CHAPTER VII
CONCLUSION AND SCOPE FOR FUTURE

This chapter summarizes the conclusion of the thesis and suggestions are made for future research in this area. The chapter wise concluding remarks of all the preceding chapters are also summarized.

7.1 INTRODUCTION
Modern power system is subject to a wide range of power quality disturbances, from steady state variations to PQ events. Despite these disturbances, the supply of electric power should be continuous without any interruption. The end user should be satisfied with the quality of power. There should be no malfunction/damage of sensitive equipment. There should be no black-out and outage which are becoming more and more costly whenever they occur. In order to avoid the malfunction and costs, it is necessary to monitor PQ continuously with advanced technologies to find out problems and provide effective solutions to forecast the occurrence of major blackouts in many power systems.

The present systems of power quality monitoring are not fully capable to cope with the smart grid applications such as wide area monitoring. Smart grid needs intelligent monitoring system to make smart grid perform efficiently, reliably with proper real-time monitoring and corresponding automatic mitigation and other required follow-up actions. The aim of this thesis is to formulate an intelligent system that may collect PQ data from various locations in the wide spread Indian power network through various measuring devices such as smart meters, PMUs, AFRs, and IEDs. These collected data are then to be communicated to the data concentrator through efficient high speed communication infrastructure.

In this thesis, the generation of electric PQ events (voltage sag) have been devised and verified experimentally. The generated waveform replicated the true features of power system during fault conditions. Whenever, there is any fault on transmission line due to single line to ground fault, the transmission line parameters such as phase angle, voltage, current, frequency, and power flow are also affected. Any fault on transmission line
causes voltage sag. The phase angle of voltage sag was not precisely detected by conventional methods. To detect the PQ disturbances, PMU based simulation study has been done which measures phase angle along the variation in the voltage, system frequency, and rate of change of frequency (ROCOF). To locate transmission line fault, simulation study has been performed with IEEE 14 bus system using DIgSILENT software tool. After, detecting/locating the transmission line fault, the PQ information has been transferred to control center to analysis the data. In case of any emergency, the system operators at control center may take appropriate actions to supervise, monitor, and control the power system. Some time, there are critical applications for which time bound action must be initiated. The time critical messages must be protected by a security mechanism with quick response time.

To incorporate the security features in smart grid, a wide area monitoring system model has been simulated considering Northern Indian power system using OPNET software tool. The PMUs located at substations sent continuous data stream i.e. 25 samples per second to the centralized PDC. The dedicated fiber optic links are used as communication media for PMU communication network. The phasor information is very sensitive and timely critical. To secure WAMS system, Diffie-Hellman share key algorithm is implemented. The RSA cryptography technique has been utilized to encrypt and decrypt the PQ data. Due to incorporation of crypto-mechanism, the end to end delay (latency) has been increased. The suitability of different cryptography for power system applications are based on trade-off between security and latency due to processing speed. The symmetric cryptography is faster than asymmetric cryptography but less secure. In power system, the requirements of cyber security are different from IT system. The cyber security requirements in power system are availability, integrity, and confidentiality.

Due to penetration of DG resources in power system has challenged the power system protection. The DG is capable to detect the islanding conditions. So, to developer anti-islanding protection system, a close before open topology in SCADA communication has been simulated using OPNET software tool and trip command has been protected by utilizing RSA cryptography simulation study using Java. RSA fulfills the latency requirement of trip signal.
The remaining sections cover the chapter wise conclusions, research contribution and future scope of research work.

7.2 CONCLUSIONS

The chapter wise conclusions are given as below:

From the exhaustive literature survey in chapter II, it is observed that specific requirements of communication network vary for different smart grid applications in terms of bandwidth, latency, priority, and security. So, it is very crucial for electric utilities to define the communication requirements power system network.

There are various reasons to monitor power quality. Monetary loss is the main reason. The voltage sag is one of the most serious power quality problems as it brings the huge financial loss compared with most other kinds of power disturbances. Voltage sag usually caused about 70% power quality problems. Considering the severity of voltage sag is taken as PQ event for generation, detection, and analysis in this thesis.

