A Review of Under-frequency Load Shedding Scheme on TNB System

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***Abstract*--Safe operation of a power system will require that system frequency is kept within a specified range. When the generation is insufficient due to disturbances, the frequency might fall under the minimum allowable value which may lead to system blackout if not properly counteracted. This frequency decline may be corrected by shedding certain amount of load so that the system is back into balanced state. This paper reports a case study on Malaysia's TNB system. UFLS scheme used by TNB was reviewed. Then modification and improvement was made to reflect the current changes in the system making the scheme more up to date. Effect of having more stages to reduce over shedding and combination of different amount of load at each stage are discussed.**

***Index Terms*--Under-frequency Load Shedding, UFLS.**

I. Introduction

THE operation of electrical equipments such as AC motors, electrically operated clocks and turbo rotors are frequency dependent. Hence, the capability of maintaining the system frequency within a certain limited range determines whether the equipments can work normally or not [1]. When a power system is subjected to disturbances such as overload or loss of generation, there will be an imbalance of power generation and load consumption and the frequency will deviate from its nominal value in a manner depending on the characteristic of the system.

With a small disturbance, the frequency decay rate will be low and the turbine governor will quickly raise the steam or water to the turbine to restore the frequency, provided the system has sufficient spinning reserve. However, if the disturbance is large, because of the definite time response of the turbine speed-governor, spinning reserve provide little assistance in short time recovery and the frequency may fall to a dangerous value before the turbine governor fully operated. The decrease in system frequency, which occurs very rapidly, if left unattended, will lead to system collapse. In this case, some immediate pre-selected load shedding provides a path for the power system to restore the frequency back to its normal value.

The decline in frequency is due to insufficient amount of generation that meets load demand. This will cause the load to acquire power from the stored kinetic energy in a rotating system and hence slowing the rotation (frequency). Most electrical machines are designed to operate under frequency of 50 Hz. Any frequency violation may cause damage to the machines. If a considerable amount of generation is lost, the only effective way to correct the imbalance is to quickly shed the load before the frequency falls so low that will eventually damage the system

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II. Under-frequency Load Shedding

Under-frequency load shedding (UFLS) is defined as a coordinated set of controls, which results in the decrease of electrical loads in the power system. This set of possible corrective actions aims at forcing the perturbed system to a new equilibrium state (balancing the load and generation and thus maintaining system frequency within nominal range). The load shedding system is composed of several stages; each of them is characterized by tripping frequency, amount of load and delay before tripping.

The objective of an under-frequency load shedding scheme is to quickly recognize generation defiency within any system and automatically shed a minimum amount of load, and at the same time provide a quick, smooth and safe transition of the system from emergency situation to a post emergency condition such that a generation-load balance is achieved and nominal system frequency is restored.

III. UFLS Schemes

Frequency is a reliable indicator of generation defiency or overload condition. A load shedding action is realized by an under-frequency relay, which issues a trip signal to the circuit breaker when the system frequency falls under the relay's frequency setting. The tripping is done in several stages comprising certain amount of load until the normal frequency is restored. Common practices by most utilities use 49.3 Hz as the first frequency step and between 48.5 and 48.9 Hz for the last step.

Load shedding scheme based on frequency alone has several disadvantage, among which are load may tripped unnecessarily at low import level and too much load tripped at high import level [2]. This phenomenon, commonly known as over-tripping will cause the overshoot of frequency. The reason being is that the system might not be able to recover fast enough between steps of tripping which leads to unnecessary tripping. The use of rate of frequency change (df/dt) is proposed, which provides advantages as follows:

- One can begin to trip load blocks without waiting until the frequency drops critically.
- Load shedding steps can trip simultaneously instead of sequentially.
- Improved response time.
- Flexible, and can be tailored to different level of imports
- Reduced frequency swing.

