11179	0.08379
14	414	0.0932	0.0932	0.0932
15	379	0.2313	0.18505	0.13881
16	369	0.10671	0.08535	0.06399
17	501	0.10719	0.085744	0.06429
18	406	0.35259	0.3183	0.28401

IV. SIMULATION RESULTS AND VALIDATIONS

Various events are simulated to justify the effectiveness of the proposed load shedding scheme. The scheme should be able to cope with the different range of power imbalance between load and generation following the events. The events consider two main scenarios: i) the loss of a generator and ii) applying disturbance on the system (overload). Test on scenario (i) is shown by test case I and II. Meanwhile, scenario (ii) is shown by test case III and IV. System frequency response is considered for different load value of the distribution network in base, medium and peak load. The descriptions of the test cases are summarized as follow:

A. *Case 1*: Trip the synchronous generator number 1.

In this case, loss of a generator in the system is simulated. Loss of a generator is a huge disturbance in this distribution system. It causes real power imbalance between generation and demand. This event can results in the drop of voltage and frequency within system; because the system has lost half of the generation. UFLS should remove optimum load of the system to recover the system frequency and voltages, and keep them in acceptable range. In this scenario, the synchronous generator number 1 will be tripped at time t=10 seconds (s). Optimum load shedding values are presented in Table II. The total load shed by DMS in different condition is observed.

TABLE II
OPTIMAL LOAD SHEDDING BY DMS

Load Case	Power Imbalance (MW)	Load Shed (MW)
Base Load	0.8322	0.66498
Medium Load	1.022	0.92362
Peak Load	1.25	0.9978

The proposed UFLS scheme keeps the frequency and voltage within the threshold value. Fig. 3 shows the frequency response of the network before and after applying the disturbance. When synchronous generator number 1 was tripped, system frequency dropped to 48.924 Hz, 48.239 Hz and 48.009 Hz for base, medium and peak load cases, respectively and recovers to 50 Hz after around 25 s.

The DMS can measure the power consumption of loads. After estimating the disturbance value and difference between generation and consumption the module will shed the optimum load, according to the load prioritization and lookup table as shown in Table I to keep the frequency and voltage within the threshold value. Fig. 4 depicts the voltage magnitude on bus 406 for different load cases.

B. *Case 2*: Trip the synchronous generator number 1, without applying load shedding scheme.

In this case, loss of a generator is simulated without the implementation of UFLS scheme in base, medium and peak load. The generator number 1 will be tripped at time t=10 seconds (s). Fig. 5 shows the frequency response of the system. This event results in the fall of voltage and frequency in the system. In this case, the generator number 2 cannot supplies the medium and peak load cases; then frequency drops to 40.318 and 27.733 Hz respectively. In base load, system frequency will recover after 30 s and it falls to 42.883 Hz (however, system frequency crosses the protection setting). Fig. 6 shows the system voltage on bus 350, 370, 406 and 425 in peak load.

