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Under-Frequency Load Shedding Technique Considering Event-Based for an Islanded Distribution Network

One of the biggest challenge for an islanding operation is to sustain the frequency stability. A large power imbalance following islanding would cause under-frequency, hence an appropriate control is required to shed certain amount of load. The main objective of this research is to develop an adaptive under-frequency load shedding (UFLS) technique for an islanding system. The technique is designed considering an event-based which includes the moment system is islanded and a tripping of any DG unit during islanding operation. A disturbance magnitude is calculated to determine the amount of load to be shed. The technique is modeled by using PSCAD simulation tool. A simulation studies on a distribution network with mini hydro generation is carried out to evaluate the UFLS model. It is performed under different load condition: peak and base load. Results show that the load shedding technique have successfully shed certain amount of load and stabilized the system frequency.

Keywords: Electricity spot market; bilateral contracts; thermal unit commitment; mixed-integer linear programming.

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1. Introduction

The rapid growth of Distributed Generation based on renewable energy and distributed technologies such as solar, hydro, fuel cells, microturbines and energy storage connected directly to the distribution system contribute to the increased in generation capacity. One of the main benefits of DG is to improve the reliability and security of power supply by implementing an islanding [1,2]. Islanding is a situation where the distribution system becomes electrically isolated from the remainder of the power system and yet continues to be energized by the DG connected to it [2].

Islanding would be formed when there is a loss of main or fault occurs in the distribution system. When the system is islanded, DG will solely dispatch power to the load in the island. Following islanding, the frequency starts to deviate with respect to the amount of power imbalance between generation and load. A large power imbalance with a surplus load will lead to under frequency. A rapid frequency drop can occurs of which can lead to system collapse if it is not tackled. Thus, shedding some amount of load can restore the frequency to its nominal. This technique is called Under-Frequency Load Shedding (UFLS).

There are a numbers of load shedding techniques have been proposed to optimize the required load to be shed. The technique can be categorized into conventional and adaptive technique. Conventional is a traditional technique while adaptive is a dynamic and modern techniques [3]. Both techniques adopted different procedure in shedding the load. Conventional shed a specified amount of load whenever the frequency drops at certain value. However, adaptive is the most reliable technique that can be used to accurately shedding certain amount of load.

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UFLS scheme applied for islanded system requires a particular approach as compared to the scheme for grid connected. There are only a few research works reported on load shedding for islanded distribution system [4-6]. As of now, the proposed load shedding schemes reported in the literature have applied several approaches to get an optimal load shedding for the islanded system. Among the technique are the scheme based on the frequency and df/dt information, customers' willingness to pay and load histories [7] and the suitable time to shed the load [8].

This paper extends the study in [1,9] by evaluating the load shedding technique in a different islanding network with a different range of load. This paper only considers event based for islanding operation. The technique shed the load based on the amount of power imbalance from the swing equation. The effectiveness of the technique is investigated by performing simulation studies on distribution network that consists of a small unit of hydro generation. Several case scenarios which including base and peak load are simulated by using PSCAD software.

This paper comprises of four sections including the current section. The scope for Section II focuses on the methodology used to develop the load shedding scheme. Results on the simulation for several cases are discussed and presented in section III. Finally, conclusion is discussed in Section IV.

2. Development of Load Shedding Scheme

A different UFLS approach is needed to address the issue of frequency drop following islanding. The island is solely supply by the DG, thus there is high possibility of insufficient generation or overload. It needs an immediate action by shedding some of the load. The proposed technique is based on an adaptive UFLS considering event-based for an islanding operation. Event -based is the event occurs the moment system is islanded. Thus, this technique determines the amount of load to be shed based on the amount of power imbalance following islanding. It shed the load based on the load ranking, where the less important load is first shed. To adopt this technique, a new controller named as Load Shedding Controller Module (LSCM) was developed based on UFLS technique.

