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Method of Determining Load Priority using Fuzzy Logic for Adaptive Under Frequency Load Shedding Technique

A. I. M. Isa[1], H. Mohamad[1]*, K. Naidu[2], N. Y. Dahlan[1] and I. Musirin[1]

[1]Faculty of Electrical Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia
[2]Electrical Engineering Department, Faculty of Engineering Universiti of Malaya, 50603 Kuala Lumpur, Malaysia

ABSTRACT

Power systems are usually exposed to numerous disturbances that can have an adverse effect on system operation. Insufficient generation could lead to frequency declination and subsequently system collapse in the absence of immediate control action. Frequency Load Shedding (UFLS) is a technique commonly applied to overcome overloading and restore the system frequency. This paper presents an adaptive load shedding approach to determine the best location with minimum amount of load to be shed. Load Ranking Fuzzy Logic (LRFL) is used to rank the load based on their sensitivity and stability index. In order to achieve this, the proposed strategy is verified using 11 kV Malaysian distributed network consisting of different type of loads connected with single and multiple Distribution Generator (DG). The simulation results show that the proposed strategy successfully stabilizes the system's frequency.

Keywords: Distribution Generator, Under Frequency Load Shedding, Load Ranking based Fuzzy Logic, Load Priority

INTRODUCTION

Power system stability is of critical importance and proper contingency plans are required to ensure its reliability and security is maintained. With increasing demand for electricity, power systems are being operated at levels that are closer to their limits, thereby, increasing risks. .

Moreover, power systems are constantly exposed to various disturbances which could affect its operation. If the power system is not designed properly poor connection or disconnection of system elements can arise (Seyedi & Sanaye-Pasand, 2009 & Haotian, Chun Sing & Loi Lei, 2014;).

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E-mail addresses:
ama;omaozzati_isa@yahoo.com (A.I.M. Isa),
hasmaini@salam.uitm.edu.my (H. Mohamad),
vkanendra@gmail.com (K. Naidu),
nofri79@gmail.com (N.Y. Dahlan),
i_musirin@yahoo.co.uk(I. Musirin)
*Corresponding Author

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In the presence of load generation imbalance, the system frequency is affected. The frequency deviation could be detrimental to the system operation if mitigating action is not taken. It could cause cascading failure, loss of synchronization and finally total collapse of the system (Ahsan et al., 2012; Kanimozhi, Selvi, & Balaji, 2014; Rad & Abedi, 2008). So, it is very important to implement a protection scheme that preserves the stability and security of power system.

Frequency Load Shedding (UFLS) is an emergency protection scheme to protect the system from frequency instability when the generation is unable to meet load demand. The most commonly used UFLS in industry is to set the frequency level, time delay and amount of load to be shed at specified set values in the distribution relay (Seyedi & Sanaye-Pasand, 2009). Drawbacks of this method, adaptive UFLS method is introduced. The adaptive method is improved by estimating the amount of power imbalance based on Rate of Change of Frequency (ROCOF). The control signal based on adaptive UFLS is send to the control centre and the decision to shed the appropriate amount of load is made.

In the load shedding method, many researches have considered voltage stability analysis as an indicator to determine the critical bus in the transmission line (J, 2013; Van Cutsem, Moors, & Lefebvre, 2002). Due to the quick nature of system collapse, it is important to determine the critical busses in the system order to avoid voltage instability. In (Sapari, Mokhlis, Bakar, & Dahalan, 2014), authors have introduced Load Stability Index (LSI) as an indicator to determine the critical load busses in the distribution network. By using the sensitivity information, an optimization problem is determined and the optimal load shedding amount established. The variation in the sensitivities with respect to the load shedding amount is initially investigated. The resulting non-linear optimization problem needs to be solved in order to obtain the best location and minimum amount of load to be shed.

With this in mind an adaptive load shedding technique using Load Ranking based Fuzzy Logic (LRFL) was introduced. The proposed technique considers load stability index (LSI) and Rate of Change of Power (ROCOP) in case of high demand and ensures the overall system is balanced in order to prevent from total system collapse. The objective of this technique is to choose the load optimally so it could prevent frequency decay and maintain load generation balance.

PROBLEM FORMULATION

Overall Concept of Adaptive UFLS

The proposed Adaptive UFLS scheme uses Load Ranking based Fuzzy Logic (LRFL) to stabilize the system by shedding the minimum amount of load at optimal location. LRFL comprises of two steps. In the first step, it will receive the input of Load Stability Index (LSI) and Rate of Change of Power (ROCOP) from the PSCAD and continuously monitor these values. The second steps, from the values obtained in first steps it will rank load according to the fuzzy rules into three categories i.e. non-vital, semi-vital, and vital load. The Load Shedding Controller will determine the amount of load that needs to be shed based on the amount of power imbalance. The overall concept of the proposed Adaptive UFLS technique is illustrated in Figure 1.

