Reduction of Power Loss of Distribution System by Distribution Network Management

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Abstract– **Reducing the losses of power distribution systems (technical and non-technical losses) is an absolutely necessary objective in the sound management of any electrical utility. The transmission & distribution losses in Indian power system are high. Recent progress in optimization practices and computer technology has made it possible to perform accurate analysis of the distribution system and distribution losses. Most of the efforts of power planners concentrate on augmenting supply by building new power plants. But saving is possible by improving operating conditions for the distribution network. Due to inadequate planning and methods adopted for load shuffling, some networks are under loaded while others are overloaded. Thus there is some scope for improvement in operating strategies. Network reconfiguration in distribution system is realized by changing the status of the sectionalizing switches and is usually done for loss reduction and avoids overloading. In primary distribution system (11KV), the need for reconfiguration occurs in emergency condition following the fault to isolate faulted section and in normal condition to reduce system losses or to avoid overloading of network. The main objective of the paper is to outline a methodology for management of distribution system for loss reduction by network reconfiguration.**

Keywords– Line Loss, Network Reconfiguration, Optimization, Distribution System and Power Loss

I. INTRODUCTION

Power distribution systems have tie and sectionalizing switches. The states of those switches determine the configuration of the network. Reconfiguration of distribution network is achieved through switching operation on switches of distribution network branches [1].

Power companies are interested in finding the most efficient configuration for minimization of real power losses and load balancing among distribution feeders. This will help to save energy and enhance the operation performance of distribution system.

To manage a loss reduction program in a transmission and distribution system, it is necessary to use efficient and effective computational tools like MATLAB that allow quantifying the loss in each different network element for system losses reduction.

A. Network Reconfiguration

System reconfiguration means restructuring the power lines which connect various buses in a power system. Restructuring of specific lines leads to alternate system configurations. System reconfiguration can be accomplished by placing line interconnection switches into network. Opening and closing a switch connects or disconnect a line to the existing network [2].

The major benefits of network reconfiguration are:

1. Efficient Electric Transmission and Distribution
2. Network reconfiguration improves the voltage stability of the system.
3. Network reconfiguration also smoothens out the peak demands, improving the voltage profile in the feeders and increases network reliability.

B. Problem Formulation

The objective of the outlined problem is to reduce the distribution loss, by deciding the optimal loading pattern of distribution network with load transfer. Subject to:

- System capacity
- Meeting the total load
- Voltage profile

C. Mathematical Formulation

The loss reduction in network reconfiguration problem is formulated as:

$$\text{Min} \sum_{i=0}^{n-1} r_i \frac{P_i^2 + Q_i^2}{V_i^2} p.u. \qquad (1)$$

Such that

$$V_{i\,min} < V_i < V_{i\,max} \qquad (2)$$

r_i = Resistance of the branch
P_i =Real power flowing through the branch
Q_i = Reactive power flowing through the branch
V_i = Voltage at the receiving end of the branch

From the above equation we can formulate new equation as below:

$$\text{Min} \sum_{i=0}^{n-1} r_i I_i^2 \qquad (3)$$

Where I_i = Current flowing through the branch

D. Defining the Objective Function

The objective is to minimize the total loss. In this study the objective function consist of two parts.

1. Iron and copper losses of power transformer
2. I^2R losses associated with the feeder

In the network there are two power transformers and 59 numbers of branches including links.

The objective function is given as:

Network power loss

$$\sum_{i=1}^{3}\left[A_0+\left(\frac{I_i}{I_{Rated}}\right)^2 * RatedCopperLoss\right]+\sum_{j=1}^{59} I_j^2 * R_j \quad (4)$$

Where,

A_0 = Rated Iron loss of power transformer
I_i = Ampere load of Incoming cable
R_j= Resistance of cables
I_j=Ampere load of 11 KV feders

E. Defining Constraints

The network reconfiguration consists of modifying the topology of the system by switching remotely controlled sectionalizing switches. In this process, the nodes can be energized through different paths through the interconnection with other feeders (substations) and/or interconnection of nodes belonging to a same feeder. Usually, distribution systems operate with a radial topological structure; the opening and closing of sectionalizing switches are made considering this constraint [3].