2.1. Modelling Load Shedding Controller Module (LSCM)

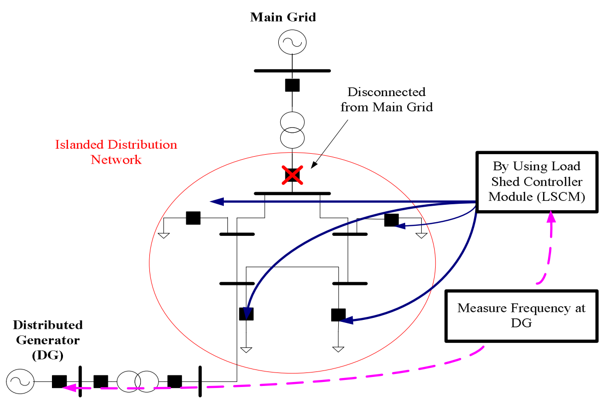

Fig.1. Principle operation of Load Shedding

Fig. 1 and 2 shows the concept of LSCM applied in this study. Measurement units that measure voltage, active power and reactive power and the Circuit Breaker (CB) are placed at each load feeder to make it easier to send data signal and trip the specified load. The status of the breaker is monitored by the LSCM. LSCM also receives frequency and active power data from DG in the test system. Frequency is continuously monitored from DG where the real-time frequency value is sent to the LSCM via the communication link. Total power imbalance is calculated by LSCM based on the measurements data. It will shed the load intelligently depend on the total power imbalance and according to the look up-table and demand load. Once the LSCM decides which load to shed, trip signal is sent to the CB to trip the specified load feeder.

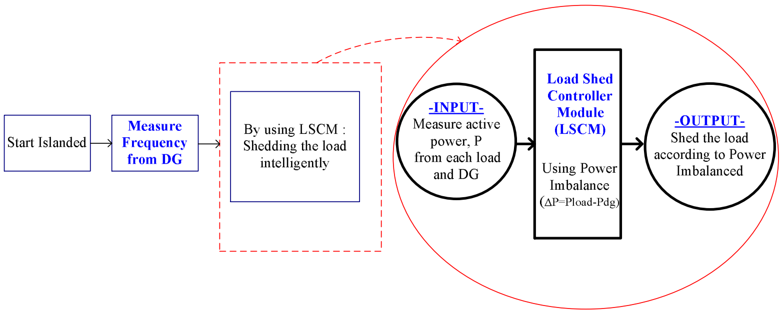

Fig.2. The development of Load Shedding Controller Module (LSCM)

The equation to calculate the power imbalance is expressed as in equation (1).

$$\Delta P = P_{LOAD} - P_{DG} - P_{RESERVE} \qquad (1)$$

Where

ΔP = Total Power Imbalance
P_{LOAD} = Total Load
P_{DG} = DG Power Generation
$P_{RESERVE}$ = Reserve for DG

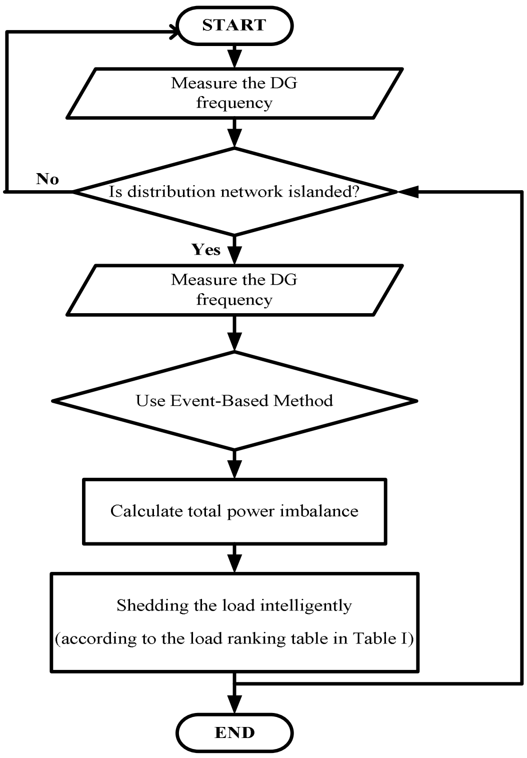

Fig.3. Principle operation of UFLS for event-based

As being discussed previously, the LSCM monitors the frequency of the system. Immediately after the system is islanded, if the frequency starts to drop from its nominal, then power imbalance is identified. Finally, the LSCM decides which load to shed and trip the corresponding CB.

