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Full Length Research Paper

System reconfiguration and service restoration of primary distribution systems augmented by capacitors using a new level-wise approach

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Ensuring continous, economical and quality power supply to customers is the primary objective of suppliers. This implies quick restoration of supply in case of faults, to maximum possible load in minimum time with minimum loss. Power quality and network loss can be improved by providing reactive power compensation using capacitors. This paper proposes a new method for system reconfiguration and fault restoration of a distribution network. The approach is applicable to both single and multiple fault cases. The hierarchy of the methodology is downward from the feeder to the bus level. Additionally, an iterative method is proposed for evaluating capacitor size and location by calculating the loss sensitivity index (LSI) of the buses. Compensation is provided to the initial network. Faults are then simulated and the effect of the existing compensation after fault restoration using the proposed method is studied. Later, a new compensation scheme is derived by altering the original scheme. Suitable compensation solution can be decided based on either minimum loss or cost restraints. The proposed method is applied to a 44-bus distribution network of R. K. Nagar, KPTCL, Karnataka, India. Comparison of the network parameters and results after fault restoration without compensation, with initial compensation and after applying the new compensation scheme shows the method is very effective in responding to faults, in practical time periods.

Key words: Single fault, multiple faults, feeder fault, network line fault, reconfiguration, supply restoration, load shedding, capacitor placement.

INTRODUCTION

The distribution network must be optimally configured to incur minimum annual cost (capital investment + overheads + running cost) while satisfying all the requirements and constraints like 1) Radial configuration, 2) All loads must served, 3) Lines, transformers other equipment should operate within current capacity limits, 4) Overcurrent protective devices must be coordinated, 5) Voltage magnitudes must be within limits. Reconfiguration means re-arranging the load, subject to availability of physical infrastructure on the ground in order to meet the above mentioned requirements. Consumer demands vary with time of day, day of the week, and season, therefore, feeder reconfiguration also enables load balancing transfers between regions. Furthermore, online configuration quickens management and distribution automation when remote-controlled switches are employed. Faults cause power outages to loads of the network. They affect the network in mainly two ways. One is feeder fault, where the feeder breaker trips causing all load supplied by the feeder to blackout. Another is network line fault causing power outage to only a portion of total feeder load. These faults can either occur at single or at multiple locations that is, single and multiple faults respectively. Multiple faults are more severe and more probable. Restoration

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means restoring the supply back to maximum possible loads in the affected area with acceptable voltage and balanced distribution of loads as best as possible, in minimum time with minimum loss.

Reactive (capacitive) power injection/compensation into the network improves the power factor and voltage of the load buses / nodes by nullifying the load point's inductive power demand, therefore decreasing the network loss and increasing feeder spare capacity. Hence, it helps reconfiguration and restoration procedure give better results. As placing capacitors at each bus is expensive, their effective locations and sizes have to be determined such that there is substantial loss recovery at minimum investment. Distribution networks are usually radial for simplifying overcurrent protection. Network reconfiguration/restoration depends on existing supply routes, source substations and load locations. Most feeders have several interconnecting tie switches to neighbouring feeders. To restore power to customers following a fault, configuration must be altered by changing the status of network switches (open/close), in such a way that radial nature, voltage and current limits are always maintained. Re-evaluating compensation and protective schemes of the new configuration is then necessary.

Since a typical distribution system has hundreds of switches, combinatorial analysis of all possi-ble options is not practical. Choosing the appropriate solution becomes a problem in itself. The radiality constraint and the discrete nature of switch values limit the use of classical optimization techniques to solve the reconfiguration/ restoration problem. Also approaching the exact required values of all result variables, that is network loss, voltage profile and line current is not possible. While one variable may be approaching the required value, another may be driven away from its value. Compromises will, therefore, have to be made using some criteria. In order to save time and effort, heuristic search techniques using knowledge-based engines are used instead of analytical techniques involving complex equations and boundary conditions.

Recent papers use expert system approach like fuzzy logic (Seong-Il et al., 2006) and techniques like Genetic Algorithm, Ant Colony System Algorithm (Gómez et al., 2004) and Simulated Annealing technique (Young-Jae et al., 2002) for finding optimal network reconfiguration. Seong-Il et al. (2006) proposed a service restoration methodology for multiple faults by classifying feeders as simple and compound interconnected feeders depending on the number of outage areas a feeder is associated to. Young-Hyun et al. (2000) proposed a left child / right sibling tree structured database using non-directional data for speeding up the tracing algorithm. Dash et al. (1991) used Artificial Neural Networks to determine an optimal compensation solution. Srinivasa and Narasimham (2008) used the Plant Growth Simulation Algorithm by defining and using a "loss sensitivity" factor of the buses in determining optimal capacitor locations and sizes. The above mentioned techniques and algorithms have also been applied in solving the compensation problem (Branko and Milos, 2004; Chung-Fu, 2008).

This paper proposes a new mechanism for system reconfiguration during normal operation and service restoration after single or multiple fault occurrences. A methodology for capacitor placement is also included and its effect on reconfiguration/restoration is studied. The compensation solution is again varied to optimize the system. These methods are iterative approaches and all the requirements and constraints mentioned above are complied with to obtain best possible practical results. The new approach reduces unnecessary load shedding, balances load on different feeders, reduces network loss to minimum level, and improves spare capacity availa-bility on feeders, if sufficient infrastructure in terms of switches, branches and parallel supply routes are available.

