CHAPTER 8

CONCLUSION

8.1 SUMMARY

Service restoration is an important task that must be attended by an electrical power distribution engineer/planner within the minimum time. Restoring the power supply to an electrical power distribution system (EPDS) after a partial or complete collapse in minimum time presents a complex problem. Most of the existing restoration plans attempt to solve the simpler problems from a limited possible initial condition with minimum operational constraints.

Hence, efforts are made in this research work to develop an efficient multi-objective multi-constraint service restoration algorithm for electrical power distribution systems using non-dominated sorting genetic algorithm. A summary of the work done and the significant results obtained during the course of this work and a few suggestions for the future line of research in the area of quick service restoration of power supply in EPDS is presented in this chapter. Before reviewing the work done, the objectives of this investigation are recapitulated below:

i) Development of a new network connectivity method for the analysis of electrical power distribution system.

ii) Development of improved power flow method for the pre-fault/ post-fault single/three phase, balanced/unbalanced, electrical power distribution system.
iii) Implementation of Preemptive Method for the consideration loads in the order of their highest priority.

iv) Development of new method for the estimation of service restoration time in electrical power distribution system.

v) A new non-dominated sorting genetic algorithm-based method to solve the service restoration problem in electrical power distribution system.

vi) Formulation of new combined objective function to solve the service restoration problem in EPDS and also the development of an overall solution algorithm of the multi-objective multi-constraint fast service restoration algorithm for EPDS.

In this thesis multi-objective multi-constraint service restoration for electrical power distribution systems using NSGA is presented. The developed mathematical model has been implemented using C++ and MATLAB6P1 software. The validity of this new algorithm is tested on various practical power distribution systems viz., 12-Bus, 16-Bus, 26-Bus, 29-Bus, 33-Bus, 69-Bus, 79-Bus and 133-bus distribution systems, using a Pentium-III, 1.4 MHz machine. The analysis of the results of the electrical power distribution systems is outlined below:

- **New Network connectivity Method**

This is a most essential method for the network connectivity analysis of the EPDS. The compensation-based power flow method for weakly meshed distribution and transmission networks by Daurish Shirmohammadi et al (1988) and modified Newton method for radial distribution system power flow analysis by Fan Zhang and Carol Cheng (1997) use tree order method for identifying the network configuration. These earlier methods need renumbering of the nodes in the order of lateral and
sub-lateral connectivity to the root node. In this thesis the developed new network connectivity method does not require any renumbering of the nodes and the formulated new mathematical model helps in the identification of the node beyond a particular node and hence, it will provide the complete knowledge of the connectivity of the pre/post fault power distribution network. The network connectivity analysis is done for the various distribution systems with and without tie lines. The simplicity of this new network connectivity method is that it needs only the line data consisting of sending end bus numbers and receiving end bus numbers. These details are presented in Chapter 2.

The simulation of operation of the breakers in the faulty section of lines is done by setting the appropriate breaker status to zero. The modification in switch status results in the change of configuration of the PDN. The new network connectivity method helps in identifying the connectivity of the PDN. This new network connectivity method is not an iterative method and the computational time is very less compared to earlier methods. From the results, it is observed that this new method is not a system-dependent one. Moreover, it is effective and faster in convergence, in addition to minimum input data requirement. Hence, this new method could be used as a generalized tool for network connectivity analysis of the pre/post-fault power distribution network. A knowledge of pre/post-fault PDN connectivity identification helps in efficient operational planning of the EPDS.

- **An Improved Power Flow Method for the pre/post-fault EPDS**

This method helps to know the status of operating condition of the EPDS. Normally the R/X ratio of the distribution networks is very high and, hence, load flow methods like Newton-Raphson load flow method and fast decoupled load flow method, fail to give an optimal solution in the minimum time. Optimal capacitor placement on radial distribution system by Meseut
and Felix (1989) and distribution feeder reconfiguration for loss reduction by Civanlar et al (1988) use forward substitution method for power flow analysis. But these methods employ simplified power flow equations, which need more computational time. In this thesis a new method has been developed for the power flow analysis of single/three phase PDN. The results of power flow method of the various distribution systems agree with results of the earlier methods. The use of forward substitution method eliminates the need for flat start assumption for initial estimation of the voltages. Moreover, in this method provision is made for the power flow analysis of the unbalanced single/three phases EPDS.

The developed recursive equations for the calculation of voltages help in achieving the desired convergence of 0.001% in the minimum computational time. The effective and faster convergences of the results show that it is an efficient power flow method for EPDS. The results reveal that this improved power flow method for EPDS as explained in Chapter 3 is efficient for use in distribution automation systems power flow studies.

