CHAPTER 1

INTRODUCTION

The distribution system is the most visible part of the supply chain and also, the most exposed to the critical observation of its users. About 30% to 40% of total investments in the electrical sector goes to the distribution systems. However, they have not fully received the technological impact as the generation and transmission systems. Many of the distribution systems work with minimum monitoring systems to involve local and manual control of capacitors and sectionalizing switches, voltage regulators and with limited computation support for the system operators. However, there is an increasing trend to automate distribution systems to improve their reliability, efficiency and service quality. In developing countries, the percentage of active power losses in the distribution system is around 20%. Hence, utilities in the electric sector are currently interested in reducing it, in order to be more competitive, since, the electricity prices in deregulated markets are related to the system losses.

In India, the technical and non-technical losses of all the states are accounted to be 28 - 30% of the total input energy. In countries like USA, UK and Canada it is between 8 - 10% in developed countries. To manage a loss reduction program in a distribution system requires use of effective and efficient computational tools, and quantification of the loss in each different network element for system loss reduction. The reduction of energy losses in
the power supply system offers great scope for energy conservation in the country and can be achieved by adopting a scientific approach in the planning of distribution systems in the country.

Power distribution systems typically have tie and sectionalizing switches whose states determine the topological configuration of the network. The system configuration affects the efficiency with which the power supplied by the substation is transferred to the load. Power companies are interested in finding the most efficient configuration, the one which minimizes the real power loss of their three-phase distribution systems.

A typical radial system of distribution is shown in the Figure 1.1. The sub transmission substation supplies the primary distribution system feeders radiating from the substation bus. They feed the distribution transformer of the substation which step down the voltage to the distribution voltage and supplies various loads through the distributor. This is also shown as radial distribution and is one the secondary distribution side. Feeders are conductors that are not tapped in between the sub-transmission substation and distribution substation, while distributors are conductors that are tapped throughout all points when they are laid from the substation transformers to the various consumers in the area to be served. Primary feeder voltage of 11kV and 33 kV are very common. The secondary distribution voltage at the consumers is 415/230 V, the system being three phase four-wire.
Typical distribution systems expect the voltage drop and power losses to be minimum with the voltage regulation requirements at the farthest load point also satisfied. Radial Distribution System (RDS) is widely operated at higher levels of loading to maximize the utilization of capital investments. From the previous works, it is inferred that voltage collapse of a line occurs due to restricted availability of reactive power which limits the real power transfer capacity. Optimal reconfiguration can be implemented through Supervisory Control and Data Acquisition System (SCADA) to route power through the RDS such that the loadability is maximized. Such an approximation is valid only for a specific operating point and cannot be used for varying loads especially, considering the nonlinear behavior of a RDS near the point of maximum loadability or voltage collapse.

The present research focuses on heuristic based search scheme for the enhancement of voltage stability and minimization of power loss in the radial networks. The development of indices computes the loadability of RDS and accordingly reconfigures the network with an objective to enhance loadability/voltage stability. The work mainly focuses on,
i. Reduction of kilowatt losses

ii. Load balancing in feeders, and improving voltage profile.

This present research includes the mathematical modelling of the constraints, indices and measures for the estimation of the proximity or current operating state of the RDS to the point of maximum loadability. A voltage sensitivity analysis-based technique using fourth order radical that computes an index at each bus and identifies the bus closest to the point of the voltage collapse is achieved. A voltage collapse index for stressed systems is analyzed to improve the voltage stability of RDS to reduce the losses. The resultant lines are of minimum length with lower values of voltage drop and minimal power loss is achieved along with optimal reconfiguration of RDS.

1.1 CONSTRAINTS

It is necessary to specify the feasible states in a network configuration and accordingly include the constraints. The major constraints include,

1. Topological Constraints
2. Electrical Constraints
3. Operational Constraints
4. Load constraints.

1.1.1 Topological Constraints

The topology or layout of the system is constrained to be the radial configuration which is typical in power distribution networks. This means that no loops are allowed in the network. The network configuration is also,
constrained to be a connected topology such that each bus is connected via at least one path to the substation. The combinations of these two requirements classify the feasible topology as a spanning tree.