This methodology and programming is applicable to any network. Large data collection is necessary. That is, number of feeders, branches and nodes in each feeder, bus and line data, generator and feeder capacities, number, location and status of switches etc. Identification and rectification of faults is not included in this paper. Since the network load keeps changing with time, it is assumed here that the load is constant till the entire proposed method is run and the network changes are implemented. Faulty feeders and lines are assumed to be priorly known and are inputs to this approach. The mutual coupling between conductors is neglected and all the phases are assumed to be balanced. The possible values for compensation and its variation are in discrete steps. Stepped variable compensation is done through installation of on-off capacitor banks. The approach is practical and close to actual practice. It uses simple terminology. Extensive mathematics is avoided, other than what is needed in MATLAB, hence is easy to understand and implement. The results give clear and simple operator instructions for implementation with sufficient time to spare. Any contingency can be tackled with ease.

PROPOSED METHODOLOGY

The new level wise approach

Faults are classified, depending on the location as:

1. Feeder fault
2. Network line fault

Depending on the number of faults occurring simultaneously, as:

1. Single fault
2. Multiple faults

Single faults can be either feeder or network line fault. Multiple faults are a combination of both at multiple locations. For convenience, only two faults are considered in this paper but this method can accommodate any number of faults.

Network plot for analysis

The existing geographically spread network of supply and load is converted into a plot to be used by MATLAB/load flow program. Such a plot will facilitate uni- and bi- directional load re-arrangement. It should be noted that the uni-directional / bi-directional terms have meaning only to the MATLAB program and bears no resemblance to the physical network. Since the network plot represents existing network, it has to be prepared meticulously.

Data base

Network data describing the network has to be carefully entered in a data file, which will be frequently accessed by the program. The required data are as follows:

1. Busdata (node data) gives the real, reactive load and compensation at each bus.
2. Linedata gives each line's resistance, reactance and the two nodes they connect.
3. Dummy node, dummy feeder and dummy lines data.
4. Feeder data tables give details of loading capacity, number of branches.
5. Tie data tables list all the initial tie lines and the two feeders they connect.
6. Tables of switching sequence for shifting feeder branches by priority.
7. List of all possible standard capacitor values.

Method 1

The approach is divided into five levels:

1. Feeder shifting
2. Branch shifting
3. Node shifting and shedding
4. Load picking
5. Result display and Operator Instructions

Service restoration of feeder faults starts at the feeder shifting level and system reconfiguration starts at the branch shifting level. Network lines fault restoration starts at the node shifting and shedding level. Load picking level is applicable only if there are any nodes shed in the third level. In the result display level, the feeders are checked for overload, the loss difference is measured and the operator instructions for implementing configuration changes are displayed.

Feeder shifting level

This level is applicable only for feeder faults. When feeder fault occurs, the feeder main breaker trips and the entire load supplied by the feeder are blacked out. The entire load has to be transferred onto a healthy feeder. There should be multiple tie lines for every feeder to facilitate inter-feeder load transfer. The best host feeder is decided based on any one of the criteria listed below after evaluating all possible feeder combinations:

a) Spare capacity of the healthy feeder: The healthy feeder with largest spare capacity is chosen as the host for the blacked out feeder load. After the load transfer, the new total load of the host feeder must be less than its permissible thermal loading to avoid damage due to overheating. The effect of load transfer on the host feeder loading is reduced in the subsequent shifting operations.

b) Minimum loss after each tie line connection: All tie lines connecting the faulty feeder to all the healthy feeders are listed. For each tie line closed, the network loss is determined. Healthy feeder of that tie line connection giving the least network loss is chosen as the host. This method is helpful when there are more than one tie lines from the same healthy feeder. The tie lines closer to the feeder in the radial branches are preferred as the length and the amperage load of the branch through which current has to flow decreases, lessening the I2R losses.

After performing the feeder shift using any of the above criteria, host feeder overloading and minimum voltage of the new configuration is checked. If none of them are beyond specified limits, then the resulting network is considered as "restored after feeder fault", the result display level/operator instructions are implemented and restoration ends in a positive note, else it proceeds with the resulting configuration to the next level that is, branch shifting.

Branch shifting level

Branch shifting transfers only part of the load (contained in the shifting branch) from one feeder to another. This kind of shifting redistributes the network load over all the feeders, making better use of their available spare capacity. Sending feeder is one which has the node with the least voltage in the network and receiving feeders are those which have tie line connections to the sending feeder. Host feeder is the receiving feeder chosen to host the shifted branches. This level gives better results when large number of nodes must be moved. There are two ways of branch shifting. First is uni-directional branch shifting (e.g. left). In a simple network plot, if each feeder has tie line connections with other feeders on either side, the branches of the first feeder can be shifted in both directions, but only left will be chosen (similarly for the right).

