Under-Frequency Load Shedding for Islanded Distribution Network

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***Abstract*—Load shedding scheme is enabler for islanding operation of a distribution network. Considering the needs of effective load shedding scheme, this paper presents a new approach of load shedding based on Under Frequency Load Shedding scheme. The scheme is based on a combination of adaptive and intelligent techniques. The disturbance magnitude is estimated by utilization of the transient behaviour of the system frequency. Dynamic simulation on an intentional islanding operation is performed on an existing Malaysia network. The test results show the scheme successfully reduces the power deficiency in islanded system.**

I. Introduction

Distributed Generation (DG) penetration into power system network is continuously increasing around the world. The main motivations that led to this scenario are the sustainability of the renewable energy resources. Renewable resources such as wind, water, and solar are environmental friendly energy sources and available in any part of the world. By utilising this type of energy resources, generation process of electrical power by DGs will not produce pollution, which commonly un-avoided in conventional power plant.

Intentional islanding in the system is one of the benefits that DGs can brought [1]. This operation is inspired with the high penetration level of DGs. Accordingly, IEEE 1547 group has produced a series of guide referred as IEEE Guide for Design, Operation, and Integration of Distributed Resource Island System with Electric Power System [2]. It serves as a guide for practicing an intentional islanding operation.

Whilst, DGs provide benefit for islanding operation, its integration required additional control of the network. Islanded distribution network have to support the real and reactive power of the customer loads. It should be able to keep the voltage and frequency level of the distribution network in an acceptable range. The main challenge in islanding operation is the sudden change in power generation and demand when a network is disconnected from the grid [3]. Since the islanded distribution network generally has small generators the system inertia is also small. As a result, the frequency tends to descend very quickly when there is unbalance between generation and demand. 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 acceptable value. Load shedding helps to bring back the power balance in the system and prevent voltage and frequency decay.

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 [4-6]. Thus, an optimal load shedding scheme have been developed with adaptive load shedding technique in [6, 7]. 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 [5]. 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 [8]. The load shedding scheme for islanded power system based on dynamic prioritization is proposed for Navy shipboard power system in [9]. Load shedding scheme based on the frequency information, ROCOF, customers' willingness to pay and load histories is presented on islanded distribution network in [10].

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 Under Frequency Load Shedding (UFLS) scheme adopting the event-based and response-based method. The proposed scheme is implemented to an intentional islanding operation considering existing Malaysia's distribution network. The islanding operation study is simulated through the PSCAD/EMTDC software.

II. Proposed Methodology for Distribution Network

The concept of the proposed load shedding scheme for an islanded distribution network is shown in Fig. 1.

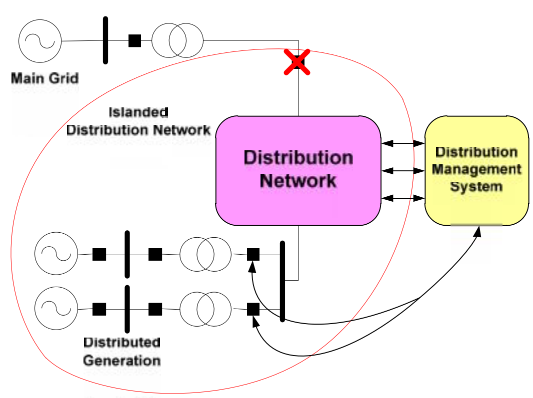

Fig. 1. Concept of proposed load shedding scheme

T-7-2

The proposed islanding scheme assumed that the distribution system equipped by reliable monitoring devices and fast communication system to transmit data for Distribution Management system (DMS). Real-time measurement units and Remote Circuit Breakers are facilitated at each bus and they can operate by DMS. It will control and monitor the distribution network and DGs. The load shedding scheme is implemented in the DMS to shed optimal load in the network according to the disturbance magnitude.

In DMS, the system frequency is measured and ROCOF is calculated. If any of the generators is disconnected from the network, the frequency of the network will follow the frequency of the generator that is in operation. Otherwise if both generators are in operation, the frequency of the equivalent inertial centre, f_c, is taken according to (1).

$$f_C = \frac{\sum_{i=1}^{N} H_i f_i}{\sum_{i=1}^{N} H_i} \tag{1}$$

Where N is the number of generators; H_i is inertia constant of each generator in seconds; f_i is the frequency of each generator in Hertz.

The calculated frequency will be compared to the frequency protection setting of each generator. If the frequency lies outside this setting, both generators will be tripped off to protect the generator (47.5 Hz in case of 50 Hz). Then, the algorithm need to decide the right strategies of load shedding based on the ROCOF and breaker status at the network and generators.