Consider the simple tree network as shown in Figure 1.

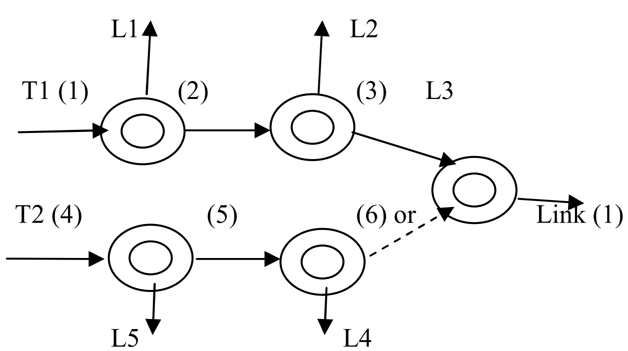

Figure 1: Simple tree network

The network has five buses, five loads and six elements (including one link). Let us assume element (1) and element (4) are the outgoing feeders and are connected to two power transformers. Element (1) is supplying power to the loads L1, L2 and L3. Element (4) is supplying power to load L4 and L5. The element (1) is further divided into sub-elements (2), (3). The element (4) is sub-divided into element (5) and link (1) or element (6). At bus (3) the switching possibility is available. From above figure equations are formed:

I(1) = L1 + I(2) ----------------------------- (5)

I(2) = L2 + I(3) ----------------------------- (6)
I(4) = L5 + I(5) ----------------------------- (7)
I(5) = L4 + I(6) ----------------------------- (8)

Current flowing through network element (6) or link (1) is zero as this link is kept off at bus (3). Additional equation is obtained to consider the switching possibility.

L3 = I(3) + I(6) or link(1) (9)

The link (1) could be positive or negative, depending on the switching. After solving the optimization problem, value of link (1) obtained will indicate whether addition of link is required.

One more constraint is obtained, to meet the total demand.

I(1) + I(4) = L1 + L2 + L3 + L4 + L5 (10)

The constraints are tabulated in matrix form and are given below:

$$[A]^T_{nbxe} \; X \; [I_{element}]_{ex1} = [I_{total}]_{nbx1} \quad (11)$$

In addition to the above constraint equations, one more constraint needs to be considered and the same is given below:

$$\left(\sum_{j=1}^{n} L_j\right) - \left(\sum I_{initial\ section}\right) = 0 \quad (12)$$

Where $I_{nitial\ section}$ = Current flowing through initial section of each feeder.

The objective function with all constraints is used to solve the optimization problem by using Lagrange multiplier method.

II. METHODOLOGY

A. Network Reconfiguration for Loss Reduction

Once the losses are calculated or evaluated, it is required to reconfigure the network. Network reconfiguration in distribution systems is realized by changing the status of sectionalizing switches, and is usually done for loss reduction or for load balancing in the system.

B. Solving Optimization Problem

Optimization is the act of obtaining the best result under given circumstances. The aim of the optimization is either to minimize the efforts required or to maximize the desired benefits. Since the efforts required or the benefits desired in any practical situation can be expressed as a function of certain decision variables, optimization is defined as the process of finding the condition that gives the maximum or minimum value of a function. Most of the optimization problems are subject to constraints. In the network there are number of branches and number of links, depending on the number of branches and numbers of links the constraint equations are formed. These constraint equations will be tabulated in matrix form. All these constraint equations with objective functions are used to solve the optimization problem.