Tables listing the switching sequence to be executed for shifting each branch from the sending feeder to a receiving feeder are created for all its branches with priority indicated for all directions. The priority list is arrived at based on the network physical structure and the direction of shifting. It is the creation of these tables that make the method network specific as the switching sequence for each network has to be prepared manually. For the sample network described above, two tables, one for right shifting and another for left shifting has to be created. If an acceptable configuration is not obtained in uni-directional shifting, then the second type that is, bi-directional shifting is attempted. The resulting configuration will be the one yielding the highest minimum voltage. If this type of shifting also fails, the mechanism proceeds to the third level.

a) Uni-directional branch shifting: For the first iteration, the host feeder hosting the minimum unacceptable voltage-node in the resulting configuration obtained from the previous level, becomes the new sending feeder. The receiving feeder which has the largest spare capacity becomes the new host for shifted branches. The direction of shifting is thus determined. Branches from the sending feeder will be shifted in priority order by implementing the switching sequence entered in the shifting table prepared for the corresponding direction. After shifting each branch, load flow is run and the next minimum voltage-node is obtained. The feeder of this node will become the new sending feeder for the next iteration.

b) Bi-directional branch shifting: The initial network and the sending feeder is same as in uni-directional branch shifting for first iteration. In one iteration, a branch from the sending feeder is trial-shifted to all the receiving feeders, one at a time and load flow is run to get the minimum voltage-node of the network. The shift giving higher "minimum voltage of the network" is chosen. The minimum voltage-node of one iteration determines the sending feeder for the next iteration.

For both types of shifting:

1. In a network, the numbers of branches are usually limited to maximum three or four, out of which one branch gets the supply either from the feeder's generator or through a tie line. This branch cannot be shifted as it would cut off supply to the unshifted load of the sending feeder.
2. During service restoration of feeder faults, if the initial faulty feeder itself is the sending feeder, and its supporting healthy feeder itself is to host the shifted branches, then a branch of the supporting host feeder is shifted in the same direction instead of the faulty sending feeder. This is done to avoid disconnection between the faulty and the supporting feeder.
3. A reasonable number of iterations are pre-specified. If an acceptable configuration satisfying the voltage and current constraints is obtained in any iteration within that number, then the restoration process ends and operator instructions are displayed for the resulting configuration. Else with the best configuration of all iterations, method proceeds to the third level that is, node shifting and shedding.

Node shifting and shedding level

Line fault affects only part of a branch:

For node shifting, all those nodes of the resulting configuration prevailing in the previous level which have voltage less than the specified minimum voltage limit are listed. All alternate connections possible to these nodes are tabulated. A node is then shifted over each possible alternate connection and its new voltage is checked. The alternate connection giving voltage higher than the specified minimum and with least network loss is selected for that node. If no connection is possible, then the node is shed. This procedure is repeated for all the listed nodes.

At the end of this level, the voltage constraint will be satisfied, but feeders may be overloaded (only theoretically, because in practice the generator voltage drops due to over- load). If none of the feeders are overloaded and no nodes are shed, the resulting configuration is considered as "restored after node shifting" and the result display level gives the operator instructions for implementation.

a) ***Dummy lines and dummy feeder (to effectively use Load Flow program):*** Load flow converges when all the nodes in the network are supplied. Shedding causes isolated nodes that prevent the load flow program from converging. To bypass this problem, a dummy generator node (feeder) and dummy lines (initially open) connecting shed/isolated nodes directly to the dummy feeder must be created. Nodes to be shed are disconnected from all network nodes and attached to this dummy node. To get more accurate results, the impedence of the dummy lines should be as minimum as possible and the load on the shed nodes should be made zero. This also keeps the voltage of the shed nodes at 1 P.U avoiding confusion from the network voltage values.

Load picking level

Load picking is the last standard procedure in this new approach, both for reconfiguration and restoration. It is necessary that at least one node should be shed for load picking to take place. First, a list of all possible reconnectable lines for each shed node is tabulated. Let the node at the other end of these lines be called "pair nodes".
For a shed node, if the pair-node is part of the network, and their connecting line is not faulty, then such lines get shortlisted into "possible reconnection table", else if the pair-nodes are also shed, then those lines are closed but not shortlisted. Next, for every node, taken one at a time, each of these shortlisted lines is closed one at a time and the minimum voltage of the network is determined. The reconnection resulting in "shed-but-now-reconnected-node" voltage being above minimum specified limit and least network loss are selected. If no connection satisfies the voltage constraint, then the node is permanently shed. This picking procedure is repeated for all the shed nodes.

The resulting network at the end of this level will have all its node voltages' above minimum limit. But feeders may be overloaded, in which case the third and fourth level are repeated till the loading on all the feeders are within their thermal limits and a dead end is reached beyond which no improvement is possible. Restoration of the permanently shed nodes is possible only after rectification of the fault. The network is reconfigured or restored at this point and the resulting configuration is the final configuration. The network loss of the final configuration obtained after fault restoration could be higher than that of the original network. The aim is to minimize the increase in loss.

Result display level and operator instructions

At the end of the whole methodology, this new approach prints out the operator/technician instructions that is, the list of switching changes that are to be effected in order to realize the restoration or reconfiguration in the field. This instruction is the link between the MATLAB program and the actual network in the field. This list is prepared by the program by comparing the status of all the switches in the final configuration with that of the initial/existing configuration and tabulating the changes.

The new proposed mechanism definitely decreases the network loss since load gets re-distributed more equitably. Service after fault is restored quickly with maximum load pick up as all possible search options are executed and with minimum loss difference as least number of switching changes are done in the network. In case of multiple faults, feeder fault is taken up first, then network line fault is restored. While the first fault is being restored, the nodes affected by the second fault are temporarily shed that is they are attached to the dummy feeder to obtain convergence of the load flow program. In the flowchart shown in Figure 1, "V" implies voltage limits, that is, if voltages of all nodes are above the specified minimum voltage limit, and "I" implies feeder loading that is, if any feeder is overloaded. For convenience, thermal limits of network lines are assumed to be high and neglected.