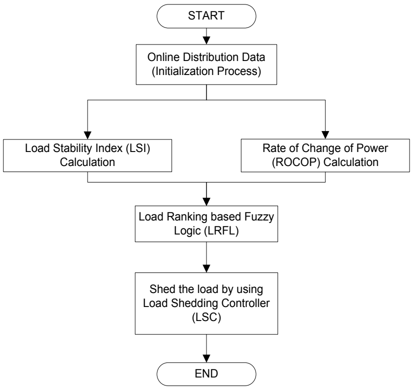

Figure 1. Overall concept of adaptive UFLS

Modelling the Load Ranking based Fuzzy Logic (LRFL)

Load ranking strategy was used based on MATLAB's fuzzy logic controller. The first step is to determine the fuzzy set parameters by normalising and fuzzification of the input values. LRFL consist of two inputs and one output which are LSI, ROCOP and Load Ranking (LR) respectively. The input of LSI is fuzzified into Non-Critical (NC), Critical (C), Semi-Critical (SC) and Most-Critical (MC) while the input of ROCOP is fuzzified into Low (L), Very-Low (VL), Extra-Low (EL), and Very-Extra-Low (VEL). The fuzzified output of load ranking values are Non-Vital (NV), Semi-Vital (SV), and Vital (V). Depending on the input values, LRFL will rank the load. The membership function for the state variable and output control are defined and constructed. LRFL input and output membership function are shown in Figures 2, 3 and 4. The Second step of LRFL is fuzzy rule base and interference mechanism. The rule base helps LRFL in making decisions based on input and output control action. The IF-THEN rule is applied as shown in Table 1.

Table 1
LRFL module

Parameter		Load Stability Index (LSI)			
Rate of Change of Power (ROCOP)	Rules	NC	C	SC	MC
	L	NV	NV	NV	NV
	VL	NV	NV	NV	SV
	EL	NV	NV	SV	V
	VEL	SV	SV	V	V

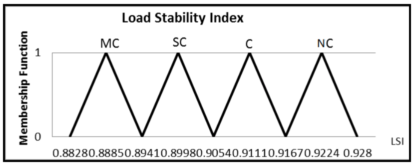

Figure 2. LSI membership function

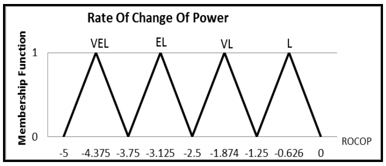

Figure 3. ROCOP membership function

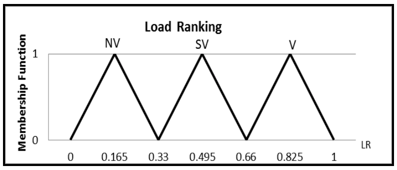

Figure 4. Load ranking membership function

Load Stability Index (LSI)

The stability index is used as an indicator for voltage instability in the power system network. The stability of the system relies between two busses and the values is between 0-1 as presented in Figure 5. The stability index is given in equation (Sapari et al., 2014):

$$|V_i|^4 - 4 \times \{P_j X_{ij} - Q_j r_{ij}\}^2 - 4 \times \{P_j X_{ij} - Q_j x_{ij}\}^2 \times |V_i|^2 \geq \quad (1)$$

In the LSI, both real power, *P* and reactive power, *Q* is considered as shown in equation (1). The bus with a LSI near to “0” is considered as a critical bus in the system.

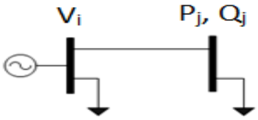

Figure 5. Stability index of distribution generator

Rate of Change of Power (ROCOP)

Rate of Change of Power (ROCOP) is normally used to assess the influence of active power variations (frequency and voltage) in the power system. In case when inertia is high in the system, for example when generator is operating parallel with the grid the impact is negligible. However, for isolated operation, the ROCOP parameter is used to take into account the state of the system frequency and voltage. The ROCOP parameter is effective on the distribution system which has an imbalance load compared to the system with balance load (Redfern, Barrett, & Usta, 1997).

