Effects of Inertia on Long Term Dynamics of a Power System

Asitha Indatissa, Swetha Perera, Niranjan Boteju, Asiri Imbulana,
Supervisors: Tilak Siyambalapitiya and Lanka Udawatta
Department of Electrical Engineering, University of Moratuwa

Abstract
This paper presents a study done to investigate the effect of inertia constant on frequency stability on long term dynamics of Sri Lanka Power System and to examine the future frequency constancy of power system respect to system inertia. This study considers several contingencies occurred in the Sri Lankan power system and how such a condition will affect the dynamics of the system in future.

I. INTRODUCTION

Sri Lanka is one nation who experiences a high number of blackouts a year. This has mostly been due to the reason that the system can't withstand a loss of key element, though the system has been designed withstand such a situation. Neither spinning reserves nor the load shedding scheme haven't been able to act to rescue the system as the rate of frequency drop has been too high. Reducing the rate of frequency drop will provide a solution as it provide more time for the governors to ac act and even for load shedding to take place.

The studies carried up to now have mostly been focused to develop more effective load shedding schemes [1], [2] & [3]. These studies have revealed improvements to the feeder selection and frequencies at which they should be shed. Shedding adequate load at certain instances and setting triggering frequencies at appropriate values will definitely improve system stability. This will make sure that shedding load is adequate to cope up with various contingencies and they are shed early enough so that the system will recover.

This study mainly focuses on how system inertia and its improvements in future will affect the stability of the system. A software model for the existing power system of Sri Lanka was built using Matlab 6.5, which is explained in the next section. Two contingency situations, a close recovery and a total system failure, were simulated using this model. The analysis was continued in comply with the generation expansion plan [5] to verify the stability of the system in future at such contingencies.

II. MODELING APPROACH

When it comes to studying long-term dynamics of a power system, it requires a comprehensive and precise network model to simulate the power system that is used for observation. Variation of frequency is a dynamic process with time and it is necessary to have a dynamic network model to study these time varying characteristics.

When selecting an appropriate software package to carry out the modeling process, we were in with two options, one being PSCAD and the other being MATLAB. On line measuring and plotting the measured quantities in graphical form is one of the most important characteristics available with MATLAB ®/ SIMULINK. The facilities to create graphical user interfaces and report generation facilities allowed us to generate the network model comprehensively and yet user friendlily [12].

The network model, in a nutshell, is set of blocks comprising generator, transmission and load models with various cross connections amongst them.

In this model, lumping was by passed whenever possible to increase the accuracy of the model and results, and hence individual generator models represent almost all the generation stations.

Generator model itself is classified in to three kinds, namely Hydro, Steam/Gas/Combined Cycle and Diesel. The subsystems, which fall in the category of Hydro, are Samanala Weva, Laxapana, Mahaweli Complex, Kukule. If we consider Mahaweli subsystem, it comprises Kothmale , Victoria, Randenigala and Rantambe generating stations where as the other three subsystems comprise Samanala Weva, Laxapana, and Kukule themselves. When it comes to Laxapana Hydro Complex, in the black out situation took place in 25 January, 2004, the complex is divided in to two lumped systems as New Laxapana and the rest of the complex.

Kelanitissa Subsystems fall under the category of Steam/Gas/Combined cycle generating plants. In this subsystem GT 1 to 6 is lumped as a single model, whereas GT 7, AES Combined Cycle and Colombo Barge generating plants are modeled individually. Subsystems ACE Horana, ACE Mathara, and Sapugaskanda Belong to the class of Diesel generating plants. In the subsystem Sapugaskanda all the plants in the form of Lakdanavi, Asia Power and CEB owned Sapugaskanda power plants are lumped in to a single model.

Transmission lines were taken in "pi" model while neglecting the lines shorter than 30.km. Double circuits also interpreted by single circuits with appropriate modifications to inductances and capacitances.

Load model implements a three phase parallel RLC load connected in Y configuration, with the neutral connected to the ground and Transformer model implements a three phase linear transformer by using three single-phase linear transformers.

When it comes to the Relay model it holds a noticeable significance. Not only it was custom built but also the fact that it performs a remarkable function during the operation of the power system, particularly at an instance a frequency fluctuation. This block is the component, which activates the load shedding scheme as well as Generator tripping, when the frequency is fluctuating. First we shall discuss the way it is created and then we may have a look at the way it implements the load shedding scheme and generator frequency tripping.