1.1.2 Electrical Constraints

Being an electrical circuit, the status of a power system network must also satisfy Kirchhoff’s voltage and current laws. Since a distribution system can be quite large, involving thousands of buses, the formulation of these constraints can be rather involved.

1.1.3 Operational Constraints

It is possible that the network configuration which theoretically minimizes the real power losses in the system might undesirably require one or several of the components in the system to be operated at a level beyond its physical limitations. Each line, transformer, and switch in the system has a certain thermal limitation, which restricts the maximum allowable current through that component. In general, these physical limitations can be accounted for by constraining the line currents, line flows, and bus voltages to line within the appropriate bounds.

1.1.4 Load Constraints

The power company’s customers have certain requirements for the electrical power they receive. For example, one expects to get approximately 230 Volts at 50 Hz from a wall outlet. The power company is able to maintain a certain voltage level at each bus in the system while supplying the power demand of each customer.
Table 1.1  Rules for load allocation of Constraints on substation and feeders

<table>
<thead>
<tr>
<th>Constraints on substation</th>
<th>Constraints on feeders</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rule 1: If the load of the substation is greater than 70% of the installed capacity of its main transformer, a new substation is needed</td>
<td>Rule 1: The Current of each feeder is limited to be less than 300 A to avoid overloading of typical ACSR Conductor.</td>
</tr>
<tr>
<td>Rule 2: If the load point of a main transformer exceeds 90% of its installed capacity and some of its feeders are overloaded, some loads on these feeders must be reallocated to a main transformer in the new substation. Otherwise, only the load transfers between the feeders of the same main transformer are required to alleviate feeder overload.</td>
<td>Rule 2: For example, the desirable load of each feeder is between 2800 KVA and 6300 KVA. If the load on a feeder exceeds 6300 KVA, load transfer should be performed in this feeder to reduce the load to a level less than 6300 KVA. For that part of the load between 2800 KVA and 6300 KVA, load transfers is optional. If the load on an existing feeder is less than 2800 KVA, no load transfer will be considered.</td>
</tr>
<tr>
<td>Rule 3: The number of feeders for each main transformer is limited. For example, a main transformer with an installed capacity of 25 MVA is restricted to have at most five feeders.</td>
<td>Rule 3: At most two load points are allowed to connect to the same load point.</td>
</tr>
<tr>
<td>Rule 4: The voltage regulation of each load point must be within ±5%</td>
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</table>

Use of the first rule helps to justify the need for a new substation. Rule 2 can help to identify the main transformers which need load transfer. The loads on the feeders supplied do not need reallocation regardless of the peak loads and the maximum current of these feeders.
1.2 OBJECTIVES OF THE PROPOSED WORK

(i) The problem of RDS reconfiguration requires the determination of a combination of branches, one from each loop to be switched out, such that the resulting configuration of the RDS has the maximum loadability. Within the framework of the optimization techniques using Genetic Algorithm (GA), multiple objectives are dealt with and the scheme for voltage improvement and reduction of power losses in the distribution systems coexist.

(ii) The objective of the capacitor placement problem is to determine the locations and sizes of the capacitors, so that the power loss is minimized and the annual savings are maximized. Although some of the reported methods to solve the capacitor allocation problems are efficient, their efficacy relies entirely on the goodness of the data used and does not compensate for any lack of commonly occurring uncertainty in the data. To overcome this limitation, the present work integrates the heuristics judgments into the capacitor allocation optimization process by using Neural Network (NN). Furthermore, the solution obtained from the proposed algorithm is adaptive and can quickly assess the feasibility of the distribution systems.

(iii) A Wireless Application Protocol (WAP) based monitoring with capacitor switching of the RDS is proposed for reducing the power losses and to improve the voltage profile. The application capability has wireless connectivity by using Wireless Mark-up Language (WML) to identify the location
from the substation. A system to monitor the electrical parameter and instantly convey decisions for quick action using WAP is proposed and percentage reduction in line loss and voltage regulation is achieved. The expert system using the developed algorithms and knowledge base is applied to reallocate some loads in a distribution system. The proposed method can handle all the heuristic rules. The load flow and branch conductor optimization techniques are used as a subroutine in the generalized distribution planning algorithm. The research methodology is shown in Figure 1.2.

