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Optimal Reconfiguration of Power Distribution Systems

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Abstract:
Due to the rapid increase in the demand for electricity, environmental constraints and competitive energy market scenario, the power sector(both transmission and distribution) are being operated under overloaded conditions at most of the time. Today, the major concern is efficient dispatch of power to the customers on an individual basis. This can be done by proper reconfiguration of the distribution system. The scope of reconfiguring the network is not limited to only dispatch of power but extends to minimizing the system losses, minimizing power interruptions, increasing the system reliability and most importantly, the proper maintenance of the costly devices like transformers, huge electric machines, etc at the factories which need constant good quality power input. Again there are places like hospitals; defence corporations etc where power interruptions for the slightest time can also cause blunders. To add to these factors, the occurrence of blackout is also a major concern as stabilizing the grid after such an incident is a tedious job. So it is always better to avoid such events. The above discussion clearly states the importance of proper management of the power system, especially the distribution sector. System reconfiguration to achieve the optimal structure is highly essential as it leads to an operating condition with minimum power loss and maximum reliability. The project deals with optimizing the distribution system considering the two factors namely power loss and system reliability. New methodology to reconfigure an electric power distribution network under normal operating conditions to reduce the active losses of the network or to balance the load of the system's feeders is also proposed in this research paper.

1. Introduction

Electrical energy is generated in Hydro-electric, thermal & nuclear power stations. These stations are generally situated far away from distribution system and loads. Hence it required transmission network. Power system, mainly divided into three parts: one is generating station, second is transmission system, third one is distribution. Transmission system is divided into primary and secondary transmission. Distribution system is also divided into primary and secondary. Transmission lines transmit bulk electric power from sending end to receiving end station without supplying consumers in route. But distributers or distribution lines supply consumers directly. The maximum generation voltage in advance countries is 33kV, but in India is 11kV.The amount of power transmitted through transmission lines is very large and if this power is transmitted at 11Kv or 33kV, the line current and power loss is very large. So this voltage is stepped up to a higher value at sending end and again stepped down to lower value of voltage.

Determination of how much generation capacity is required to give a reasonable assurance of satisfying the load requirements is one of the basic elements of power system. A second but equally important element in the planning process is the development of a suitable transmission network to convey the energy generated to the customer load points. But due to dynamic nature of load, the operation and control of distribution system is more complex. System loads are uncertain on different feeders. Due to this system load is more than its generation capacity that makes relieving of load on feeders is not possible and hence voltage and current profile of the system will not improved to the required level of load demand. So reconfiguration of the network is required time to time. As the demand for electrical energy is increasing day by day, the transmission and distribution lines are heavily loaded. From the recent black outs, we can see that most of failures occurs at the distribution level. The majority of the service interruptions to the costumers come from the distribution system. So reliability evaluation of distribution system gains significance in planning and operating stage of power system.

The network reconfiguration to minimize the real power loss and to improve voltage profile considering reliability is the best choice in this modern world. The concept of network reconfiguration can be successfully implemented in real world transmission network. It can also be extended to conceive the concept of feeder reconfiguration. Different methodologies are also addressed by some electrical engineers, professors and senior members of different electrical universities in all over the world. Probabilistic reliability models are used in order to evaluate the reliability at load points. The commonly used objectives for distribution system reconfiguration have been minimization of the transmission loss and voltages deviations at the buses. Generally, in our power distribution system radial distribution network is used.

In the scenario of the modern day world, there is a rapacious demand for electricity to satiate the needs of people. To meet this never-ending demand, the Transmission and Distribution system is compelled to be operated under a condition that is overloaded for most of the time. As a result, a reduction in the efficiency of the system and increased power unavailability come into existence. Times are gone when the only concern was efficient generation and transmission. Today, the major concern is efficient dispatch of power to the customers on an individual basis. Therefore, any development in this area shall be highly beneficial in improving the efficiency of the overall system. The distribution system accounts for the maximum losses. Thus this should be the field of concentration of all the researchers today. The efficiency of a power system can be raised by choosing the best structure for the distribution system because only the best arrangement of the feeders can transfer power to the consumers in the most reliable manner. There are methods for obtaining the best feeder arrangement known as feeder reconfiguration.

System reconfiguration to achieve the optimal structure is highly essential as it leads to an operating condition with minimum power loss and maximum reliability. The project deals with optimizing the distribution system considering the two factors namely power loss and system reliability. All the proposals under this project have vast scope in practical applications and can be utilized in reorganizing the system structure in the best possible manner to ensure efficient circulation of electricity throughout the nation thereby reducing all the related mishaps.