Load shedding schemes can be grouped into three main categories: traditional, semi adaptive and adaptive [3]. The traditional scheme is the most simple and used by most utilities. It sheds a certain amount of load when the system frequency falls below certain threshold. The semi-adaptive method measure the rate of change of frequency (ROCOF) when the system frequency reaches certain threshold. According to that value, different amount of load are shed. The adaptive method used model obtained from the complete generating unit, along with its governor.

There are several methods of dynamic or adaptive UFLS proposed and discussed in literature [4]-[8]. All approaches are based on the use of the generator swing equation. In [4] an adaptive methodology is given for the setting the under-frequency relays, based on the initial rate of change of frequency at the relay. In [6] a method using both frequency and voltage changes is presented. In [7] an adaptive scheme that uses both frequency and rate of change of frequency measurement to dynamically set under-frequency relays is presented.

IV. UFLS Considerations

Before a load shedding program can be developed, it is necessary to evaluate several criteria as listed below [2]-[3].

- The steam has priority over the electrical system. The steam system must be able to recover or both will fail.
- Electrical load shedding coordinates with the steam system by shedding load as soon as possible.
- Facilities which are essential from a safety standpoint are not shed.
- Facilities which can be shed without disruption of process operations are shed first.
- Facilities which are easier to restore to normal operation are shed before those which are difficult to restarts.
- The action has to be quick, so that the frequency drop is halted before a situation of danger has occurred.
- Unnecessary actions have to be avoided.
- The protection system has to be liable and redundant, as a malfunction of it would surely lead to a major failure of the whole system.
- The amount of load to be shed should always be the minimum possible, but anyway sufficient to restore the security of the grid and to avoid the minimum allowable frequency being overcome.

The main motivation in UFLS scheme is to avoid the frequency deviating from its nominal value. Most rotating machine is designed for optimum performance at a specific frequency. Often, rotating machine cannot operate safely or effectively at more than a few percent below rated frequency [9]. Continuous operation of steam turbines should be restricted to frequencies above 48.5 Hz. Operation below 48.5 Hz should be limited to very short periods of time.

The design of a load shedding scheme is essentially determining a workable between providing maximum system protection and interrupting a minimal amount of service. Although there is no established rule for achieving such a balance, there are certain design decisions that must be made in order to successfully implement a load shedding scheme. The design decisions, which is considered separately are as follows [10]:

- Maximize the anticipated overload.
- Select the number of load shedding stages.
- Determine the amount of load to be shed at each stage.
- Calculate the relay settings.
- Select which loads should be shed at each stage.

V. TNB System Case Study

Tenaga Nasional Berhad's (TNB) UFLS schemes have been installed to disconnect load with respect to falling frequency in the event of a major loss of generation. The scheme is designed to disconnect load at predefined frequency stages so as to match the losses in generation.

A. Case I

After the system collapse of 29th September 1992, TNB implemented a 4-stage load shedding scheme of 1579MW in July 1993 based on a credible generation loss of 1500MW [11]. The 4-stage scheme was revised again immediately after the August 3rd 1996 system collapse when considerably more than 1500MW of generation was lost, to a 6-stage 2700MW scheme (Table I).

TABLE I
6-Stage UFLS Scheme

Stage	1	2	3	4	5	6	Total
Frequency (Hz)	49.5	49.3	49.1	49	48.8	48.5	
Load (MW)	300	400	TNB -PUB I/C Trip Out	600	600	800	2700

It was decided to have an independent review of this 6-stage scheme to determine whether any improvement could be discovered. The static review of the 6-stage scheme was done using the formula given by Western Council Coordinating Council (WSCC) [12]. As a rule of thumb to minimize over shedding, it is always better to have more stages with smaller load at each stage. Moreover, tripping a big block of load at one time will give a large impact to an already weakened system. A new 11-stage scheme was recommended as shown in Table II. The new 11-stage scheme was designed to minimize the changes to the 6-stage scheme. It shed the same amount of load in the same frequency range as in the 6-stage scheme.

