Under Frequency Load Shedding Based on Dynamic System Information

HYR Perera[1#] and RVDHN Rajapaksha[2]
[1]*Department of Electrical Engineering, University of Moratuwa, Moratuwa,*
Sri Lanka
[2]*Ceylon Electricity Board, Sri Lanka*
[#]hyrp@elect.mrt.ac.lk

Abstract— *Under Frequency Load shedding is an effective mechanism to prevent a disturbance – induced collapse of a power system. Ceylon Electricity Board (CEB) also uses such a system with the support of under frequency load shedding relays. The load shedding table used for this is a static one which has some inherent drawbacks. An intelligent load shedding system can provide faster and optimal load relief by using actual operating conditions and knowledge of past system disturbances /Rekha 2013/. This paper proposes an intelligent load shedding scheme which uses a regularly updated load shedding table avoiding the shortcomings of the currently used system. Superiority of this scheme is demonstrated through simulation studies using Power System Simulator for Engineering (PSS/E). Application of the proposed scheme can further minimize events of total failures /Ghaz 2012/ while completely avoiding unnecessary load shedding which obviously is a nuisance for the respective customers.*

Keywords— *Intelligent Load Shedding, Under Frequency Load Shedding, Total Failure*

I. INTRODUCTION

Sri Lankan power grid is fragile for total failures due to its relatively small size and large chunks of generation done in the same locality. On top of this the transmission lines are exposed to tropical lightning and in coastal areas also to sea pollution increasing line failure rates. The largest unit in the system has the capacity of 300 MW and there are three such units in the same power station. If all three units are running in full capacity they deliver 3×270=810 MW to the system which is more than 80% of the off peak demand. Cost of running such plants at a reduced load during off peak is heavy due to increased operational cost and also due to reduction of plant life caused by unnecessary thermal stresses that occur every day. Keeping other plants with sufficient capacity running as spinning reserves is even costlier. Under frequency load shedding is a much more affordable solution which is capable of drastically reducing the probability of total failures at the cost of unannounced power cuts imposed on certain groups of customers. However, the current scheme of load shedding has some shortcomings discussed in section II. This paper presents a scheme that selects loads for shedding based on actual system data updated on line. Simulation results are also presented to demonstrate the superiority of the proposed scheme.

II. EXISTING LOAD SHEDDING SCHEME

The load shedding scheme currently in operation uses a predefined set of loads, subsets of which are shed in a sequence of stages. In selecting loads for inclusion in the table the daily load profile is compared with the system load profile. The loads with profiles that approximately resemble with the system load profile are selected for inclusion in the table. However, there is no guarantee that the selected loads vary with time strictly proportional to the system load variations. In addition day to day differences in selected loads are far more than those in the system load. This results in excessive or inadequate shedding further delaying the system stabilization or even leading to system collapse. Further, any interruption is a burden for the customers and thus excessive load shedding should be avoided wherever possible. This is identified as the major weakness of the current system.

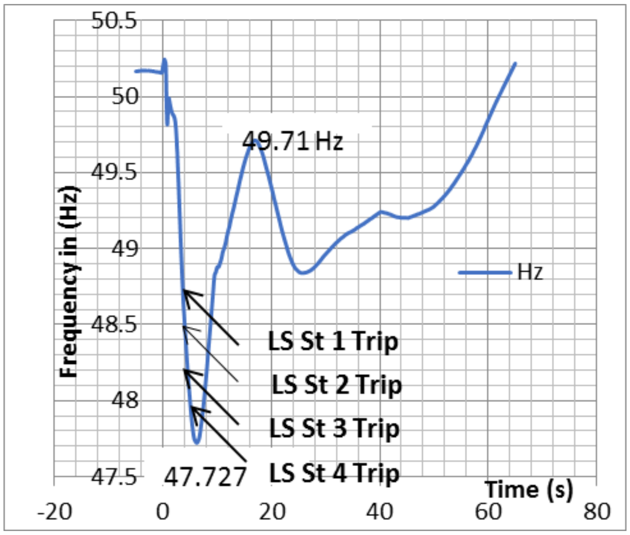

Figure 1. Frequency plot of the failure on 06th May 2013

In order to illustrate this load shedding sequence that actually took place in the event of failure that occurred on o6th May 2013 at 20.41 hrs is studied. The failure was initiated by an earth fault in one of the circuits (line 1) in the 132 kV Sapugaskanda – Kelaniya double circuit line. If the faulty line were to be isolated from both ends there would have been no serious instability in the system. However, this did not happen and only the distance protection at Sapugaskanda end worked. Isolation on the Kelaniya end did not work and instead back up protection of line two worked and line 2 was isolated from Kelaniya end. Some loads have been disconnected in the process and as a result a slight increase in the frequency has taken place. The 60 MW barge mounted power plant has tripped as the first in line of several power plants tripping one after the other. The frequency drop due to loss of generation has initiated Under Frequency Load Shedding. As shown in Fig. 1 four Load Shedding (LS) stages out of six available have taken place to bring the system back to stability.