3.2. Test Network

A. Test System

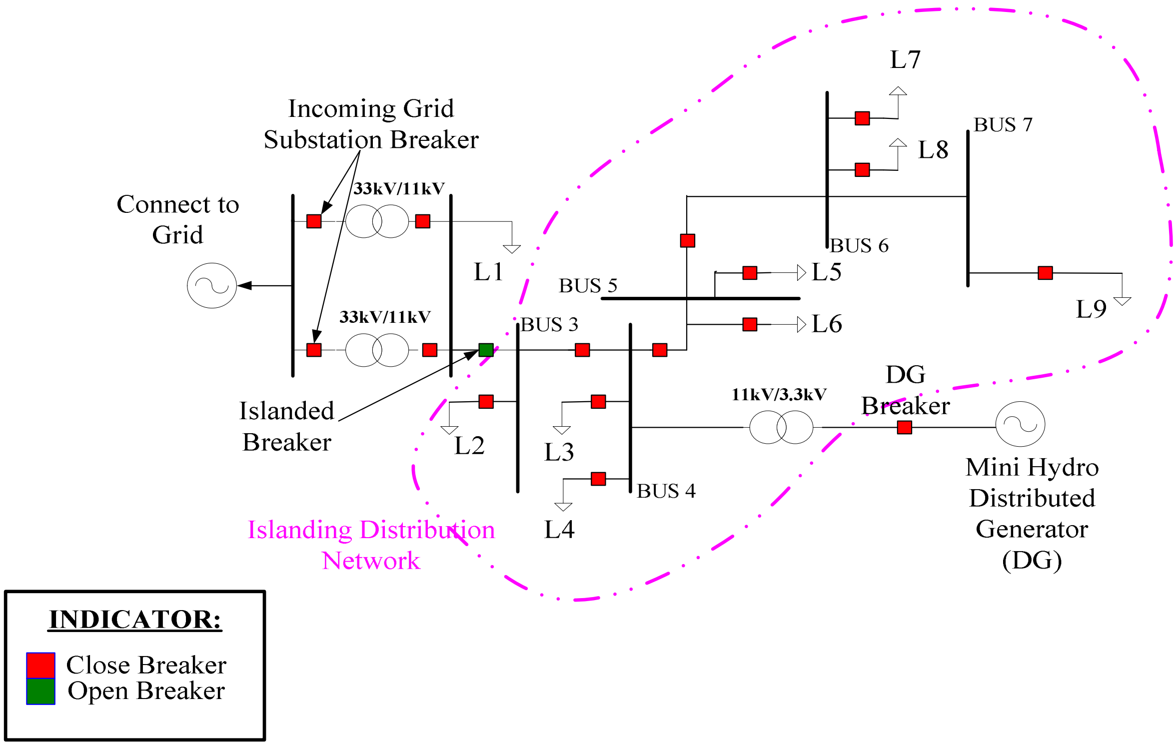

Fig.4. Test System

The test system shown in Fig. 4 was modeled using PSCAD simulation tool. The system comprises of 7 buses, 10 lumped loads with 1 mini hydro generator. This mini hydro generator is rated at 2 MVA and is operated at 3.3kV voltage level. The generator transformer is connected to the DGs to step up the voltage level to 11kV. The distribution network is connected to the main grid via two parallel steps up transformer (11kV/33kV) rated at 20 MVA. The system has 17 units of circuit breakers (CB) which comprises of 2 breakers for incoming grid substation, 9 breakers for load feeder, a DG breaker, an islanded breaker and another 4 is an additional breaker. This circuit used the PSCAD standard model of synchronous DG which includes exciter and governor model.

B. Load Model

Table 1 tabulates the amount of active and reactive power for all connected load. The loads are ranked based on their priority to be shed and load ranking table has been created based on their prioritization. Load is categorized into three categories which are non-vital, semi-vital and vital. For example, the non-vital load such as houses is known as unimportant load. Factory and hospital is an example of semi-vital and vital load respectively. The load shedding technique will shed according to the priority ranking.

TABLE 1. Load ranking table

Load Rank	Load Name	Peak Load (MW)		Base Load (MW)		Load Category
		P	Q	P	Q	
1	L1	0.5625	0.2724	0.3937	0.1907	NON-VITAL
2	L2	0.2437	0.1020	0.2106	0.0714	NON-VITAL
3	L3	0.3375	0.1102	0.2966	0.0771	NON-VITAL
4	L4	0.1500	0.0442	0.1050	0.0309	NON-VITAL
5	L5	0.2700	0.1307	0.2490	0.0915	SEMI-VITAL
6	L6	0.3375	0.1634	0.2362	0.1144	SEMI-VITAL
7	L7	0.4125	0.1452	0.2543	0.0716	VITAL
8	L8	0.6125	0.3452	0.4543	0.2716	VITAL
Total		**2.93**	**1.32**	**2.20**	**0.92**	

4. Results and Discussion

4.1. Case Studies

In order to evaluate the UFLS technique, an intentional islanding is simulated on the test system by opening an incoming grid substation breaker at time t=5.0 seconds (s). Following system islanded, all load in the island is supplied by a mini hydro generator (DG). If the amount of load is greater than active power supplied by the DG, load shedding must be applied to this system to sustain the islanding operation. Without application of load shedding, frequency would drop below 47.5Hz and eventually could cause a system collapse.