Reactive power compensation

With assumptions stated in the introduction section, finding the accurate compensation solution is possible but time consuming. Hence a compromise has to be made between loss reduction and the time taken to obtain and implement the solution. Following the assumptions, a compensation solution specific to the network configuration is achieved. But after fault restoration, the network configuration changes and some of the buses and capacitors may be shed. Initial reactive power injected by capacitors at some buses may not be appropriate. Hence a new compensation solution will have to be arrived at after each of the different fault restoration scenarios. And to achieve this, variable capacitors must be installed at both generator/feeder and load buses in the network (Figure 2).

Method 2

Variable capacitors are inducted at the generator buses. If the load flow program does not facilitate this addition, four fictitious nodes must be introduced right beneath the generator buses, before the

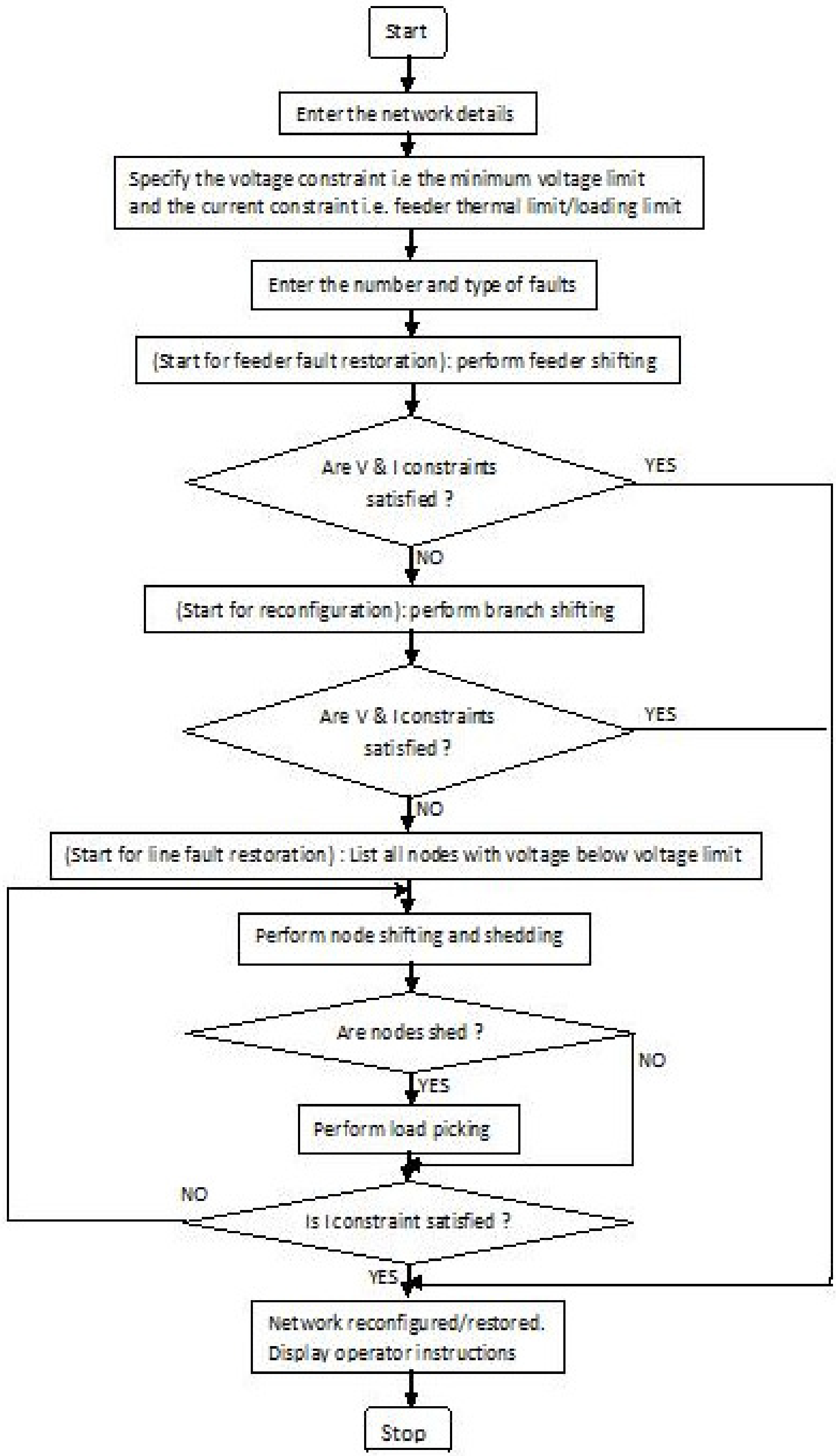

Figure 1. The new level-wise approach applicable to all types of faults

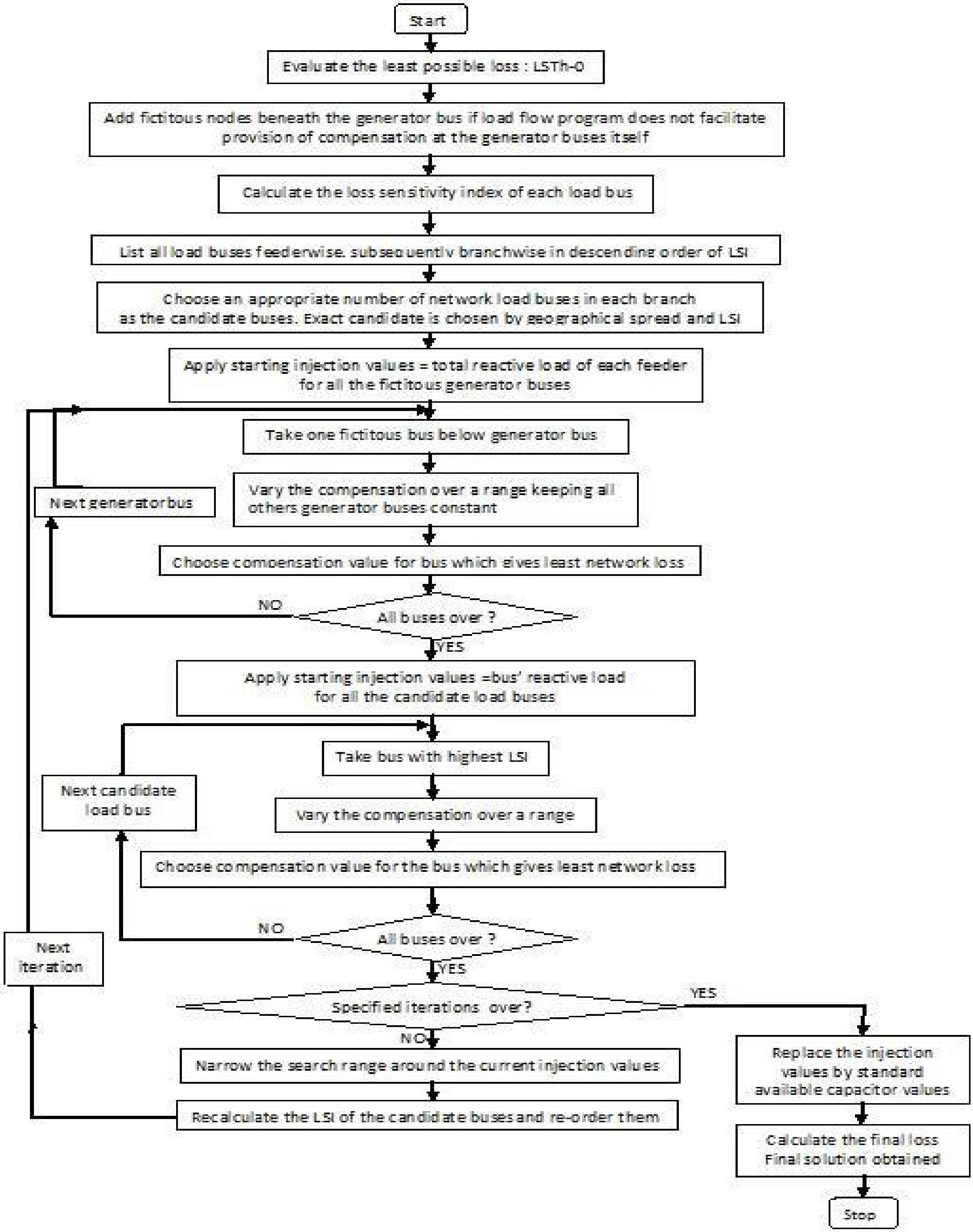

Figure 2. Proposed methodology for reactive power compensation of a distribution network

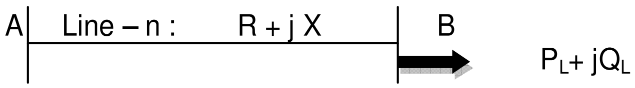

Figure 3. Line section of a distribution network.

load buses. The load at these fictitious buses must be zero and impedence of the lines connecting these buses to the generator buses must be as low as possible for better accuracy. The theoretical least possible loss (LSTh-0) in the network can be obtained by nullifying the reactive load at each bus and reactance of every line in the uncompensated network. This is done by injecting reactive power equal to the reactive load at each bus and capacitors at both ends of each line. Injecting reactive power higher than these values will result in increased losses. Again achieving LSTh-0 is not practical due to capacitor cost constraints. Hence, only a few numbers of buses must be identified for compensation based on some criteria like loss sensitivity index (LSI). LSI is the sensitivity of