III. Inertia Constant

Inertia constant, also known as H constant, can be defined as follows [8] & [9],

$$H = \frac{\text{Kinetic Energy}}{\text{Apparent Power of Rotatong Machines}} \qquad (1)$$

H constant of the overall system is defined as,

$$H_{\text{system}} = \frac{\sum H_i s_i}{\sum s_i} \qquad (2)$$

Where,

H_i is h constant of the i^{th} machine
s_i is the apparent power of the i^{th} machine

IV. Results

A. Close Recovery

This occurred on 19th September 2003 at 11.35 am. This contingency was initiated with tripping of a privately owned combine cycle power plant at Kelanitissa, while serving 17% system load.

The system has started to recover with operating two load shedding stages, while in recovery path GT7 tripped due to operation of its under frequency relay. System continued with its load shedding scheme and tripped feeders assigned to stage three and recovered its nominal frequency. Figure below is the frequency plot obtained from the simulation.

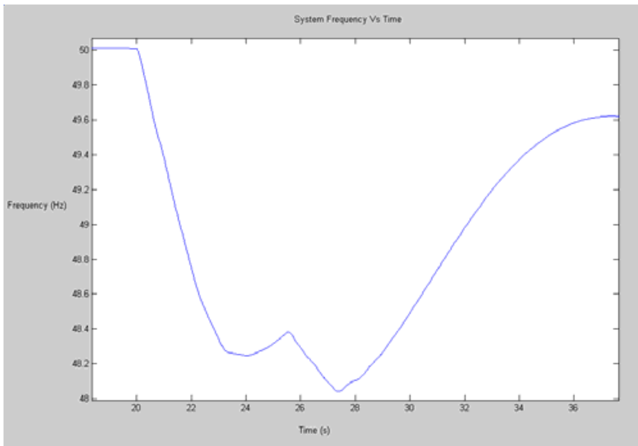

Fig. 1 Frequency plot for the contingency on 19/09/2003

When the same contingency was modelled for year 2005 with two diesel engine generation plants come to the scene. Here too the system recovers but after four stages of load shedding, which implies the increased vulnerability of the system. Frequency plot below given clearly depicts this.

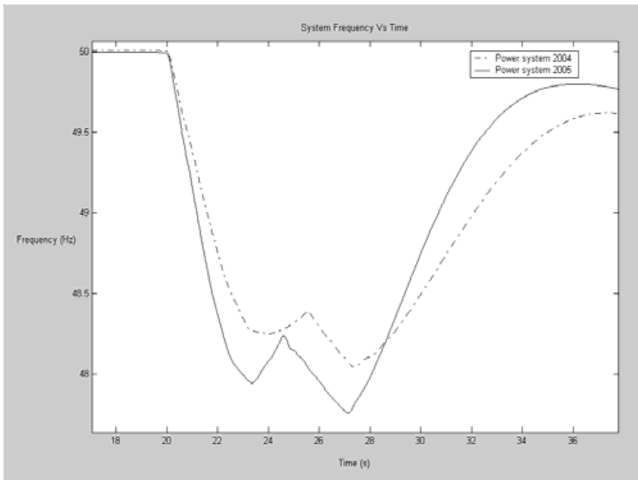

Fig. 2 Comparison of frequency plots of similar contingencies of systems of years 2003 and 2005

System H constant reduces with the arrival of diesel engine generation plants due to its low inertia value. This causes the system to be more unstable. This becomes clearer as the system becomes more stable when the diesel engines generation plants are replaced with steam turbine plants.

This produces a slight improvement on the frequency plot of year 2003 and a large improvement on the plot for year 2005 with the diesel engines. As the high inertia steam turbine plants improve the system inertia the system has become more stable and improved on its frequency variation. Followings are plots of system frequency when diesel engines are replaced with steam turbines and a comparison of both.

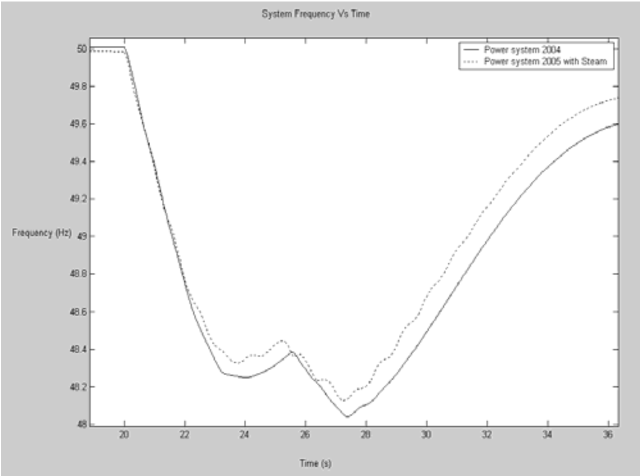

Fig. 3 Comparison of frequency plots of similar contingencies of systems of 2003 and 2005 with diesel engines replaced with steam.