For this test system, two case studies are simulated which considers base and peak load. The total load demand for base load and peak load is 2.20MW and 2.93MW respectively. The total system loss is considered in the LSCM calculation.

The total power imbalance between load and generation following system islanded is estimated using the LSCM calculation. The amounts of power imbalance for both cases are recorded in Table 2.

TABLE 2. Optimal Load Shedding by LSCM

Load Case	***P_{load} (MW)***	***P_{dg} (MW)***	***Power imbalance (MW)***	**Load being shed**
Base load	2.200	1.730	0.470	L2
Peak load	2.930	1.730	1.200	L2, L3, L4

A. Base Load

As recorded in Table 2, the total power imbalance is 0.47MW for the base load scenario. The greater amount of load over generation would causing frequency drop unless mitigation technique such as UFLS is employed. Fig. 5 shows the frequency response without any load shedding. As can be seen, the system frequency drops and raises back to 46.6Hz. The frequency response would trigger the under frequency protection setting (set at 47.5Hz) and would eventually trip the DG's circuit breaker. This indicates that load shedding is needed to bring back the frequency to its nominal.

By using LSCM, only one load being shed i.e L2 according to the load ranking table. LSCM has chosen only L2 due to its value which is 0.39375 MW is the nearest to the power imbalance, 0.47MW. The result in Fig.6 shows that the frequency declines to 47.7 Hz and recovers to its nominal for duration of 15.0 seconds after the load shedding.

The voltage profile is also observed to make sure the system is in normal condition. As can be observed in Fig.7, the voltage at the DG terminal after islanding is 0.9735 p.u. This is acceptable since it is still in the range of normal voltage profile i.e between 0.95 p.u to 1.05 p.u.

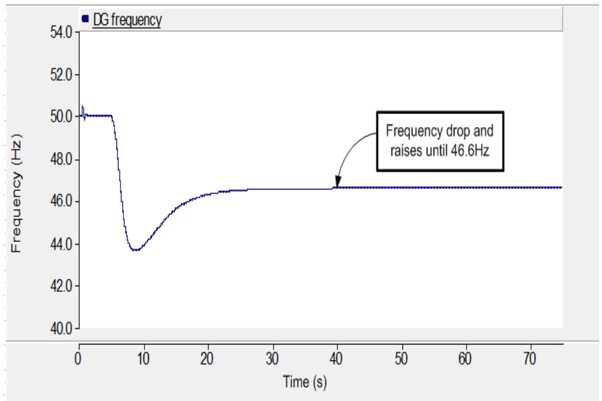

Fig.5. System frequency response without load shedding

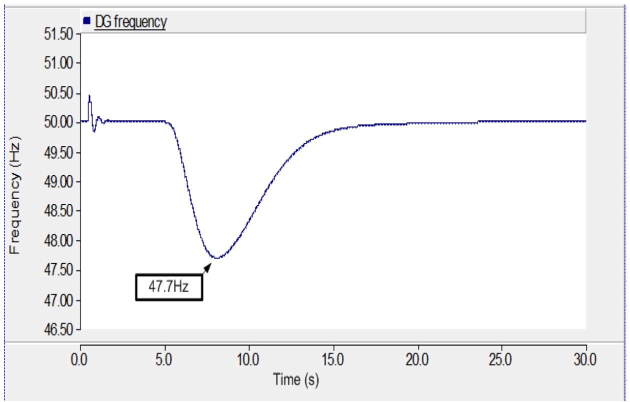

Fig.6. System frequency response with load shedding

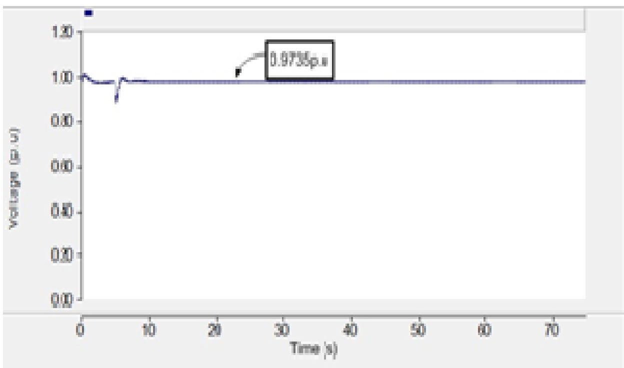

Fig.7. DG Voltage terminal's response

B. Peak Load

For the peak load scenario, the total power imbalance is 1.20MW. This is considered as an excessive amount of load over generation. Thus, it needs a rapid response from LSCM to shed several load. Fig.8 and Fig.9 show the frequency response without and with load shedding scheme respectively.