TABLE II
RECOMMENDED 11-STAGE UFLS SCHEME

Stage	1	2	3	4	5	6
Freq (Hz)	49.5	49.4	49.3	49.2	49.1	49.0
Load (MW)	300	200	200	200	200	200
Stage	7	8	9	10	11	-
Freq (Hz)	48.9	48.8	48.7	48.6	48.5	
Load (MW)	300	300	200	300	300	

The effect of minimizing over-shedding is illustrated in Fig. 1 where the percentages of over-shedding for both schemes are compared. It shows the results of static analysis for the 25 scenarios. In the first scenario, a 300MW generation deficiency is modeled. Further 100MW generation loss is added for the subsequent scenario. The over-shed percentage is defined as the ratio of actual amount of load shed to the amount of generation loss. Out of the 25 scenarios, the 11-stage scheme shed less load in 14 scenarios.

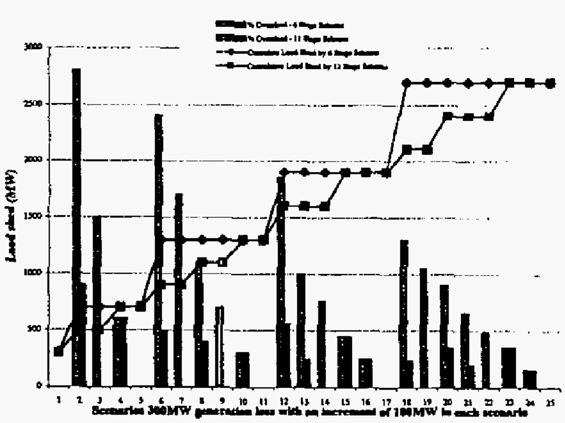

Fig. 1. Comparison of 11-stage and 6-stage UFLS

Keeping the tie line between utilities during system disturbances is a controversial subject. On one hand, the system is exposed to more disturbances because of larger geographic area. On the other hand, the system frequency variation due to disturbance is reduced because of the bigger equivalent system inertia. Neglecting the higher frequency of disturbances, the benefit of interconnection between utilities can be easily demonstrated by static analysis.

TNB system is interconnected to Singapore PUB system via 230 kV tie lines. The load and generation at Singapore PUB is assumed to be balance at 4000MW. Since the frequency decay rate is the function of percentage overload in the interconnected system, having the Singapore PUB connected would reduce the percentage overload and hence reduce the frequency decay rate. Fig. 2 shows the effect of tripping and not tripping the tie line to Singapore PUB in 6-stage scheme. The rate of frequency decay increase from 1.2 Hz/s to 2.3 Hz/s when the line is tripped.

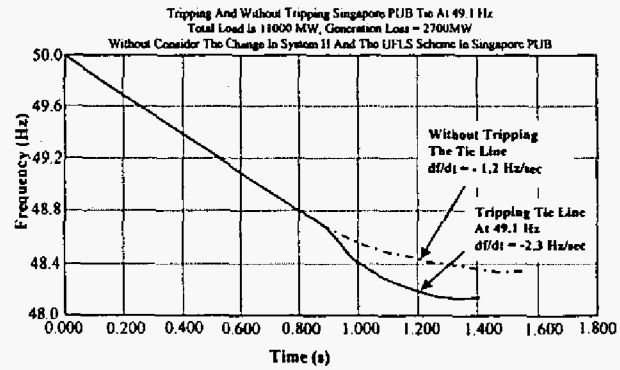

Fig. 2. Effect of tripping and not tripping the tie line.

B. Case II

Based on a projected peak load of 9300MW, and projected base load of 6263MW, a 15-stage load shedding scheme as at May 1999 was modified to reflect 5600MW generation loss. A sensitivity analysis was carried out by varying the load shed blocks as shown in Table III.

This analysis was performed to observe the effect of shedding more and less loads in the initial three stages as opposed to equal load distribution.