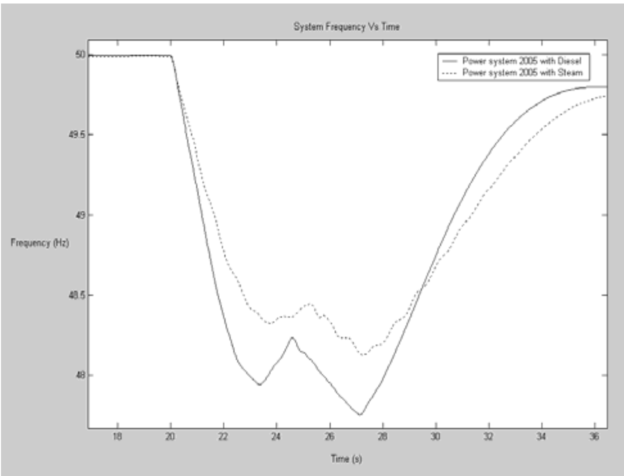

Fig. 4 Comparison of frequency plots of same contingency of system of 2005 with diesel engines and them being replaced with steam turbines.

A combined cycle plant(Kerawalapitiya) and a hydro plant (Upper Kotmale) are expected to come to the system in the recent future, the model for year 2009 was build with them making parts of it. As these kinds of plants have higher inertia values system becomes more stable. The rate of change of frequency and the frequency drop reduces by year 2009. This can be clearly identified in the graph below.

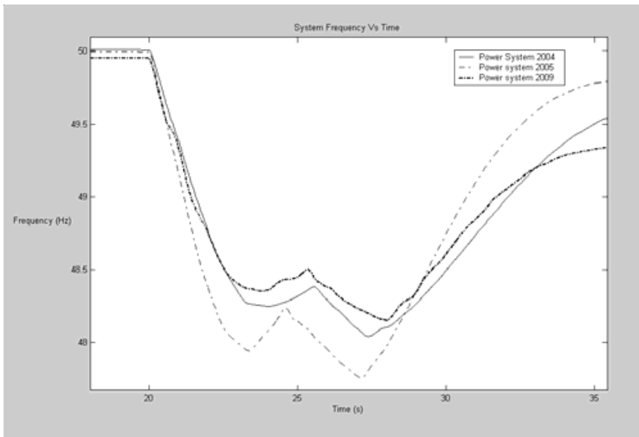

Fig. 5 Comparison of frequency plots for similar contingency for the systems of 2003, 2004 and 2009

B. Blackout

The system failure, which occurred on 25th January 2004, was simulated afterwards. This was initiated with an earth fault in the Biyagama substation followed by isolating diesel engines at Sapugaskanda. This resulted in overloading the system by 20% collapsing the whole system. Below given is the frequency plot obtained.

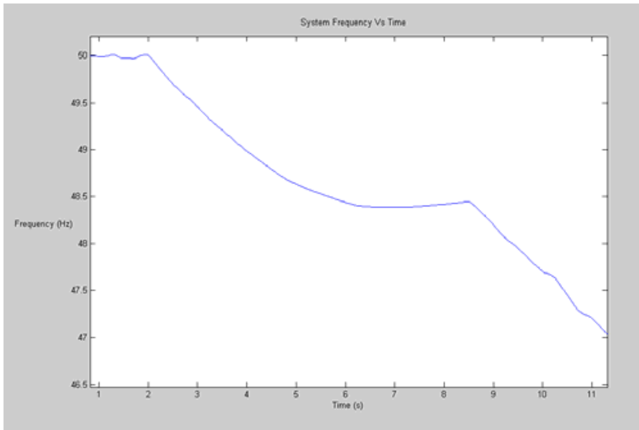

Fig. 6 Frequency plot of the total system failure occurred on 25/01/2004.

According to the system control unit of CEB high inertia machines such as Kotmale, Victoria and Samanalawewa weren't connected to the system. This has caused a great reduction in system inertia and has made the system vulnerable. This high rate of frequency drop caused governor operation and load shedding to be ineffective.

As earlier, similar contingency, 20% over load, was simulated with the system of 2005. This resulted in the frequency plot given below.