![Figure 1.2 Research Work Methodology](image)

The new techniques proposed are GA based power loss minimization by network reconfiguration in RDS, Neural Network based power loss variation with optimal capacitor placement and WML based power loss minimization by variable load monitoring using WAP.
1.3 GA BASED POWER LOSS MINIMIZATION BY NETWORK RECONFIGURATION IN RDS

1.3.1 Introduction

A heuristic based search scheme for the enhancement of voltage stability and minimization of power loss of the radial network is proposed. The development of indices compute the loadability of radial distribution systems and few schemes reconfigure the network to enhance the loadability or voltage stability. The research concentrates on reconfiguration of radial systems with a focus on the reduction of kilowatt losses and/or load balancing in feeders and/or improving the voltage profile. Extensive work has been done on voltage stability margin estimation and optimal enhancement in power transmission systems and a similar attention needs to be bestowed on RDS. The expert system using the developed algorithms and knowledge base is applied to relocate some loads in a distribution system. The proposed method can handle all the heuristics rules. The load flow and branch conductor optimization techniques are used as subroutine in the generalized distribution planning algorithm.

1.3.2 Switching Based Voltage Profile Improvement

In this solution, RDS has several loops and each loop has several branches. These branches forming the loops are switched out without affecting the radial nature of the RDS. The switching in/out of branches alters the flow of power and changes the resulting kW or kVAR losses and voltage profile. At a given time, one branch from each loop is switched out. It involves a combination of branches, one from each loop, such that the resulting RDS yields the maximum loadability and the best voltage profile.
1.3.3 Switching Algorithm

The problem of determining a single configuration for a primary distribution network that minimizes energy losses throughout a given period while considering the demand variations is formulated as,

$$\text{Min}_{s \in S} \sum_{t \in T} \sum_{n \in N} \sum_{a \in A_n} \Delta t^a r^a (p_{ta}^2 + q_{ta}^2)$$

(1.1)

subject to,

$$s \in \{0, 1\}$$

$$t = 1, 2, ..., T$$

$$P_{tn-1} = \sum_{a \in A_n} P_{ta} + P_{tn}$$

$$Q_{tn-1} = \sum_{a \in A_n} Q_{ta} + Q_{tn} (P_{ta}, Q_{ta}) \in \Omega_{PQ}$$

$$G^t = (N, A^t)$$ is a tree

(1.2)

where, $s$ represents a switch (closed for $s=1$ and open for $s=0$), $S$ is the set of all available switches, $T$ is the set of time intervals, $N$ is the set of nodes in the graph representing the primary distribution network ($G=(N,A)$), and $A_n$ is the set of arcs emanating from node $n$ (all branches that extend from it), $\Delta t$ is the duration of the interval $t$, $r_a$ is the resistance of the arc $a$, $P_{ta}$, $Q_{ta}$ are, respectively, the active and reactive power flows on the arc $a$ during interval $t$.

A 33 - bus RDS has been considered for the study and include the load data distribution line details with tie lines along with the Switch regulated control (either open/ closed). In order to quantify the maximum loadability of the RDS, the total additional load that may be drawn from the
RDS before it suffers a collapse is determined. This additional load is referred to as the kVA Margin to Maximum loadability (KMML) and is increased in the present work, while retaining the existing power factor of the loads and load distribution in the RDS.

1.4 NEURAL NETWORK BASED POWER LOSS VARIATION WITH OPTIMAL CAPACITOR PLACEMENT

1.4.1 Introduction

The Optimal Capacitor Switching (OCS) is an important measure for loss minimization in the distribution systems via an optimal capacitor dispatch schedule. The OCS is used to improve the voltage profile and minimize the system losses. Capacitor placement is a hard problem in power system research as it involves integer variables for determining the placement, locations and discrete variables for deciding the number of capacitor banks to be installed. It is a large-dimension constrained optimization problem when the system and investment constraint. In the present research, a novel training scheme for Neural Network (NN) is used and utilizes minimum number of iterations to solve the OCS problem in the RDS. For a typical distribution network, where a power flow is used in an unbalanced phase, it is necessary to optimize the number of switched banks in the bus of each single phase independently.