The total loss in generation due to tripping of the generators Barge mounted (60 MW), WPS 2 (25 MW), Kukule (2×38 MW), Asia Power (42 MW) and AES Kelanitissa (160 MW) amounted to 263 MW. The total of loads disconnected due to failure and load shedding stages amounted to 343 MW producing a mismatch of 80 MW. This is due to the fact that the actual loads of the predefined feeders that are disconnected in the shedding process do not match the expectations. Further, non-consideration of the loads that are disconnected during the failure process prior to initiation of UFLS also contributes to this mismatch.

Reactive power consumed by the feeders is not taken into consideration in selecting the loads for shedding. This could lead to voltage sags and swells in certain locations in the system causing further instability due to voltage fluctuations, adding to the unstable situation. Such voltage sags were observed at Kotugoda substation and Norochcholei grid during the failure analysed above.

In analysing the failure on 7th December 2007 it was observed that in order to compensate for 163 MW (initiated by Kelanitissa Combined Cycle Plant failure) of generation loss only 122.2 MW of load was shed in the first five stages. This was grossly insufficient to halt the frequency collapse and the result was cascade tripping leading to a total failure.

Further analysis of loads shed during above and other failures revealed that some loads that were shed contributed very little and such loads should have not been considered for shedding in that particular event.

III. ON LINE UPDATED LOAD SHEDDING TABLE

In order to overcome the shortcomings identified above a mechanism is proposed to update the load shedding tables based on actual consumption data of feeders obtained through Supervisory Control and Data Acquisition (SCADA). Under this mechanism it is possible to use actual consumption data on real and reactive power by the feeders and thus the static load shedding table is replaced by a dynamic table which gives real time information.

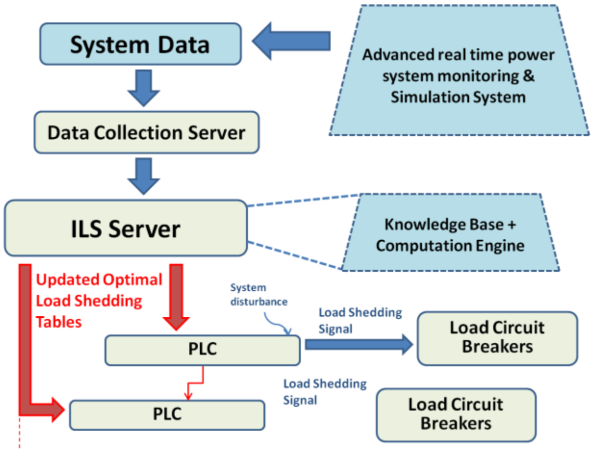

Figure 2. Mechanism for updating the load shedding table

An advanced real time power system monitoring system captures the real time system data by means of data collection servers located at each of the substations and passes them to a centralized Data Collection Server. An "Intelligent Load Shedding (ILS)" server located at system control center uses this data and updates the load shedding table after performing necessary calculations. For this the server also uses a data base that contains system data that is updated regularly.

ILS server receives data from data collection server on line and based on settings it is requested by the the knowledge base periodically to update the load shedding table, thus ensuring optimum load shedding in case of a disturbance /Faro 2005, Sher 2005/.

The PLC's sensing the system disturbance through frequency variations activate the load circuit breakers that are listed in the load shedding table. The entire system is depicted in Fig. 2.

The key benefits of this real time dynamically updated load shedding table over the static load shedding table can be summarized as given below:

- Time variant load shedding table reflects the true status of the loads
- The optimal combination of feeders can be obtained in such a way that exactly the required amount of load is shed
- Fast response

IV. PSS/E SIMULATIONS

In order to validate the suitability of the proposed scheme several disturbance scenarios were simulated using PSS/E power system simulator. For this the reduced network shown in Fig. 3 was taken.