network loss (LSN) to incremental change in the reactive load of each of the network buses. The LSI of each bus is calculated and buses are tabulated in descending order of LSI. It is prudent to inject reactive power at few buses with higher LSI. But, the candidate buses for compensation must be geographically distributed in the network to cater for the loss of buses due to shedding during outage. Therefore, the buses are arranged feederwise and branchwise in descending order of their LSI, and two buses of each branch of every feeder are chosen as the candidate buses. The chosen number of buses that is, two is user specified for convenience and/or the buses can be chosen based on geographical spread.

Once the locations are determined, selected buses are compensated such that the network loss LSN approaches LSTh-0. The injection values are determined first for the fictitious buses near the generator buses, and then for the chosen network nodes to achieve LSN closer to LSTh-0. The proposed method is an iterative process for obtaining the optimal compensation solution. For the first iteration, starting values equal to the total reactive load of their respective feeder are applied to each fictitious bus. Thereafter, power injection values are varied over a range, for one bus at a time, keeping the starting values of other buses constant. The injection value resulting in least LSN is selected for that bus. Compensation for the next and the remaining buses are similarly determined. Alternatively, compensation values for each fictitious bus are obtained by permutation and combination. The range is initially from zero to the maximum allowed injection. The maximum is the sum of the network reactive load. The initial search steps should be large enough for this range in order to obtain results quickly, but the results will be not exact yet. Next, starting injection value equal to its reactive load is applied to each candidate load bus. The candidate buses are taken up one at a time in descending order of their LSI and their injection values are varied over the same range. The compensation values are obtained in the same manner as above.