2. Description of Work or Method

This section will discuss about reconfiguration of distribution network i.e. radial network, concept of reliability probabilistic reliability approach and BPSO algorithm.

2.1. *Why Need for Network Reconfiguration?*

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].All 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. System reconfiguration means restructuring the power lines which connect various buses in a power system. In [2]-[3], branch exchange based techniques are employed to find the optimal network reconfiguration. To maintain the radial reconfiguration of the network an open switch is closed and a closed switch is opened. System reconfiguration can be accomplished by placing line interconnection switches into network. Opening and closing a switch connects or disconnect a line tithe existing network [4].

The major benefits of network reconfiguration are:

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

Network reconfiguration is a complex combinatorial, non-differentiable constrained optimization problem. 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. Merlin and Back [5] first proposed network reconfiguration problem. They used a branch-and-bound-ty 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.

2.2. Problem Formulation

We have considered a network of series connected buses (end to end connection). Thus in between any two buses, there is only one connecting line. In this manner any 'n' number of buses may be incorporated in the network and can be analyzed for optimality. The values of voltages and powers are taken in per unit quantities. The voltage at 1^{st} bus is set at 1 p.u. and its power input is determined according to the loading conditions. By iterative procedure the voltage, power input and loss at each subsequent bus is determined. For simplicity of our analysis, we haven't considered the terms of reactance (X) and thus the reactive power (Q). Thus, in this manner real power and the corresponding loss along with voltage at each bus can be determined through the use of the below mentioned formulae

- **Diagrammatic View of the Distribution Network**

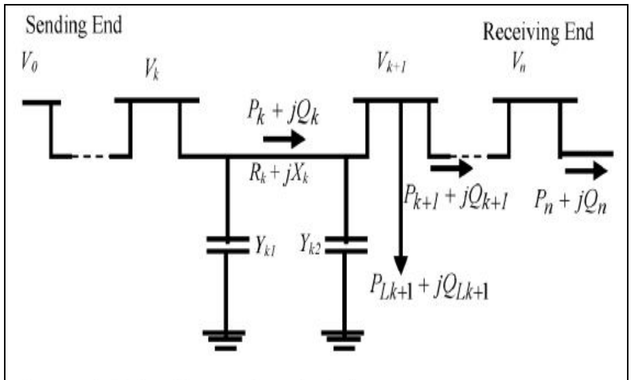

Fig. 1. Single-line diagram of a main feeder.

Figure 1

2.3. Power Flow Equations

Power flow in a distribution system is computed by the following set of simplified equations:

$P_{k+1} = P_k – P_{loss,k} - P_{Lk+1}$

$= P_k - [R_k/|V_k|^2]\{P_k^2 + (Q_k + Y_k|V_k|^2)^2\} - P_{Lk+1}$

$Q_{k+1} = Q_k – Q_{loss,k} - Q_{Lk+1}$

$= Q_k - [X_k/|V_k|^2]\{P_k^2 + (Q_k + Y_k|V_k|^2)^2\} - Y_{k1}|V_k|^2$

$-Y_{k2}|V_{k+1}|^2 - Q_{Lk+1}$

$|V_{k+1}|^2 = |V_k|^2 + (R_k^2 + X_k^2)/|V_k|^2 (P_k^2 + Q'^2_k) - 2(R_kP_k + Q_kX_k)$

$= |V_k|^2 + (R_k^2 + X_k^2)/|\Delta V_k|^2 (P_k^2 + (Q_k + Y_k|V_k|^2)^2)$

$-2(R_kP_k + X_k(Q_k + Y_k|V_k|^2))$

Power loss in the line section connecting buses k and k+1 may be computed as:

$P_{loss}(k,k+1) = R_k (P_k^2 + Q_k^2) / |V_k|^2$

The total power loss of the feeder$P_{T,LOSS}$ may then be determined by summing up the losses of all line sections of the feeder, which is given as:

$P_{T,LOSS} = \sum_{K=1}^{n} P_{loss}(k,k+1)$

The power loss of a line section connecting buses between k and k+1 after reconfiguration of network can be computed as:

$P'_{loss}(k,k+1) = R_k(P'^2_k + Q'^2_k) / |V'_k|^2$

Total power loss in all feeder sections, $P'_{T,LOSS}$ may then be determined by summing up the losses in all line sections of network, which is written as:

$P'_{T,LOSS} = \sum_{K=1}^{n} P'_{loss}(k,k+1)$

2.4. Loss Reduction Using Network Reconfiguration

Net power loss reduction,ΔP^R_{Loss} , in the system is the difference of power loss before and afterreconfiguration, that is given by:

$\Delta P^R_{Loss} = \sum_{K=1}^{n} P_{loss}(k,k+1) - \sum_{K=1}^{n} P'_{loss}(k,k+1)$

The objective of the problem is to formulate the above power loss reduction equation and maximize it in distribution system, using some optimization techniques to be mentioned in the next chapter.

where,

- Vmax=maximum bus voltage
- Vmin=minimum bus voltage
- I(k,k+1)=current in line section between buses k and k+1
- I(k,k+1),max=maximum current limit of line section between buses k and k+1
- A=bus incidence matrix (R + jX)

3. Optimization Method Applied for Solving

The Loss Minimizing Problem

3.1. Lagrange Multiplier Method

Consider the following inequality problem:

Maximise f(x)

Subject to

$G_j(x) <= 0$, j = 1,2,3,4,…..,m
To apply the ALM method , the inequality constraints of the above equation are first converted to equality constraints as
$G_j(x) + y_j^2 = 0$, j = 1,2,3,4,….,m
Where y_j^2 are the slack variables. Then the augmented lagrangian function is constructed as
$A(X,ƛ,Y,R_k) = f(x) +_{j=1}\sum^m[G_j(x) + y_j^2] + _{j=1}\sum^m R_k [G_j(X) + y_j^2]^2$
Where the vector of slack variables Y is given by
$Y=\{ y_1\ y_2 \ldots y_m \}$
If the slack variables y_j, j= 1,2,3……,m, are considered as additional unknowns , the function A is to be minimized with respect to X and Y for specified values of $ƛ_j$ and R_k . This increases the problem size.It can be shown that the fucntion is equivalent to
$A(X,ƛ,R_k) = f(X) +_{j=1}\sum^m ƛ_j\alpha_j + R_{kj=1}\sum^m\alpha_j^2$
Where,
α_j= max { $g_j(X)$. $-ƛ_j/2R_k$
Thus the solution of the problem stated above can be obtained by minimizing the function A, as in the case of equality constrained problems using the formula
$ƛ_j^{(k+1)} = ƛ_j^{(k)}+ 2 R_k\alpha_j^{(k)}$, j = 1,2,…….,m

3.2. Application of Lagrange Multiplier Method in Network Analysis
Power loss reduction in the system is given by ,
$\Delta P_L^R = {}_{K=1}\sum^n P_{t,loss}(k, k+1) - {}_{k=1}\sum^n P'_{t1,loss}(k,k+1)$----------(1)
Lagrangian function L is given as
$L = \Delta P_L^R + \lambda({}_{K=1}\sum^n P_{G,K} – (P_k + P_{loss,k}))$---------(2)
$P_K' = \alpha P_k\alpha 9=0.41$ (approx)---------(3)
$\partial L\backslash\partial P_k= {}_{K=1}\sum^n 2R_k/V_k^2 (1-\alpha)P_k –\lambda [1+ (2R_kP_k\backslash V_k)\alpha^2]$--------(4)
${}_{K=1}\sum^n P_k= \lambda V_k^2/(1.2R_k-2\lambda R_k)$----------(5)[This is the solution $\partial L/\partial ƛ= 0$]
$\partial P_k\backslash\partial\lambda=1.2R_kV_k^2 /(1.2R_k– 2\lambda R_k)^2$-------------(6)
$\Delta P_k = \Sigma P_k' - \Sigma P_k$------------(7)
Here Pk′ = sum of power input at all the buses
Pk = value of Pk from equation (5)
$\Delta\lambda = \Delta P_k / (\partial P_k/\partial\lambda)$ [at $\lambda = \lambda_k$] ---------------(8)
If $\Delta\lambda <= \varepsilon$ ($\varepsilon = 0.001$) ,
Optimization is reached
Else
$\lambda_{(k+1)} = \lambda_{(k)} + \Delta\lambda$
The procedure is repeated by calculating P_k , ΔP_k , etc. from equation 5 to 8.