In this proposed method, the combination of adaptive and intelligent UFLS scheme is implemented. These methods are adopted the Event-based and Response-based methods to determine the amount of loads that are needed to be shed. Frequency, ROCOF and breaker status are determined continuously. In response based method to remove any small disturbances in the system, the magnitude of ROCOF is compared with $ROCOF_{min}$. If it is less than $ROCOF_{min}$ then it needs to shed some part of the customer loads. The power imbalance is estimated by using the i-th generators swing equation of the system with N machines derived from the swing equation which is expressed in (2):

$$\Delta P = \frac{2\sum_{i=1}^{N} H_i}{f_n} \times \frac{df_c}{dt} \tag{2}$$

Where ΔP is the imbalance power in per-unit and f_n is the rated value of frequency in Hertz;

Event-based strategy will be applied when one of the generators is tripped off 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. Test System

The test system of distribution network is shown in Fig. 2. It consists of 26 buses, 20 lumped loads with 2 mini-hydro generators. The system quality and stability are controlled by DMS. Both mini-hydro generators are connected to the main bus bar and comprises of two synchronous generator units. They have 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 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 is also chosen as a hydraulic turbine model.

Loads are ranked based on their priorities of its application. The proposed scheme will disconnect the load according to the order of priority. Three types of load priorities are defined for this purpose; vital, semi-vital and non-vital. Vital load and semi-vital loads are like hospital and offices. Meanwhile, non-vital load is residential area. Table 1 shows the load classification and value of active power during the low, medium and peak load of the test system.

TABLE I
LOAD RANKING TABLE

Load Ranked	Bus Number	P (MW)			Priority
		Peak Load	Medium Load	Base Load	
1	1013	0.0456	0.03649	0.02739	Non-vital
2	1141	0.0531	0.04255	0.03201	Non-vital
3	1012	0.0531	0.04249	0.03189	Non-vital
4	1050	0.063	0.0501	0.0372	Non-vital
5	1047-1079	0.11721	0.09831	0.07941	Non-vital
6	1057	0.126	0.0816	0.0372	Non-vital
7	1058	0.132	0.10564	0.07929	Non-vital
8	1010-1039	0.15009	0.12864	0.10719	Non-vital
9	1018	0.11619	0.09294	0.06969	Semi-vital
10	1004	0.14151	0.09726	0.05301	Semi-vital
11	1020	0.1845	0.1476	0.1107	Semi-vital
12	1046	0.1701	0.1701	0.1701	Semi-vital
13	1154	0.1398	0.11179	0.08379	Semi-vital
14	1064	0.0932	0.0932	0.0932	Semi-vital
15	1029	0.2313	0.18505	0.13881	Semi-vital
16	1019	0.10671	0.08535	0.06399	Vital
17	1151	0.10719	0.085744	0.06429	Vital
18	1056	0.35259	0.3183	0.28401	Vital

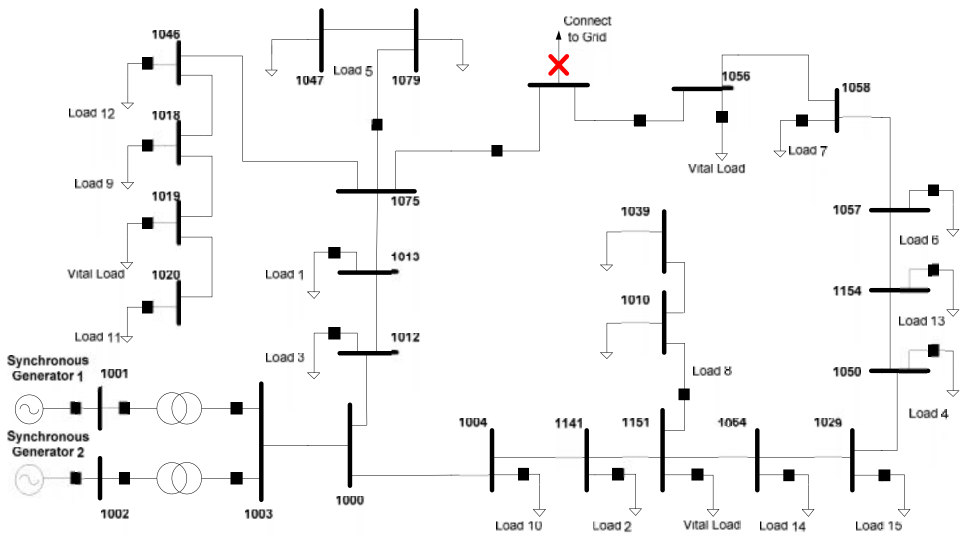

Fig. 2. Test system

IV. Simulation Results

Various events are simulated to study the effectiveness of the proposed load shedding scheme. The scheme should be able to cope with the different range of power imbalance following the events. The events consider two main scenarios: 1) the loss of a generator and 2) applying disturbance on the system (overload). System frequency response is considered for different load value of the distribution network in base, medium and peak load.

