CHAPTER 5

Conclusions and Further Research

This chapter summarizes the main accomplishments of this research. Recommendations for further research and conclusions are provided.

5.1 Conclusions

This thesis mainly focuses on a new technique for optimal measurement placement for power system Harmonic State Estimation (HSE). The new solution provides the optimal number of measurements and the best positions to place them, in order to identify the locations and magnitudes of harmonic sources. The minimum condition number of the measurement matrix is used as a criterion in conjunction with sequential elimination to solve this problem. Measurement placement in the HSE algorithm for a three-phase unbalanced power system has been tested using the New Zealand test system. The IEEE 14-bus test system has been used for testing a balanced power system.

Although algorithms for power system state estimation for the fundamental frequency have been investigated extensively, the application of this theory to estimating harmonics is a problem that has received inadequate treatment.

Electric utilities have renewed interest in the analysis of harmonics in power systems since the effect of these signals on power system apparatus, loads, and measurement devices presents very important and serious problems. The importance of knowing harmonic levels and estimation where those signals are being injected is evident from the fact that the IEEE has developed a standard which gives recommended practices and harmonic content limitations in power systems. Because direct measurements of each point are impractical, the development of state estimation for harmonic signals is necessary.

Using HSE it was found that the systems are not fully observable with some measurement placements. To solve HSE directly in such case, measurement matrix is singularity, only SVD can be used and give correct answer at observable bus.

Moreover, the measurement placements are not the same for all harmonic orders, but the measurement placements obtained from the proposed algorithm are sufficient to uniquely calculate all state variables for all harmonic orders of the system correctly. In such a case, both normal equation and SVD can be used to solve the problem.

However, to minimize the number of locations, trial-and-error should be considered. First, each site is selected with fully placement at all possible measurement placements using the measurement matrix at any harmonic order. For different network system, if only one site is not sufficient for fully observable, then additional site is needed. For example, the IEEE14-bus test system, fully placement at four sites are required to solve all state variables.

5.2 Further Research

As for further research work, the following important topics are worth studying:

5.2.1 Development of other techniques for an optimal measurement placement and comparing their performance.

5.2.2 Sensitivity analysis for model accuracy and network configuration changes on HSE.

5.2.3 HSE modelling in consideration of non-linear network and interaction between harmonics of interest.

5.2.4 Due to the dynamic behavior of a power system, harmonic signals are not stationary. Kalman filter applications for dynamic harmonic state prediction should be investigated.