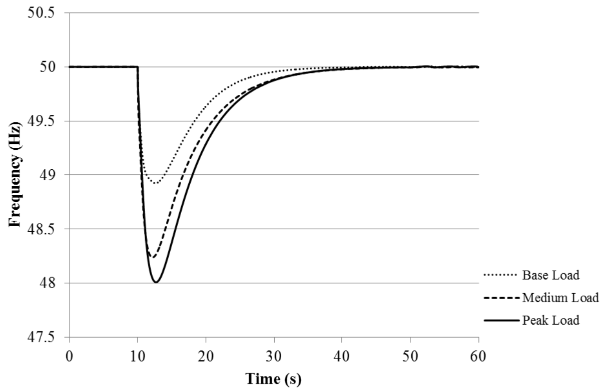

Fig. 3. System frequency and load shedding for case 1

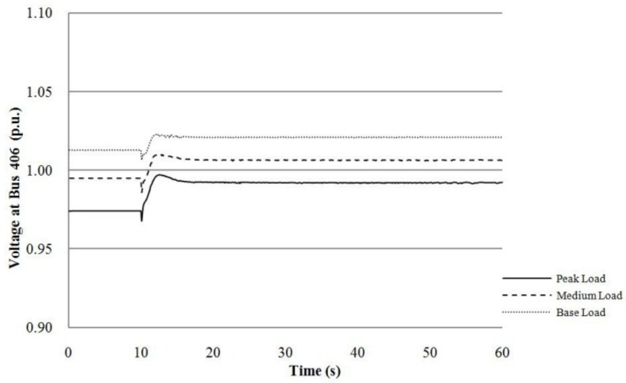

Fig. 4. System voltage at bus 406 and load shedding for case 1

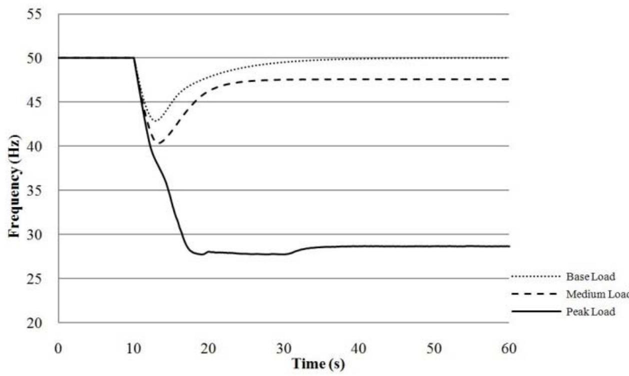

Fig. 5. System frequency without load shedding for case 2

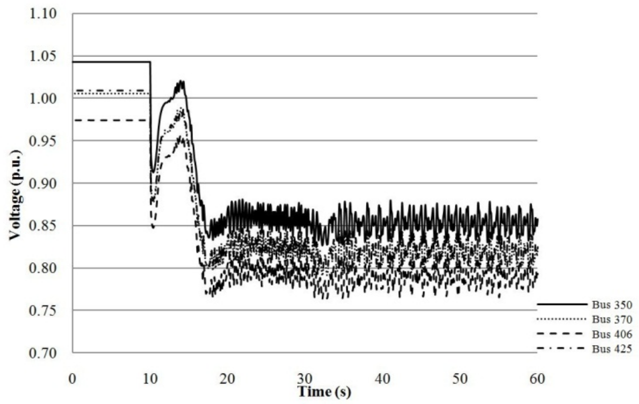

Fig. 6. Voltage magnitude without load shedding for case 2

C. Case 3: Overload in the system at bus 408 and 425.

This case considers two sequences of disturbances, which is overloading in the system. The first and second disturbances are applied to the system on bus numbers 408 and 425 at the time t=10 and 50 seconds (s), respectively. Fig. 7 reveals the system frequency response after applying overloads in the system. System voltage of bus number 406 is shown in Fig. 8. The DMS estimate the disturbance magnitude for both of them and then will shed the required load. In this case, the first disturbance equal to 0.27 MW is applied on bus numbers 408 and second disturbance is applied on the system of 0.42 MW in magnitude. Values of load shedding are represented in Table III for load cases.

TABLE III
OPTIMAL LOAD SHEDDING BY DMS

Load Case	*Load Shedding for First Disturbance (MW)*	*Load Shedding for Second Disturbance (MW)*
Base Load	0.2079 (number 1 to 5)	0.3464 (number 6 to 10)
Medium Load	0.17165 (number 1 to 4)	0.2856 (number 5 to 7)
Peak Load	0.1518 (number 1 to 3)	0.30621 (number 4 to 6)

Firstly, the DMS will estimate the disturbance magnitude then it will shed the load from low ranked. If the load with lowest ranked had been disconnected in the system then the controller will curtailment the load with next ranked, intelligently.

D. Case 4: Overload in the system at bus 379 and 350.

Case 4 includes the two disturbances on the system at different buses in contrast to *Case 3*. The First and second disturbances are applied to bus 379 and 350 at the time t=10 and 50 seconds (s), respectively. In this case, the first disturbance equal to 0.27 MW is applied and second disturbance is applied on the system of 0.42 MW in magnitude. The DMS estimate disturbance magnitude for both of them and then will shed the required load. System frequency response and system voltage of bus number 406 are shown in Fig. 9 and Fig. 10, respectively. System frequency response in this case is similar to *Case 3* (Fig. 7) in contrast to magnitude and time response.

The DMS will estimate the disturbance magnitude and it will be disconnected the required value of the load according to Table III. From the tests, it can be clearly seen that the proposed load shedding scheme can shed the optimum load according to the disturbance magnitude regardless the location of the disturbance. These results can be seen in *Case 3* and *4*, where suddenly load is increased at different locations.

The DMS estimated the magnitude of the disturbance without depending on overload location. The proposed method can prevent the frequency drop by shedding the optimal load in order to maintain the system stability. This method can provide better frequency profile, when a large disturbance applied in the distribution network. Because required value of load to be shed is determined by power swing equation and load shedding will be done in one step.