- **New Algorithm using Preemptive Method for the consideration of loads in the order of their highest priority**

  This method helps to consider the various classes of loads in the order of their priority. Most of the earlier researchers have not considered ranking method of loads in the order of their priority. The consideration of loads in the order of their priority helps to restore the power supply to high priority loads first and least priority load next. The priority order of consideration of the loads using preemptive method has been tested on various distribution systems. The preemptive method has given good results and hence it is a suitable method of priority order consideration of loads.
The load switching is performed till the capacity of the feeder and transformer is reached. The feeder overloading and also transformer overloading are continuously monitored and these violations are minimized while restoring the power supply to the PDN. Hence, in addition to maintaining safe operating condition of the feeder and transformer, the vital loads are also given high priority in restoring the power supply. This priority-based load switching algorithm helps the electrical power distribution engineers/distribution system substation operators to survive in the field of power distribution. The results reveal that it is a highly suitable load priority algorithm for use in efficient operational planning of electrical power distribution system. These details are reported in Chapter 4.

- **Estimation of service restoration time**

The estimation of service restoration time based on the probability consideration of various protective devices helps in the analysis of exact duration of the restoration of power supply in EPDS as explained in Chapter 5. The additional consideration of the optimistic time, pessimistic time and mostly likely time of operation of the protective devices, which is based on the probability, manufacturing defects and operator’s experience, help in improving the accuracy of the estimation of service restoration time in the EPDS. The analysis of the estimation of service restoration time has been carried out for various distribution systems. A knowledge of service restoration time helps in prediction of exact duration of operating time of the relays. A knowledge of this exact service restoration time analysis helps the electrical power distribution engineers/planners to minimize the period of power blackouts in the EPDS. Hence, this improved method could easily be incorporated in service restoration algorithms of distribution automation systems for restoring the power supply to the consumers in minimum time.
• **A new NSGA based method for service restoration in EPDS**

  Rigorous mathematical calculations can be avoided with the help of the new method. The generalization and modification in selecting the parameters for NSGA help to use the service restoration as a general tool to solve the service restoration problems of electrical power distribution system. The change in the configuration of PDN can easily be incorporated in the selection of the parameters for the NSGA. Hence, this new method could be used as a generalized tool for the EPDS service restoration problems as detailed in Chapter 6.

• **Multi-objective multi-constraint fast service restoration algorithm**

  To effectively solve the service restoration problems of electrical power distribution systems in the multi-objective multi-constraint fast service restoration, a new combined objective function is formulated with the following operational constraints viz.,

  - Lost load minimization
  - Real power loss minimization
  - Minimization of the number of switch operations
  - Voltage limit violation minimization
  - Transformer load balancing
  - Feeder load balancing and
  - Consideration of loads in the order of their highest priority

  For efficient operational planning of the EPDS and to formulate the service restoration problem, the combined new objective function is expressed as sum of the seven functions. The developed overall solution algorithm of the multi-objective multi-constraint fast service restoration helps to solve the
EPDS service restoration problems. Within a few generations of the NSGA, the combined objective function value has reached the global minimum. These details are presented in Chapter 7.

Estimation of the service restoration time and the results of all the electrical power distribution systems show effective and faster convergence under different loading/faulty conditions of EPDS. Eliminating the system dependency makes the new algorithm a general tool for solving the service restoration problems of the EPDS. For converting multi-objective function into an equivalent single objective function, the new approach does not require weighting factors. Multi-objective multi-constraint fast service restoration algorithm is superior compared to past service restoration methods due to the following reasons:

a) Simplicity of implementation  
b) Improved computational efficiency  
c) Solution feasibility and optimality

Multi-objective multi-constraint fast service restoration algorithm is essential due to the minimum computational time requirement, flexibility, validity, faster and effective convergence of the results for the efficient operational planning of the EPDS.

8.2 FUTURE LINE OF RESEARCH

This section presents the scope for further research in the area of quick service restoration of power supply in EPDS.

a) The proposed algorithm with modifications in network connectivity method could be employed for real time control of electrical power distribution systems.
b) The new network connectivity method could be modified to suit dynamic network reconfiguration for the operational planning of EPDS.

c) The accuracy of the estimation of service restoration time could further be improved by considering the life time expectancy of all the associated protective devices in the operation of the EPDS.

d) The application of this multi-objective multi-constraint fast service restoration algorithm could also be used for reducing the run time complexity.