3.3. Matlab Programming

```
R = [0.055 0.055 0.055 0.055 0.055];
V=[1 0 0 0 0 0];
Pl=[0 0.1 0.1 0.1 0.1 0.1];
P=[0.55 0 0 0 0 0];
Ploss=[0 0 0 0 0];

for k = 1:5
Ploss(k)=R(k)*(P(k)*P(k))/(V(k)*V(k));
P(k+1)=P(k)-Ploss(k)-Pl(k+1);
V(k+1)=sqrt((V(k)*V(k))+((R(k)*R(k))*(P(k)*P(k))/(V(k)*V(k)))-2*R(k)*P(k));
end

totloss=sum(Ploss);
totpower=sum(P);
totvolt=sum(V);
totres=sum(R);

disp(P)
disp(Ploss)
disp(V)
disp(totloss)
disp(totres)
disp(totvolt)
```

```
R1 = [0.275,0.055,0.165,0.055,0.055];
V1=[1 0 0 0 0 0];
Pl1=[0 0.1 0.1 0.1 0.1 0.1];
P1=[0.55 0 0 0 0 0];
Ploss1=[0 0 0 0 0];

for k = 1:5
Ploss1(k)=R1(k)*(P1(k)*P1(k))/(V1(k)*V1(k));
P1(k+1)=P1(k)-Ploss1(k)-Pl1(k+1);
V1(k+1)=sqrt((V1(k)*V1(k))+((R1(k)*R1(k))*(P1(k)*P1(k))/(V1(k)*V1(k)))-  2*R1(k)*P1(k));
end
totloss1=sum(Ploss1);

disp(P1)
disp(Ploss1)
disp(V1)
disp(totloss1)

lmda=0.8;
alpha=0.41;
dellmda=1;
fn=(1.2*alpha*totres*totvolt*totvolt)/((1.2*totres-2*lmda*totres)*(1.2*totres-2*lmda*totres));
P2=[0 0 0 0 0 0];

while(dellmda>=0.001)
for k=1:5
P2(k)=(lmda*alpha*alpha*alpha*V(k)*V(k))/(3*(1.2*R(k))-(2*lmda*R(k)));
end

sumP2=sum(P2);
delP=totpower-sumP2;
dellmda=P2/fn;
if(dellmda>0.001)
lmda=lmda+dellmda;
end
end
```

3.4. Results

The power(P) , power loss(P_{loss}) and voltage(V) as shown in table-1 and table-2 are obtained from the matlab programming Table -1:

P	0.5500	0.4334	0.3224	0.2160	0.1130	0.0121
P_{LOSS}	0.0166	0.0110	0.0064	0.0030	0.0008	
V	1.0000	0.9698	0.9452	0.9264	0.9136	0.9068

Table 1

P	0.5500	0.3668	0.2565	0.1406	0.0388	0.0614
P_{LOSS}	0.0832	0.0103	0.0160	0.0018	0.0001	
V	1.0000	0.8488	0.8250	0.7737	0.7637	0.7609

Table 2

Table-1 shows the values of power, power loss and voltage before configuration and table-2 shows the value of power, power loss and voltage after reconfiguration. It has been observed that before reconfiguration the losses are more but after reconfiguration the losses are less.

- Fig-2 shows the plot between per unit voltage and bus number before reconfiguration.

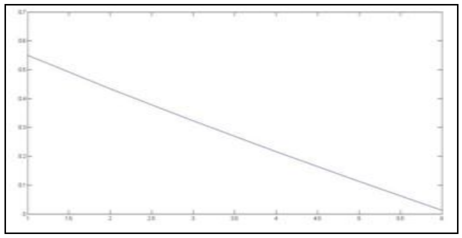

Figure 2 (Y axis –voltage in p.u, x axis - bus number)

- Fig-3 shows the plot between per unit voltage and bus number after reconfiguration.

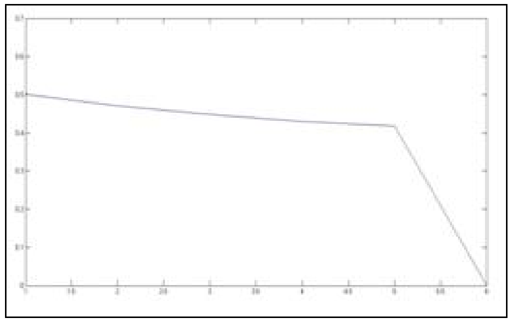

Figure 3 (Y axis –voltage in p.u, x axis - bus number)

4. Conclusion

The network reconfiguration is done using lagrange multiplier method in matlab programming. The power,power loss and voltage values are noted before and after reconfiguration.

Here we have taken a 6 bus system and applied the optimization technique. The switch configuration are also studied and analyzed. We can also implement it for 33 bus system or more.

In the calculations we have not considered the reactive power and have considered only the active power because reactive power can cause deviation in values.

Here the power,power loss and voltage values are noted before and after reconfiguration and we have noted the fall in power loss after network reconfiguration. Thus the optimization technique can be applied to any distribution network for the minimization of power loss and system reliability.

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