Without the load shedding scheme, the frequency drops to 16.7Hz, of which indicates the system collapse. However, with the load shedding scheme, the system frequency manages to restore to its nominal frequency which is 50Hz. Considering the load priority as tabulated in Table 1, three load i.e L2, L3 and L4 with a total of 1.1437 MW are shed by LSCM. Fig.10 shows the status of the breaker for each monitored load. It is obvious that three breakers representing the three load are tripped immediately after system is islanded.

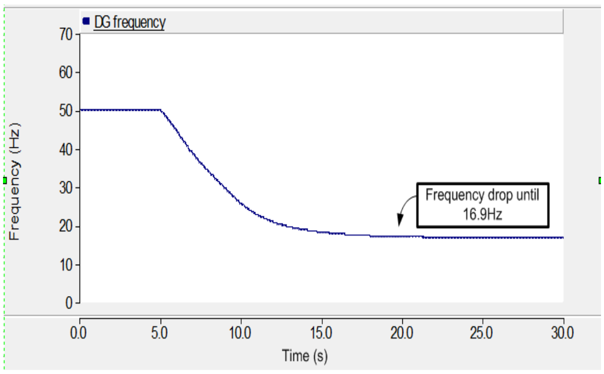

Fig.8. System frequency response without load shedding

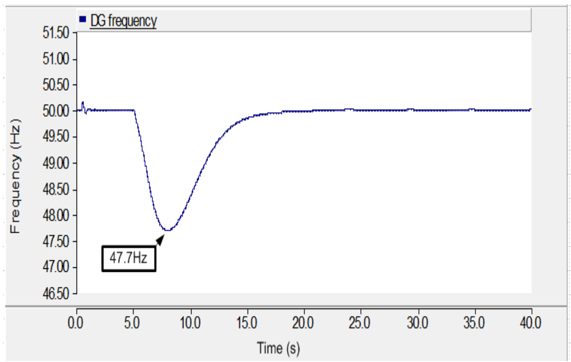

Fig.9. System frequency response with load shedding

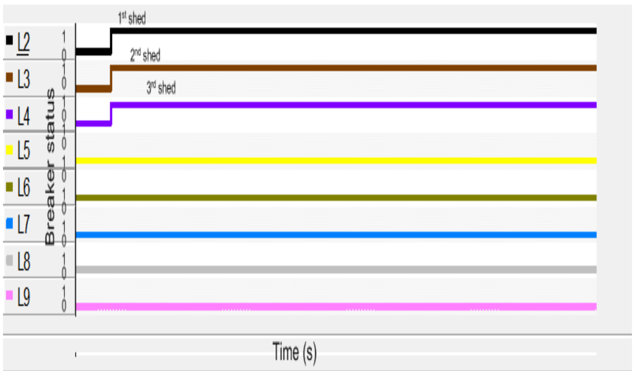

Fig.10. Breaker status of each load for peak load condition

Similar with base load, the voltage at the DG terminal is monitored to make sure it is within an acceptable voltage profile. As can be observed in Fig.11, the system voltage for this scenario is approximately about 0.9924p.u which is also in a normal voltage range.

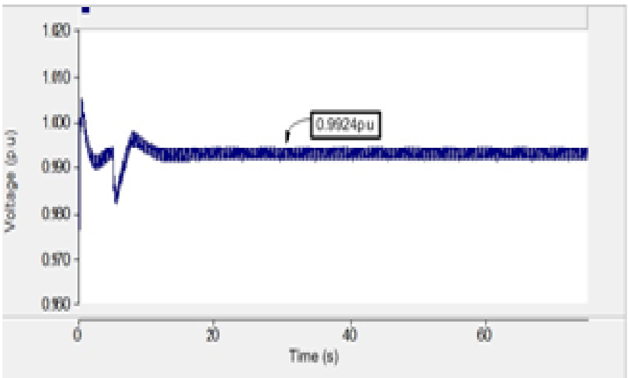

Fig.11. System voltage for peak load condition

5. Conclusion

This paper presents an adaptive under-frequency load shedding (UFLS) technique for islanded distribution network. A technique based on the event-based has been developed. The disturbances magnitude for the event based is determined based on the power imbalance using the swing equation. The effectiveness of the scheme has been investigated through simulation study on a distribution system. The developed scheme is tested for base and peak load scenario when the system is islanded. Based on the two case studies, the technique has shed a number of loads and has managed to bring the frequency back to its nominal (50Hz). Thus, it can be concluded that the power quality of the island can be sustained by using this technique.

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