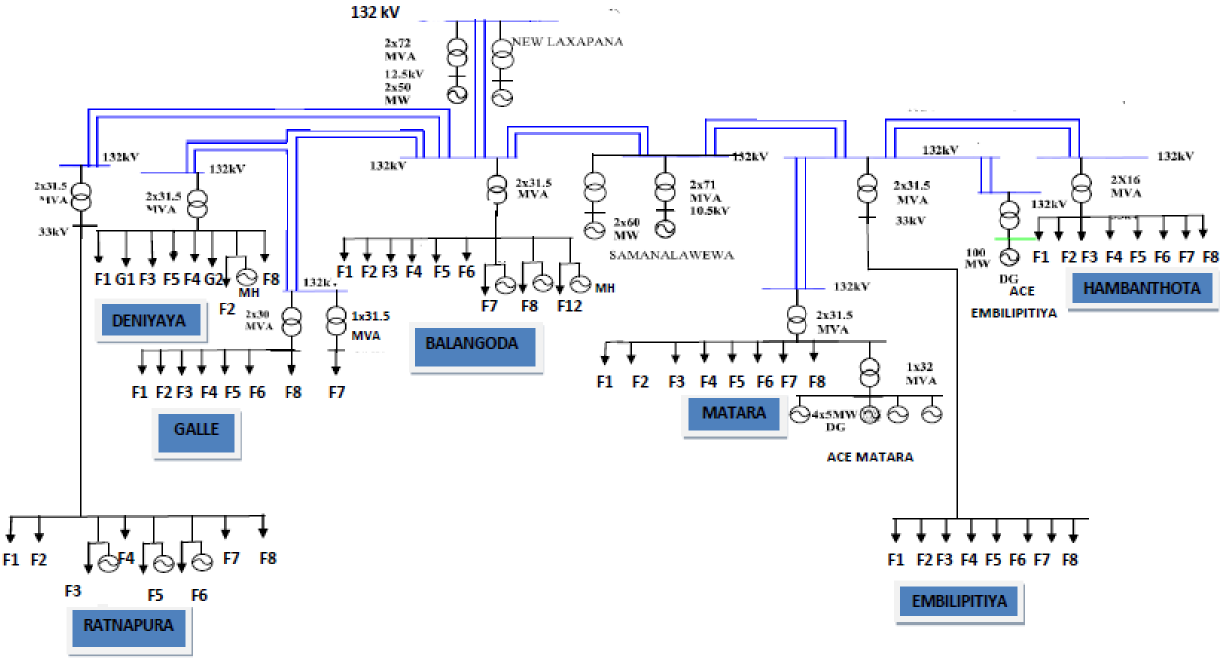

Figure 3. Reduced network selected for Simulation

The reduced network comprises two major hydro power plants New Laxapana (2× 50 MW) and Samanalawewa (2× 60 MW), two major diesel engine power plants ACE Power Matara (20 MW) and ACE Power Embilipitiya (100 MW). The network also included several mini-hydro power plants situated in Ratnapura, Deniyata and Balangoda with a total capacity of nearly 52 MW. Thus the generation capacity of the reduced system totals to 382 MW. The network encompasses 7 substations and many feeders out of which 11 feeders are identified as candidates for load shedding.

A. Simulation Run

Generation and demand data corresponding to a selected date and time (December 14th, 2014 at 19 hrs) are extracted and used. Real power and reactive power taken by each of the candidate feeders are considered separately. Depending on active and reactive power consumption of the feeders best load shedding sequence is established. Two load shedding tables are generated for different ranges of rate of change in frequency. If the frequency falls faster than 0.85 Hz/s the second table is activated otherwise the first table is considered to be good enough. Using PSS/E the load shedding events and the frequency plot corresponding to the contingency are simulated.

B. Simulation Results

Out of the several scenarios simulated one corresponding to the tripping of Unit 1 at Lakvijaya power station is presented. This actually occurred on 07th April, 2015 at 23.33 hrs. The simulation results compare the events and frequency plot for load shedding using current UFLS scheme and the proposed ILS scheme. Frequency plot is shown in Fig. 4.