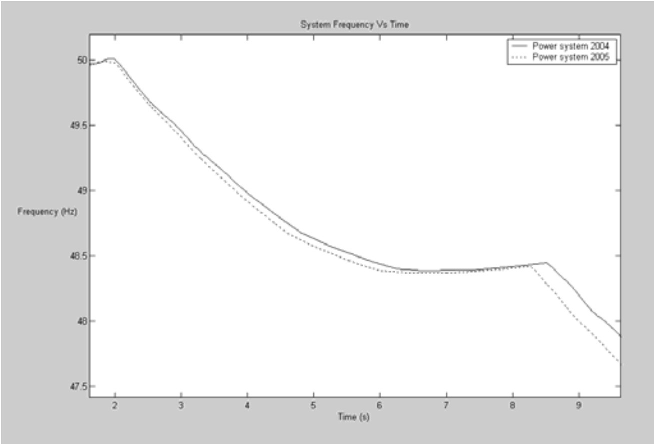

Fig. 7 Comparison of frequency plots of similar contingency for the systems of 2004 and 2005.

As in the earlier contingency diesel engines cause the system H constant to decrease and makes the system more unstable.

Entrance of Kerawalapitiya combine cycle power plant and Upper Kotmale plant hydro to the generation scenario causes the system overall H constant to increase. This makes the system to be more stable. Strictly speaking the system can even absorb a 20% overload in year 2009 under similar sort of conditions which led to blackouts in year 2004 and 2005. Following is the frequency plot obtained from the simulation.

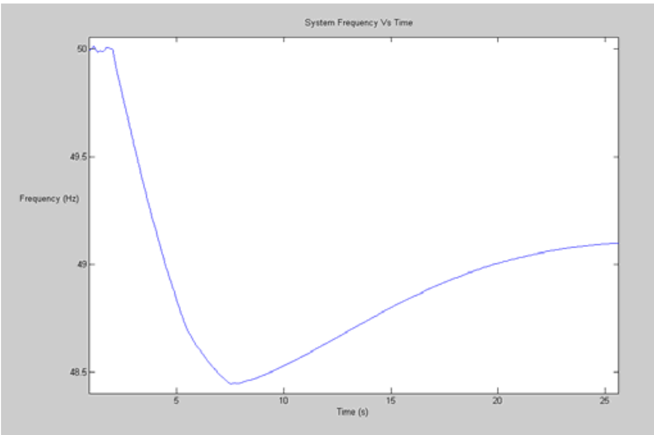

Fig.8 Frequency plot for similar contingency in year 2009

Conclusion

Based on the results of the study and practical facts, it is apparent that the system frequency stability is very much dependent on the overall H constant of the system. This has been demonstrated with the simulation results that we have taken with the system model for both contingencies.

In the close recovery it was evident that the rate of drop of frequency and frequency drop decreases with addition of high inertia machines.

In the blackout simulated too it was evident that the system becomes more stable with the addition of high inertia machines and it becomes unstable with the addition of lower inertia machines.

It is important to note that this study was done using two contingencies which occurred in the Sri Lankan power system.

References

[1]D.D.P. Yasarathne (July, 2002), ‘Review of the Existing Load Shedding Scheme of Sri Lanka’, Master of Engineering Dissertation, University of Moratuwa, Sri Lanka.

[2]N. S. Kalansooriya (December, 2001), ‘Development of a Under Frequency Load Shedding Algorithm’, Master of Engineering Dissertation, University of Moratuwa, Sri Lanka.

[3]L.N.W. Arachchige (July, 2004), ‘Effect of Embedded Generators on Sri Lankan power system’, Master of Engineering Dissertation, University of Moratuwa, Sri Lanka.

[4]The Ceylon Electricity Board. (January, 2004). Monthly Review Report: System Control Centre, CEB.

[5]The Ceylon Electricity Board. (June 2003). ‘Long Term Generation Expansion Plan 2003-2017’: Environment and Generation Planning Branch, Transmission Division, CEB.

[6]The Ceylon Electricity Board. (August 2002). ‘Long Term Transmission Development Studies 2002-2011’: Transmission Planning Branch, CEB.

[7]Elgerd O., *Electric Energy Systems Theory, An Introduction, Second Edition.* New Delhi: Tata McGraw-Hill Publishing Company Limited, 1982.

[8]Chris Middlebrook, Viswajit Ranganathan, and Noel N. Schulz, “A Case Study on Blackout Restoration as an Educational Tool,” *IEE Transactions on Power Systems,* vol. 15, no. 2, pp. 467-471, May 2000.

[9]BBC, Brown Boveri. Load shedding to influence frequency during overload condition.

[10]Basler Electric Head Quarters. Load Shedding for Utility and Industrial Power System Reliability. USA. http://www.basler.com

[11]Mike Sitarchyk and Jack Coleman Instructors, “System Restoration”, August 2003.

[12] http://www.mathworks.com