The UFLS loads have been selected at the various frequencies based on following criteria:

- No UFLS set for substation in the MSC, KLIA and KLCC areas.
- The first 3 stages are to be set at manned substations or those with remote supervisory switching facilities.
- Locations of feeders for the first 3 stages are to be rotated periodically following a major UFLS incident.
- The earlier practice of tripping the 11kV and 33kV going out feeders has been discontinued and replaced with the tripping of transformers (inside) and 66/132/275 kV feeders where applicable.
- The loads used in assignment were based on a 3 months average for June, July and August and should be updated and reviewed annually.
- The proposed UFLS assignments are based on off-

points currently employed in the grid system. In the event the off-points are changed resulting major load changes in the feeders, the UFLS assignments should be reviewed appropriately.

- Co-generation stations are tripped at 49.1Hz.

TABLE II
THREE PROPOSED 15-STAGE UFLS SCHEMES

	Scheme 1	Scheme 2	Scheme 3
Frequency Stages (Hz)	Load Shed (MW)	Load Shed (MW)	Load Shed (MW)
49.5	470	350	250
49.4	470	350	250
49.3	470	350	250
49.2	350	375	400
49.1	350	375	400
49.0	350	375	400
48.9	350	375	400
48.8	350	375	400
48.7	350	375	400
48.6	350	375	400
48.5	350	375	400
48.4	350	375	400
48.3	350	375	400
48.2	350	400	400
48.1	350	400	450
Total	**5600**	**5600**	**5600**

The proposed UFLS is also designed to address the phenomena of a frequency stalling. When the system frequency stalls for a minute or more below 49.5Hz, the UFLS loads at 48.1Hz, 48.2Hz and 48.3Hz are tripped in delayed times of 60 seconds, 90 seconds and 120 seconds respectively. Hence, the last 3 stages of UFLS scheme serve two purposes:

- To shed load when the frequency is actually at 48.3Hz and below
- To shed load after preset delay time for frequency below 49.5Hz in order to assist frequency recovery

The amount of over-shed appears to be less when the loads to be shed are evenly distributed. The dynamic models for different 15-stage schemes were subjected to various generation loss scenarios as shown in Table IV for peak load and Table V for base load. It can be observed that by shedding more loads at the initial stages, the lowest frequency reached before the system stabilizes is higher.

TABLE IV
LOWEST FREQUENCY REACHED FOR DIFFERENT SCHEME WITH VARIOUS GENERATION LOSS (PEAK LOAD)

Generation loss (MW)	Lowest frequency reached (Hz)		
	Scheme 1	Scheme 2	Scheme 3
555	49.73	49.73	49.73
1100	49.49	49.46	49.48
1580	49.35	49.28	49.19
2070	49.26	49.17	49.06
2660	49.08	48.98	48.87
3110	48.97	48.87	48.75
3550	48.79	48.68	48.59
4140	48.63	48.49	48.38
4750	48.39	48.27	48.20
5355	48.16	48.17	48.09

TABLE V
LOWEST FREQUENCY REACHED FOR DIFFERENT SCHEME WITH VARIOUS GENERATION LOSS (BASE LOAD)

Generation Loss (MW)	Lowest frequency reached (Hz)		
	Scheme 1	Scheme 2	Scheme 3
520	49.67	49.67	49.67
1040	49.45	49.43	49.42
1510	49.19	49.10	49.08
2011	48.99	49.89	48.79
2443	48.79	48.69	48.59
3065	48.49	48.39	48.29
3737	48.16	48.17	48.08

VI. CONCLUSION

UFLS schemes have been applied almost universally in power system to provide the fastest possible remedial action in the event of severe generation-load mismatch. Such scheme has proved their effectiveness so many times when disturbance occurs. The load shedding scheme must be tailored to adapt the changes in the power system such as an increase in demand and changing operating condition.

In the Load Management system, load will be monitored at different locations of the plant and the information will be sent to the Distributed Control System main control room via radio link. It will provide an opportunity to confirm the load consumption by different feeders and substation locations. The data gathered will be used to inform the operator with respect to MW load availability at different steps. It can also be used for more informed decision making for the manual load shedding, if required.

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IX. Biographies

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