A. *Case 1: One synchronous generator is trip off*

In this case, loss of one generator causes 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 the system; because the system has lost half of the generation. UFLS should react quickly to recover the system frequency and voltages in acceptable range. To simulate this scenario, the synchronous generator will be tripped at time t=10 seconds. The total load shed by DMS is shown in Table II.

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 successfully keeps the frequency and voltage within the threshold value as shown in Fig. 3. It shows the frequency response of the network before and after applying the disturbance. When synchronous generator 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 25 s.

The DMS can estimate the disturbance magnitude 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 1. Fig. 4 depicts the voltage magnitude on bus 1056 for different load cases.

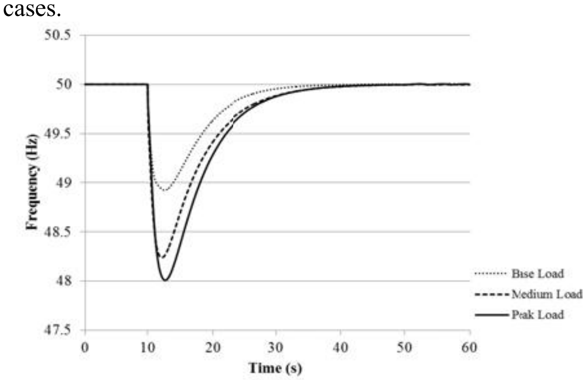

Fig. 3. System frequency and load shedding for case 1

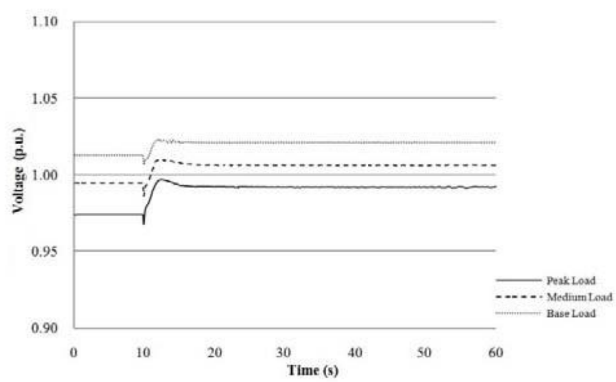

Fig. 4. System voltage at bus 1056 and load shedding for case 1

T-7-2

B. Case 2: Overload in the system at bus 1058 and 1075

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 1058 and 1075 at the time t=10 and 50 seconds, respectively. Fig. 5 shows the system frequency response after applying overloads in the system. System voltage of bus number 1056 is shown in Fig. 6. The DMS estimate the disturbance magnitude for both cases and then shed the required load. In this case, the first disturbance equal to 0.27 MW is applied on bus numbers 1058 and second disturbance is applied on the system of 0.42 MW in magnitude. Values of load shedding are presented 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)

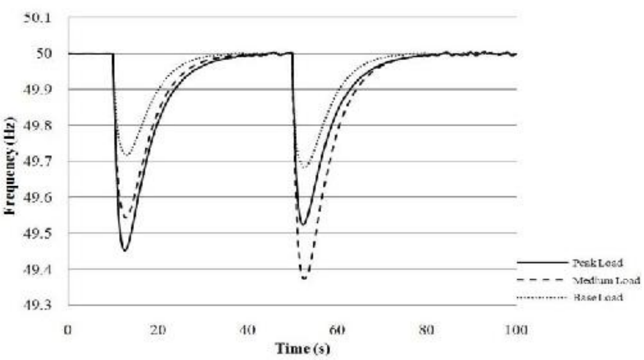

Fig. 5. System frequency and load shedding for case 3

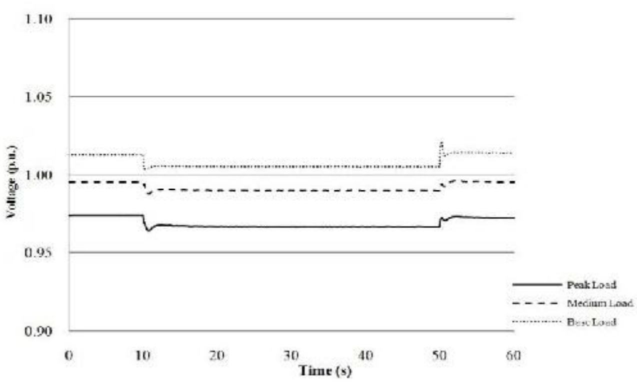

Fig. 6. Voltage magnitude at bus 1056 for case 2

V. CONCLUSIONS

This research developed the load shedding scheme based on frequency and ROCOF for islanded distribution network. 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. The proposed UFLS scheme disconnected the required load according to the load prioritization.

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. The proposed scheme provides a fast decision to prevent the frequency decline in the system.

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