In chapter III, A MATLAB based program is developed and implemented successfully to simulate symmetrical and unsymmetrical voltage sags. The experimental verification has been done with a suitable hardware set up for generating voltage sags. The signals are generated using voltage sag generator based on impedance based method. It generates voltage sag of any desired depth and duration. This method is advantageous being simple, effective and computer compatible. The experimental results verified the simulation of the voltage sags with satisfactory performance.

The conventional method of detecting voltage sag does not take into account all the characteristics like phase angle jump. When a significant power quality disturbance occurs in a power system due to fault at any phase, there are variation in the voltage magnitude, phase angle, frequency, rate of change of frequency (ROCOF), and power flow. The next step in power quality monitoring is detection of PQ problems.

In chapter IV, transmission line fault (voltage sag) is detected using phasor measurement unit (PMU). The MATLAB simulation of PMU based fault detection using power system line parameter like voltage, positive sequence voltage, frequency, ROCOF, and phase angle has been carried out. The single line to ground fault (SLGF) of three phase of power supply is considered. The transmission line fault location is carried out by using
standard software DIgSILENT considering IEEE 14 bus system. The maximum voltage deviation and direction of power flow at fault line is considered to find location of fault. The advantage of this technique is the fast transfer of data and detection of faulty line.

In chapter V, wide area monitoring system is simulated considering the Northern Indian power system using OPNET. Deffie-Hellman cryptographic algorithm for secure key exchange has been implemented. The RSA cryptography has been implemented to encryption and decryption the data. Furthermore, a set of simulation in Java are carried out to determine the communication system characteristics such as end to end delay. It is observed that with incorporation of crypto-mechanism, the end to end delay (latency) has been increased. So, there must be trade-off between latency and security.

Chapter VI is an extension of Chapter V. This chapter covers cyber security studied for local SCADA systems of power network. The penetration of DG resources in power system has challenged the protection system. A very important requirement which is mandatory to DGs is their ability to detect islanding conditions. So, there is a need to develop anti-islanding protection system which is fast and secure. So, development of close before open technique of anti-islanding protection has been carried out. In this chapter, RSA cryptography has been implemented using Java to secure trip signal.

### 7.3 MAJOR CONTRIBUTIONS

The major contributions of this thesis are as follow:

i. A technique for generation of electric power quality events has been devised and verified experimentally. The signal generated replicates the true features of power system during fault conditions.

ii. The transmission line fault (voltage sag) detection technique using phasor measurement unit has been developed using MATLAB. PMU measures the variation of phase voltage, positive sequence voltage, phase angle jump frequency, and rate of change of frequency (ROCOF) with time. Further, the fault location on IEEE 14 bus system is determined using DIgSILENT (software tool) by creating single line to ground fault.

iii. The security issues of wide area monitoring (WAMS) in smart grid are studied and cyber security techniques have been implemented to enhance the security
issues using OPNET software tool. The WAMS model is a representation of Northern India power system network. The suitability of different cryptography for power system applications has been determined keeping in view the latency and processing speed. It is observed that RSA cryptography encryption and decryption time increase with the data size. The selection of cryptography technique is depending upon the trade-off between speed and latency requirements of smart grid applications.

iv. The security challenges in communication system for local power system protection have been studied and a suitable secure technique to demonstrate the problems has been implemented. A close before open topology is simulated for anti-islanding power system protection. To secure local SCADA communication system, RSA cryptography has been implemented.

The above contributions will help to devise a suitable an intelligent system for power quality monitoring. The work will help to formulate guidelines for suggesting a secure communication system for smart grid applications.

7.4 SCOPE FOR FUTURE WORK

The above work may be further extended as follow:

- In WAMS, a huge amount of data and information are collected, transmitted, stored, and analyzed from thousands of data points across the power network and over large geographical areas. As WAMS evolves, research in data mining may be carried out to manage voluminous critical data.

- In the future, the communication channel is expected to be more dedicated, for example, by employing a fiber optic network for communication with quality of service (QoS) implemented. Not surprisingly, this also demands a unified protocol for better communication among different monitoring and control areas.

- The computational power doubles approximately every 18months and it is also observed that the cost of computation is reducing drastically with time. So, cryptographic techniques must constantly evolve to respond to advances in code-breaking techniques and increasing computer processing power. So, there is further scope for research in key management.