At the end of the first iteration, an approximate compensation solution is obtained and the network loss will have either remained same or decreased. This process is repeated first with the generator buses and then the candidate load buses over multiple iterations. In each subsequent iteration, the search range and steps have to be narrowed down in order to approach accurate injection values. Also the sensitivity of the load buses change after each iteration due to change in its net reactive load. Hence, the LSI has to be re-evaluated for all the candidate load buses and again taken in its decreasing order. The injection values so obtained need not be the standard values of commercially available compensation. The number of iterations can be limited to an expert-user-specified value or till the difference between the losses values of two consecutive iterations is less than specified tolerance limit. At the end of the iterations, the loss value will have approached the least network loss possible that is, LSTh-0, but the bus injection values obtained might not be standard available commercial values. If continous compensation variation is possible, these values can be used, else they have to be replaced by nearest standard compensation values. For the latter case, new loss sensitivity list of the candidate buses are obtained and for each bus taken in decreasing order of the LSI, the immediate higher and lower standard compensation values are tested and the value giving lesser network loss is chosen for the particular bus. In this case, the network loss may increase due to the approximation made in the compensation values, but it will be acceptable in view of the time and cost constraints.

After fault restoration, the network configuration changes and some buses may be shed. In such a case, the compensation solution may not reduce the network loss to its lowest, or instead it might add to the losses. Hence, the optimal solution will have to be re-evaluated. Again, the same iterative procedure is applicable. The candidate buses remain the same, only their injection values have to be altered. The existing injection values serve as the starting values for both the fictitious generator buses as well as the candidate load buses. The initial search range of injection values will be wide i.e. from zero to the maximum allowable compensation value. The maximum allowable compensation value has to be re-calculated for the new configuration

Calculation of loss sensitivity index (LSI) of a bus

Consider a distribution line (line - n) with impedance R+jX and load of PL+ jQL connected between buses 'A' and 'B' as shown here (Figure 3):

Active power loss in the nth line is given by

$$P_{LINELOSS}[n] = \frac{(P_L^2[B] + Q_L^2[B]) * R[n]}{(V[B])^2} \quad \text{....... (1)}$$

Similarly, reactive power loss in the nth line is given by

$$Q_{LINELOSS}[n] = \frac{(P_L^2[B] + Q_L^2[B]) * X[n]}{(V[B])^2} \quad \text{....... (2)}$$

Where,

PL [B] = Total effective active power supplied beyond the bus 'B'.
QL [B] = Total effective reactive power supplied beyond the bus 'B'.
V [B] = Voltage at bus 'B'.

Network loss includes both real and reactive loss. Reactive loss of the network is directly proportional to its net reactive load. But, sensitivity of the network real loss needs to be studied. Hence for purpose of studying the effect of reactive power compensation, network loss can safely refer to only the network real loss. Therefore:

$$\text{Total network loss (LSN)} = \sum_n P_{LINELOSS}[n] \quad \text{...... (3)}$$

LSI of a bus B is now the sensitivity of network real loss to incremental change in reactive load at bus B. It is obtained by differentiating LSN w.r.t QL [B].

$$LSI[B] = \frac{\partial (LSN)}{\partial (Q_L[B])} = \frac{2 * Q_L^2[B] * R[n]}{(V[B])^2} \quad \text{...... (4)}$$