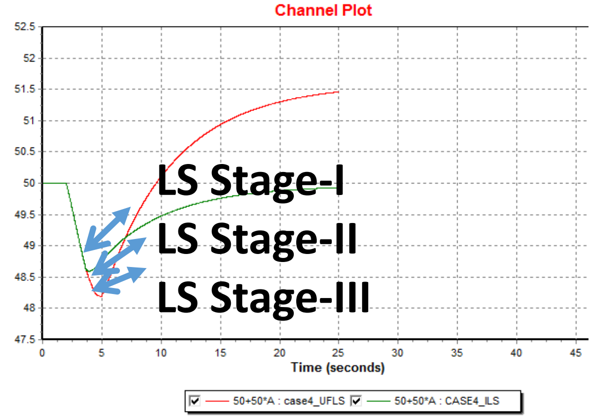

Figure 4. Frequency plot corresponding to the failure of Lakvijaya unit 1

As shown in Fig. 4, under ILS load shedding stage I has shown immediate results making further shedding stages completely redundant. Under UFLS load shedding has continued up to stage III. This trend was confirmed by all the scenarios that were simulated and compared.

It is further observed that the frequency starts to improve before the second round of load shedding and keeps on improving attempting to reach the saturation level at a value close to the nominal frequency. This is to be expected as the actual value of the load shed is more close to the generation lost. Under UFLS excessive load shedding has taken place in three stages and as a result of that frequency tends to go well over the nominal frequency as seen in Fig. 4. This observation is also common to other scenarios that were simulated.

All the scenarios simulated displayed that the frequency starts to recover seconds earlier under the new system than under UFLS. This gives crucial time for operator interventions to bring back the system into normal drastically reducing the probability of a total failure.

IV. CONCLUSION

Under Frequency Load shedding Scheme (UFLS) currently used by CEB does not take the actual loads of the feeders into consideration in making the shedding decisions. It can even happen that some feeders are not at all energized at the time of shedding. This leads to mismatches between generation lost and the loads shed delaying the return to stability and even causing a total failure.

The proposed Intelligent Load shedding (ILS) scheme overcomes these shortcomings by updating the load shedding tables on line considering the actual loads taken by the candidate feeders. PSS/E simulations demonstrated that the new scheme is much superior to the current system and requires a lesser number of shedding stages and that the system is brought back to normalcy much faster. The new scheme reduces the probability of a total failure in case of a contingency and also eliminates unnecessary load shedding minimizing customer interruptions.

ACKNOWLEDGMENT

The Authors gratefully acknowledge Department of Electrical Engineering, University of Moratuwa for the support given in various ways. System Control Center, Ceylon Electricity Board is thanked for making data available for this study.

REFERENCES

Ghazanfar Shahgholian, Salary M E (2012), Effect of load shedding strategy on interconnected power systems stability when a blackout occure, International Journal of Computer and Electrical Engineering. Vol. 4, N0.2, April 2012.

Farrokh Shokooh, Dai J J, Shervin Shokooh *et al* (2005) An Intelligent Load Shedding (ILS) System Application in a large Industrial Facility, Industry Applications Conference, 40th IAS Annual Conference, Irvine, California, USA, pp 417-425.

Rasha M, El Azab, Lataire P et al (2011), Simulation programs for load shedding studies: Experimental results, International Journal of Simulation Systems, Science and Technology (IJSST), Vol. 11, No. 6, December 2011.

Rekha A, Kumar r, Kumar (2013), Vanith D, An intelligent load shedding to improve power system congestion, International Journal of Current Research, Vol 5, Issue 04, April 2013, pp 973-977.

Shervin Shokooh, Tanuj Khandelwal, Farrokh Shokooh *et al* (2005) Intelligent load shedding need for a fast and optimal solution, IEEE PCIC Europe.

Rudez U, Mihalic R (2012), Adaptive UFLS schemes in modern power systems – conceptual and simulation proved comparision, International Journal of Energy Engineering, May 2012, pp 100-107.

BIOGRAPHY OF AUTHORS

[1]Author is a Professor in Electrical Engineering at University of Moratuwa. He graduated from University of Moratuwa and obtained his Dipl.-Ing. and Dr. Ing Degrees from RWTH Aachen, Germany. His research interests include Power Systems Reliability, Mathematical Modeling and Renewable Energy Development. He functioned as the Dean, Faculty of Engineering at Sir John Kotelawale Defence University from October 2011 to September 2014. He also served as Director General/CEO of Public Utilities Commission Sri Lanka from April 2008 to December 2009 and as Chairman of Arthue C Clarke Institute for Modern Technologies from October 2013 to February 2015.

[2]Author is an Electrical Engineer at Ceylon Electricity Board working as maintenance planning Engineer in transmission asset management division. She graduated from University of Moratuwa and obtained her MSc also from University of Moratuwa. Prior to joining CEB she worked as a design Engineer at Central Engineering Consultancy Bureau.