C. Statement of an Optimization Problem

An optimization or a mathematical problem can be stated as follows:

$$\text{Find } X = \begin{Bmatrix} X_1 \\ X_2 \\ . \\ X_n \end{Bmatrix}$$

which minimizes f(X) (13)

Subject to the constraints

$$g_j(X) \leq 0,\ j=1,2,........m$$

and

$$l_j(X) = 0,\ j=1,2,.........p$$

Where X is an n-dimensional vector called the design vector, f(X) is called the objective function and $g_j(X)$ and $l_j(X)$ are respectively, the inequality and the equality constraints. The number the variables n and the number of constraints m and/or p need not be related in any way.

D. Solution by Method of Lagrange Multiplier

In Lagrange Multiplier method, we introduce one additional variable to the problem for each constraint. Thus if the original problem has n variables and m equality constraints, we add m additional variables to the problem so that the final number of unknowns becomes n+m [4].

Necessary condition for a general problem

The equation for a general problem with n variables and m equality constraints is as:

$$\text{Minimize } f(X) \quad (14)$$

Subject to $g_j(X) = 0$, j=1,2,...................m

The Lagrange function L, in this case is defined by introducing one Lagrange multiplier λ_j for each constraints g (X) as:

$$L(x_1, x_2, ... x_n, \lambda_1, \lambda_2, ... \lambda_m) = f(x) + \lambda_1 g_1(x) + \lambda_2 g_2(x) + ... + \lambda_1 g_1(x) \quad (15)$$

By treating L as a function of the n=m unknowns, $x_1, x_2, ... x_n, \lambda_1, \lambda_2, ... \lambda_m$ the necessary conditions for extreme of L, which also corresponds to the solution of original problem stated in equation (15) given by;

$$\frac{\partial L}{\partial x_i} = \frac{\partial f}{\partial x_i} + \sum_{j=1}^{m} \lambda_i \frac{\partial g_i}{\partial x_i} = 0 \quad (16)$$

$$\frac{\partial L}{\partial x_i} = g_i(x) = 0 \quad (17)$$

Where i=1,2,...............n
J=1,2,...............m

The above equations (16) and (17) represents n+m equations in terms of n+m unknowns, x_i and λ_j. The solution of equation (16) and (17) gives:

$$X^* = \begin{bmatrix} x_1^* \\ x_2^* \\ x_3^* \end{bmatrix} \quad \text{and} \quad \lambda^* = \begin{bmatrix} \lambda_1^* \\ \lambda_2^* \\ \lambda_n^* \end{bmatrix}$$

III. RESULTS AND CONCLUSIONS

In this work loss analysis of distribution network is carried out with initial and optimal configuration. It is observed that solving the problem for power loss minimization leads to significant reduction in losses.

Software program using MATLAB codes is used for evaluating objective function.

Following inputs are provided to the MATLAB:

- Starting bus number and ending bus numbers of each power transformer
- Starting bus number and ending bus number of each element
- Starting element and ending element of each power transformer
- Starting bus number and ending bus number of each link
- Ampere load of each distribution transformer
- Cable resistance of each element
- Cable resistance of each link

Power loss with initial configuration and final configuration is given below in Table 1:

Table 1: Power loss: Initial & Final configuration

Status	Power Loss in KW	Load in Amp
Initial configuration	616.60 KW	1180 Amp
Final configuration	572.19 KW	1180 Amp

With the initial configuration the network loss is evaluated is 616.60 KW and the load on distribution system was 1180 Amp. With the final configuration the loss is evaluated as 572.19 KW. The significant reduction of 7.20 % was observed.

In both the cases the load remains same i.e., 1180 A, it indicates the loss reduction has not affected the load. The losses are reduced without sacrificing the load.

An attempt has been made in this paper to present a technique for distribution network reconfiguration energy loss reduction. Loss reduction is possible with optimal operation of distribution network. Overall substantial saving is possible if the losses are reduced by network reconfiguration.

Table 2: Loading of Transformers: Initial & Final configuration

Power Transformers	T1	T2	T3	Total
Initial Configuration	566 A	200 A	414 A	1180 A
Final Configuration	433 A	367 A	380 A	1180 A

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