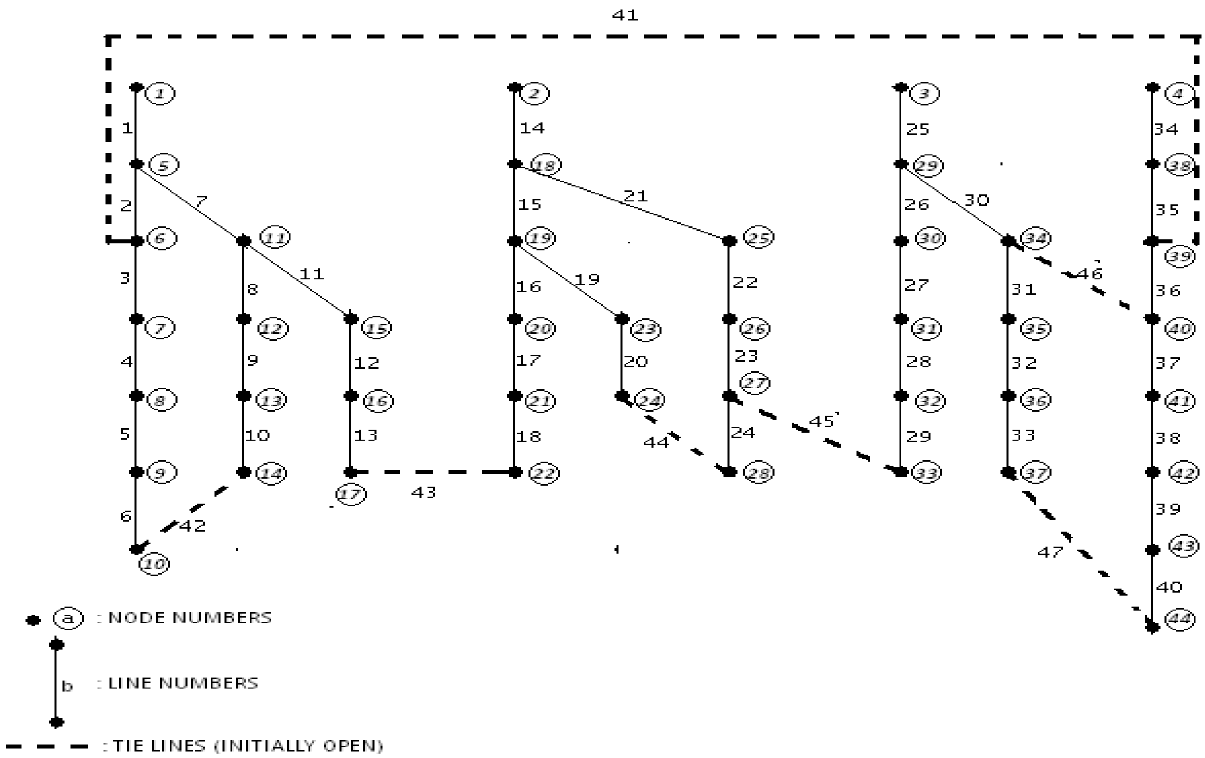

Figure 4. Sample distribution network Nodes 1-4 are generator buses. The remaining are load buses.

Table 1. Standard available capacitor values.

	1	2	3	4	5	6
Capacitor rating (MVAR)	0.15	0.30	0.45	0.6	0.9	1.2

Once the LSI of all buses are calculated, they are arranged in descending order of LSI and used.

Sample system

A practical primary distribution system of R. K. Nagar, Karnataka Power Transmission Corporation Limited (KPTCL), of 11 KV having 44 buses, 40 sectionalizing switches and 7 tie lines have been taken as the sample system. The line resistance, reactance and voltage are measured in P.U. Real, reactive and apparent power are measured in MW, MVAR and MVA respectively. The network plot shown in Figure 4 is derived from the practical network, drawn suitable to processing by MATLAB. No changes are made in the circuit.

Programming was done in MATLAB 7.6 in Windows XP on a 1.5 GHz processor. The load flow program used is based on GAUSS-SIEDEL method also written in MATLAB. Newton-Raphson method can also be used, but the variables must be carefully tapped out. Presenting existing network to MATLAB is very important in order to obtain correct results and so also is interpreting the results to the operator. All the relevant data and tables are created and stored in a data file in MATLAB. The maximum feeder capacity is taken as 15 MW and the minimum voltage limit is entered as 0.98 P.U (user defined). For convenience, only the feeder's maximum current (load) capacity is considered. The capacity of the network lines is assumed to be sufficiently high for all scenarios. The permissible feeder overloading is taken as 40%. The voltage profile, total network loss, switch positions (that is, switch status on/off), generation and spare capacity of all the feeders are recorded at all the stages of the program from the initial to the final network.

The standard available capacitor values are given in Table 1. All possible capacitor combinations are made from these standard values and are applied to obtain the compensation solution. For convenience, the capacitor cost constraint is neglected for this case study and solution for minimizing the network loss is the primary objective.

RESULTS

A single feeder fault is simulated at feeder 2. Service is restored to the outage load using the new approach without compensation. Later, a compensation scheme to reduce network loss is determined for the initial sample network. The same fault is simulated and restoration is attempted again. After restoration, the existing compensation is then altered to minimize the network loss. The voltage profile, network loss, number of switching changes, generation and spare capacity of the network

Table 2. Operator instructions without and with compensation.

	Before fault		After fault		
	Without comp	With comp (A)	Without comp	With comp (A)	Altered comp (B)
Number of switching changes	-	-	9	9	-
Switches to close	-	-	41,43,44,45	41,43,44,45	-
Switches to open	-	-	2,6,16,20,21	2,6,16,19,21	-
Generation (MW)	30.9757	30.9267	27.1894	28.4211	27.1398
Spare cap (MW)	29.0243	29.0733	32.8106	31.5789	32.86
Loss (In MW)	0.3669	0.3155	0.3391	0.3436	0.2902
Reduction in loss as % of initial network loss + increase / - decrease		-14.01 %	-7.565 %	-6.346 %	-20.90 %
Load to be compulorily shed	-	-	-	-	-
Nodes shed permanently	-	-	10,18,19,23	10, 18, 19	10, 18, 19
Actual load shed	-	-	4.90	3.752	3.752
Minimum voltage (Node)	0.9730 (22)	0.9773 (10)	0.9811 (25,28)	0.9829 (22)	0.9834 (23)
Feeders overloaded	-	-	-	-	-