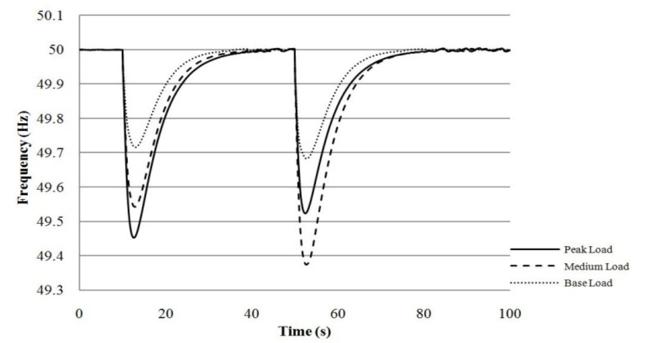

Fig. 7. System frequency and load shedding for case 3

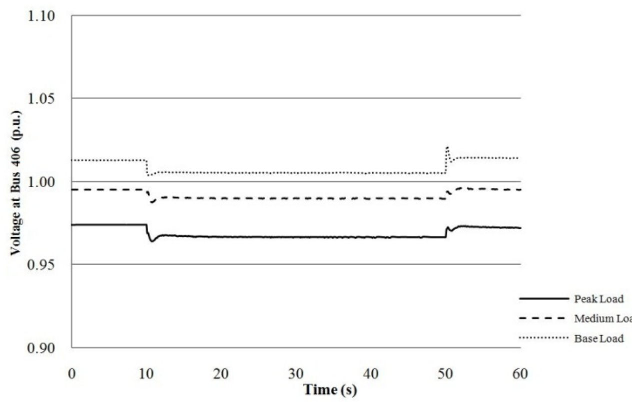

Fig. 8. Voltage magnitude at bus 406 for case 3

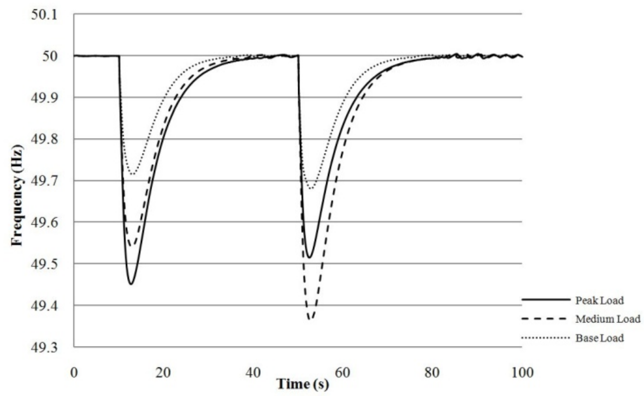

Fig. 9. System frequency and load shedding for case 4

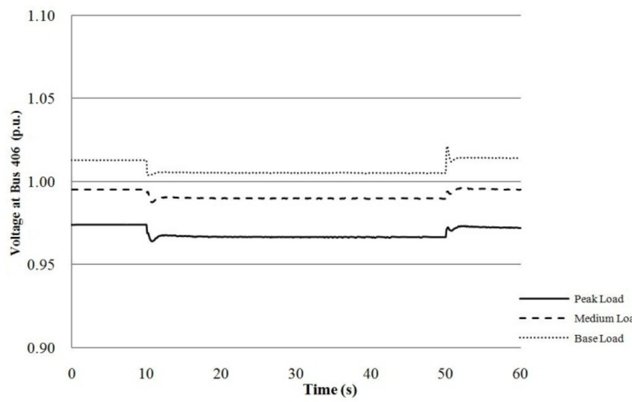

Fig. 10. Voltage magnitude at bus 406 for case 4

V. Conclusion

Load shedding techniques are developed to prevent frequency decline due to over loading in the system. This scheme adopt an UFLS scheme to improve the system stability and security by enhancing the frequency and voltage response of the system on occurrence of contingency in the power system. This research developed the load shedding scheme based on frequency and ROCOF for islanded distribution network. Also, it used the response based and event based method to improve the frequency response. The adaptive and intelligent schemes were considered to develop the proposed load shedding scheme. Developed UFLS scheme provide a fast decision to prevent the frequency decline in the system. The UFLS scheme disconnected the required load according to the load prioritization. Proposed method considers the load shedding without depending on overload location.

This UFLS method maximizes system benefit and stability, minimizes load curtailment and provides a better response of the system frequency and voltage. It can also, keep the system parameters in an acceptable range. This method will shed the optimal value of load without frequency overshoot.

VI. Acknowledgment

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