Capacitor banks are added to the radial distribution systems for power factor correction, loss reduction, and voltage profile improvement and in a more limited way, the circuit capacity increases. With these various objectives in mind and subject to the operating constraints, the optimal capacitor placement aims to determine capacitor types, size, and locations and control schemes.
1.4.2 Proposed Approach for Optimal Capacitor Placement

The purpose of placing the capacitors is to improve the node voltages and reduce the system losses. It is well known that the reactive power flow is more responsible for voltage drop in a power system than the flow of active power. Moreover, a large portion of the power system loads being of constant power type, low voltage becomes responsible for high power losses. Thus, capacitor placement methods are developed using node voltages and active and reactive branch power losses. These methods are very sensitive to the weighting factors representing the membership functions. There is no guarantee that the same set of factors will perform uniformly for all the networks. The novelty of the research is to explore the development of the Neural Network, which is less dependent on the above set of factors.

1.4.3 Algorithm of NN Based CSI Selection

Step 1

Read Normalized INPUTS PLI; PV and

Compute Normalizes Neural output

Step 2

If [OP >=threshold] above then

Place Capacitor

The Per unit node voltages (PV) and Power Loss Index (PLI) are the inputs to the Neural Network and is used to determine the suitability of a node in the capacitor placement problem using a Capacitor Suitability Index (CSI) at each node. The higher values of CSI are chosen as the best locations for
capacitor placement. The power loss indices are calculated using Loss reduction, Minimum and Maximum reduction and number of bus. The actual relation among them is discussed in the chapter 4 of the thesis.

1.5. POWER LOSS MINIMISATION BY WAP BASED MONITORING

Distribution systems have to bear different load patterns at different times. This variable load causes distribution feeders to be either over loaded or lightly loaded. If not compensated well, the voltage at different buses exceed the nominal voltage and the real power losses on the feeders increase, leading to high operating cost of the system. It is possible to drastically reduce the distribution system energy loss and also conserve energy. WAP can be deployed anywhere and integrated with RDS. This application has wireless connectivity to identify the location from the sub-stations. In a sub-station / distribution system, there is need to continuously measure and monitor the voltage, frequency and power factor associated with the transformers, circuit breakers and switches.

1.5.1 Automated Regulation of Power Loss using WAP

The feeder data chosen in the present research includes,

(i) Resistance/Reactance of feeder
(ii) Loads as-well-as voltages at various nodes
(iii) Voltage variations at the tail ends of each branch/spur
(iv) Currents and losses in various branches
(v) Total power
(vi) Energy losses and
(vii) Percentage of Energy losses and the node at which the maximum voltage variation occurs.

The algorithm is scalable with a facility to draw a single line diagram of the feeder and monitor the results and real time values at various nodes. Allowed modifications include re-conductoring (Change of conductor size) or rerouting of the network for system improvement. Also, re-distribution of loads and reactive compensation requirements are done to regulate the voltage variation.

1.6 ORGANIZATION OF THE THESIS

The research carried out is presented and explained in the following chapters of the thesis.

In Chapter two, literature survey of the work done in network reconfiguration in RDS, power loss minimization, Optimal Capacitor Placement and Variable load monitoring using WAP along with the proposed technique is presented.

Chapter three presents the optimal switching criterion based minimization of power loss /Enhance loadabilty / Voltage stability / Load balancing/Improving voltage profile for the distribution systems. System contingencies such as overloading of the main transformers and occurrence of the faults in a distribution system are effectively handled. The optimal switching criterion can increase the operating efficiency of the distribution systems by minimizing the power loss. The load profile of the distribution feeders and the load patterns of the different types of load (customers) are used to evaluate the loading condition at each moment of variation and the feeder load behavior is represented more accurately.
In chapter four, GA and NN based Network Reconfiguration with OCS is proposed to find the size and location of the capacitor for loss reduction and to improve the voltage profile in RDS. Networks are less dependent on the weight factors and are more generic than the conventional NN based capacitor placement methods. Also, the use of forward-only algorithm simplifies the computation process in second order training that can handle arbitrarily connected in neural networks and has the benefit of speed for networks with multiple outputs.

Chapter five presents Server Architecture and Application of WAP based monitoring of capacitor switching of the RDS using WML. This results in reducing the power losses and to improve the voltage profile.

Summarizing the aim of the research, the results and discussion is presented in chapter six. Finally, the conclusion and future scope is presented in chapter seven.