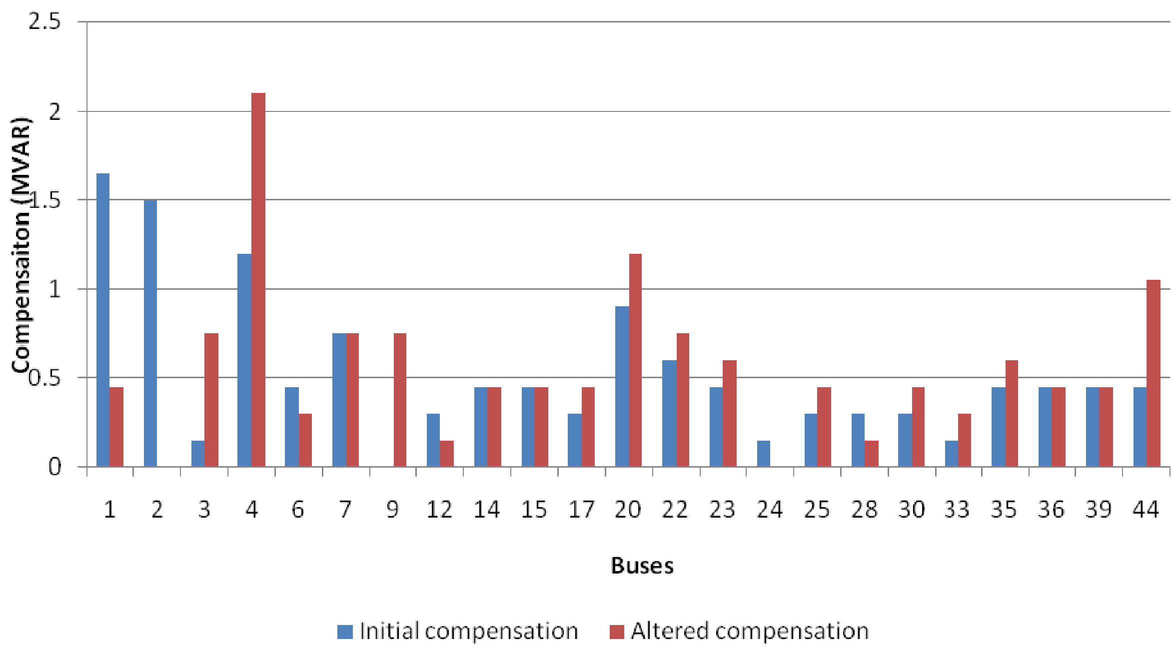

Figure 5. Initial and altered compensation values applied at compensated buses of the sample distribution network.

are tabulated in Table 2 and compared before and after restoration, without and with compensation.

Fault type: Feeder 2 fault
Outaged load: 9.73 MW

Minimum possible loss for:

Initial network = 0.310 MW

Network after fault restoration = 0.2883 MW

As seen in Table 2, fault restoration using capacitors results in lesser load shedding and better voltage profile. Voltage profile improves further and loss reduction is enormous after the compensation is altered at the same locations. Figure 5 shows the original and altered injection values at all the compensated buses. The improvement in voltage profile is evident in Figure 6.

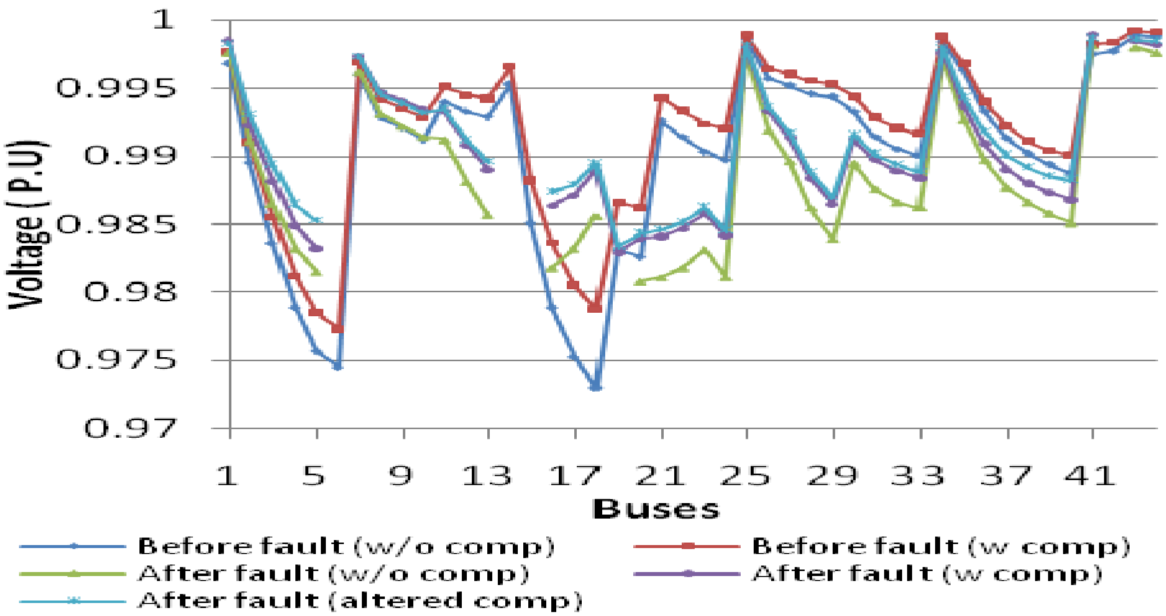

Figure 6. Voltage profiles of the sample distribution network before and after fault restoration for both without and with compensation cases.

SCOPE FOR IMPROVEMENT

This program can be extended to include real time fault identification and rectification. Feedback control to detect fault location and to periodically check the network condition can also be incorporated. Including more details like maximum network line capacities and varying load condition makes the mechanism more practical. This method can be used to plan new networks. Capacitor costs can be included while determining the optimal solution and payback/break-even time period.

Conclusion

This paper gives a new, fast and effective method for system reconfiguration, service restoration and providing reactive power compensation of a primary distribution network. An iterative method is used to determine an optimal compensation solution which also enables variation of the solution when the network configuration changes. Application of the new approach decreases the network loss enormously with lesser switching changes while maintaining the voltage profile and line loading within limits. Applying compensation using the proposed method helps in saving additional power, improves the voltage profile further and causes lesser load shedding during restoration. Since the methodologies are iterative, the results obtained are optimal for given conditions.

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