Load Shedding Controller (LSC)

The principle operation of Load Shedding Controller (LSC) is shown in Figure 6. The LSC algorithm will always checks for system disturbance and continuously monitors the breaker status and system frequency. The main function of LSC is to calculate power imbalance based on the swing equation as shown in Equation 2.

$$\Delta P = P_m - P_e = \left(\left(2 \times \sum \frac{H_i}{f_n}\right) \times \frac{df_{coi}}{d_t}\right) \ldots\ldots(2) \qquad (2)$$

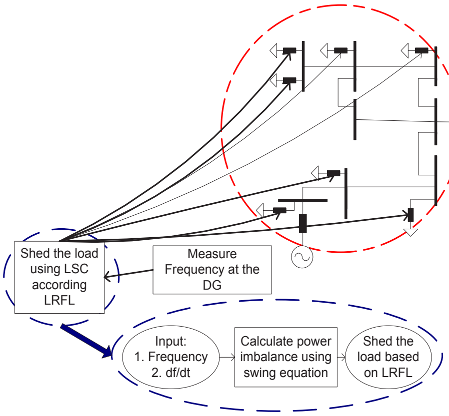

Figure 6. Principle operation of LSC

CASE STUDY

Test Network

Test system shown in Figure 7 is used to validate the performance and accuracy of proposed Adaptive UFLS technique. The system is connected to a 50 Hz, 33kV and 100MVA generator. The system consists of one unit mini hydro generator rated at 2MW and seven lumped loads. There are 2 units of 33/11 kV step-down transformers which are rated at 20 MVA and 1 units of 11/3.3 kV step-down transformer which is rated at 2MVA.

Load Sensitivity Case Study based on LRFL

The proposed Adaptive UFLS technique is tested in a distribution network for islanding operation. The islanding scenario is created by disconnecting utility breakers from the distribution network at t=10.0s. Due to power mismatch between generation and load, frequency declination occurs. Without a proper UFLS technique, the frequency will continue to decline until system collapse. As mentioned earlier, the LSI and ROCOP based ranking uses priority sequence of loads to be shed. Table 2 shows the load profile for each load in the distribution network.

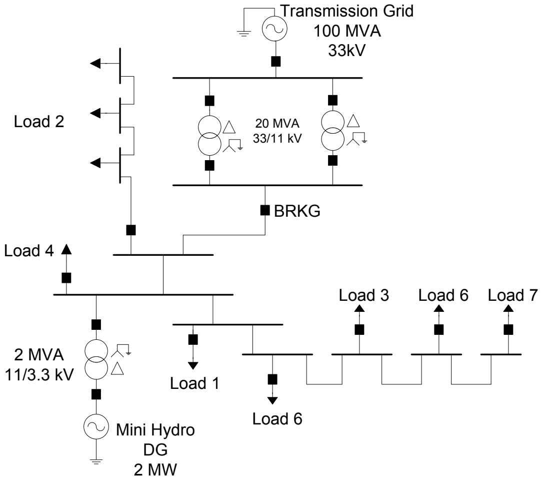

Figure 7. Test system

Table 2
Load Profile Table

Load	LSI	ROCOP	Load Values		Load Ranking	
			P (MW)	Q (MVAR)	Adaptive UFLS	Proposed UFLS
1	0.8827	-0.3809	0.0748	0.0464	NV1	NV2
2	0.9279	-0.5852	0.0976	0.0606	NV2	NV1
3	0.8853	-1.2651	0.1582	0.092	NV3	NV3
4	0.9205	-2.453	0.2786	0.1606	SV1	SV2
5	0.8953	-1.2471	0.1658	0.0906	SV2	SV1
6	0.9001	-3.774	0.5345	0.3074	V1	V2
7	0.8853	-3.679	0.5061	0.2827	V2	V1

Both LSI and ROCOP indicate the sensitivity status of each load in the system. In LSI “0” represents a critical load and “1” represent a stable load. For ROCOP, the lowest value represents critical load in the system. In this research, the sensitivities of loads are monitored throughout the simulation process.

CASE 1: Islanding Operation at 0.14 MW Power Mismatch

In the first case, an islanding scenario with a power mismatch of t 0.14 MW is carried out. The total load demand for this case is 1.81 MW and the power supply from mini hydro is 1.67 MW, and the grid supply the remaining power. The system is islanded by opening the grid’s breaker at t=10.0 s.

When the grid is disconnected from the system, the proposed Adaptive UFLS technique monitors the system frequency to determine if threshold limit of 49.5Hz is violated. If the frequency drops below the threshold limit, the LRFL is activated to rank the load based on their sensitivities and LSC will estimate the power imbalance and total load to be shed. Depending on the amount calculated and the load rank, the technique will trip certain number of load breaker in order to stabilize the frequency.

Table 3
Adaptive UFLS Parameter for Islanding Operation at 0.14 MW Power Mismatch

Parameter	Without load shedding	Adaptive UFLS	Proposed Adaptive UFLS
Power Imbalance	0.14	0.14	0.14
Total Load Shed	0	0.0748	0.0976
Load Disconnected	No load	Load 1	Load 2
Frequency Undershoot	47.5 Hz	48.5 Hz	49.0 Hz

Based on the test system, there are 7 loads (Load 1-Load 7). The load is categorized into non-vital, semi-vital and vital load as shown in Table 2. The ranking of loads is based on LRFL, where it will rank the loads based on their sensitivities of LSI and ROCOP. The loads will be shed according to its priority where the Non-vital load will be shed first.

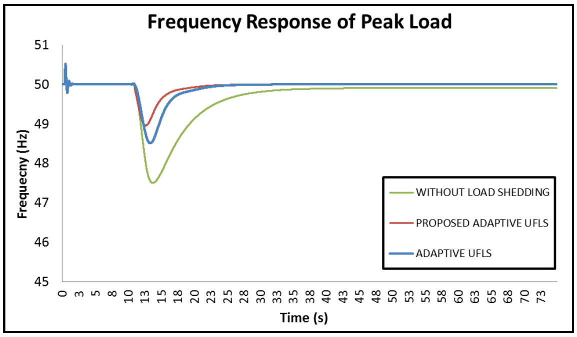

Figure 8. Frequency response during islanding operation at 0.14 MW power mismatch

The power imbalance which is calculated based on the swing equation is 0.14 MW as shown in Table 3. Only a single load needs to be shed which is load 2 (0.0976 MW). By using the proposed adaptive UFLS technique, the frequency drop to 49.0 Hz as shown in Figure 8. It can be clearly seen that the proposed adaptive UFLS technique has a better frequency response compared to conventional and previous adaptive UFLS technique and system without load shedding.

CASE 2: Load Increment in Islanded System

In the load increment case, an additional load (P = 0.6 MW and Q = 0.3106 MVAR) is connected to the system at t=25s. Obviously, the excess load leads to frequency instability, unless load shedding technique is initiated. Table 4 shows the parameters of the proposed adaptive UFLS technique for load increment. In this case, load 2 is initially shed the moment the system islanded. Load 1, Load 3 and Load 4 is selected to be shed after the additional load is added to the network. As a result, frequency is restored to its nominal value.

Table 4
Adaptive UFLS Parameter for Load Increment in Islanded System

Parameter	Without load shedding	Adaptive UFLS	Proposed Adaptive UFLS
Power Imbalance	0.6	0.6	0.6
Total Load Shed	0	0.4216	0.5116
Load Disconnected	No load	Load 2, Load3 and Load 5	Load 1, Load 3 and Load 4
Frequency Undershoot	47 Hz	47.3 Hz	47.9 Hz

Figure 9 shows the frequency response for load increment scenario. In this situation, the frequency drops until 49 Hz due to the islanding event in case 1. By using the proposed technique, the frequency is able to return to its nominal value. To further verify the effectiveness of this technique, additional load is applied to the system. Despite this, the proposed technique is able to restore the nominal frequency of the system.

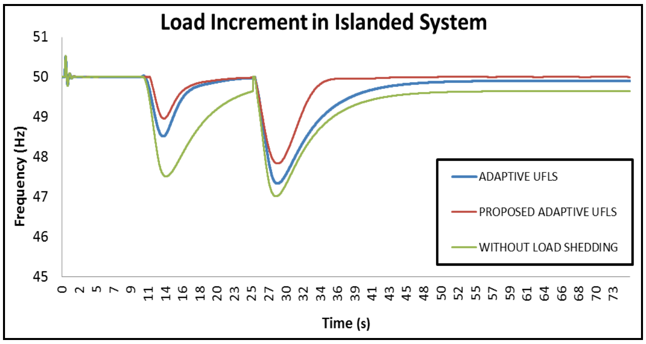

Figure 9. Frequency response for load increment scenario

CONCLUSION

This paper presents an Adaptive Under-Frequency Load Shedding (UFLS) scheme based on Load Ranking based Fuzzy Logic (LRFL) for distribution network. The algorithm for LRFL was developed using MATLAB's (Fuzzy Controller). The power imbalance or disturbance magnitude is determined by the swing equation and the algorithm of Adaptive UFLS is implemented in the PSCAD simulation software. The accuracy and effectiveness of the proposed Adaptive UFLS technique is investigated on a distribution test system. Two different cases involving power mismatch of 0.14 MW and load increment were investigated. Simulation results have shown that the proposed technique has successfully performed load shedding by ranking shedding the load according to the power imbalance and thereby restores the frequency back to its nominal value.

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