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Optimization Approach to Reduce Technical Losses in ECG Distribution System

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Abstract—**Largely, system loss of around 6 to 8% is internationally accepted. In developing countries, 20 to more than 40% system losses is common. In Ghana system losses in the distribution network of the Electricity Company of Ghana (ECG) hovers around 23 to 24 %. Even though the company has embarked on a number of loss reduction strategies to 'fight down' the losses, the result has been very marginal. In this paper, a simple technique based on Lagrange multipliers' concept to reduce technical losses has been used. It is shown that the method can reduce I2R losses (technical losses) in power distribution system by 80%. The method is relatively cheaper and comparatively easy to implement.**

Index Terms— **Technical losses, Langrage Multiplier, Optimization, Feeder**

I. Introduction

SYSTEM losses in power distribution system continue to threaten the financial viability of utility companies. The magnitude of the losses varies and depends on the country and the state of the power distribution networks. Generally, system loss of around 6 to 8% is internationally accepted. In developing countries, 20 to more than 40% system losses have been recorded. Over the years, losses in in the distribution system of the Electricity Company of Ghana (ECG) has hovered around 23 to 24 %. It is important to note that ECG has adopted a number of loss reduction strategies including deployment of AMR, arresting and prosecuting customers who engaged in illegal connections and power thefts. In spite of these efforts, the result has been very insignificant. This study looks at system loss reduction from system reconfiguration and load dispatch perspective. The study uses a simple technique based on Lagrange multipliers' concept to dispatch load that will result in minimum I2R loss. It is shown that the method can reduce I2R losses (technical losses) in power distribution system by 80%. The method is relatively cheaper and comparatively easy to implement.

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II. Concept of Lagrange multipliers – Optimization Techniques

The focus here is on theoretical concepts, not the mechanics. For detail on Lagrange multipliers in the calculus of variations refer to [1,2].
In optimization technique, it is expected that a maximum benefit would be derived at given limited resource [3, 4]. For example, a power distribution network may be designed with a transfer capability of 20 MW at 5% system losses. Using the same distribution network, one would want to transfer the 20 MW using an alternative means with the most cost-effective performance to achieve say 2% system losses. The method of Lagrange multipliers is a powerful tool for solving this class of problem.

The following example is just to illustrate how technical losses in a simple distribution network can be reduced using a simple optimization technique and to confirm the technique by the Lagrange method.

Two 33 kV feeders are required to supply a total load of 5A over a distance of 4 km.

Resistance per km of feeder 1 is 0.3 ohm.
Resistance per km of feeder 2 is 0. 45 ohm.

How should the load be distributed between the two feeders to ensure the losses are kept minimum?

First, the total resistance of each feeder needs to be estimated:

Total resistance for feeder 1 = 0.3×4 =1.2 Ω
Total resistance for feeder 1 = $0.45 \times 4 = 1.8$ Ω

Next, the load was distributed between the feeders in permutation order and the losses at every point of the load distribution calculated. The Excel in the Microsoft program was used to perform the computation, see Table 1. Note that at any given point, addition of the loads in the two feeders add up to 10 A. It can be seen from Table 1 that the minimum loss of the network (72 W) occurred at load distribution of 6 A for Feeder 1 and 4 A for Feeder 2.

This is a very simple optimization technique that can be verified by the Lagrange Multiplier as given below.

Power loss due to Feeder 1 (P_{F1}):

$$P_{F1} = I_1^2 R_1 \tag{1}$$

Power loss due to Feeder 1 (P_{F2}):

$$P_{F2} = I_2^2 R_2 \tag{2}$$

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Table 1: Same load at varying I^2R losses based on the feeder loadings

Determining Optimum Losses											
Feeder 1 (A)	0	1	2	3	4	5	6	7	8	9	10
Feeder 2 (A)	10	9	8	7	6	5	4	3	2	1	0
R_1	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
R_2	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
I_1^2	0	1	4	9	16	25	36	49	64	81	100
I_2^2	100	81	64	49	36	25	16	9	4	1	0
$I_1^2R_2$	0	1.2	4.8	10.8	19.2	30	43.2	58.8	76.8	97.2	120
$I_2^2R_2$	180	145.8	115.2	88.2	64.8	45	28.8	16.2	7.2	1.8	0
Total Power loss (W)	**180**	**147**	**120**	**99**	**84**	**75**	**72**	**75**	**84**	**99**	**120**

For minimum power loss

$$\frac{d(P_{F1})}{dI_1} = \lambda \tag{3}$$

$$\frac{d(P_{F1})}{dI_1} = \lambda \tag{4}$$

From (3) and (4),

$$2I_1R_1 = \lambda \tag{5}$$

$$2I_2R_2 = \lambda \tag{6}$$

From (5) and (6),

$$I_1 = \frac{\lambda}{2\times R_1} \tag{7}$$

$$I_2 = \frac{\lambda}{2\times R_2} \tag{8}$$

Note that

$$I_{Total} = I_1 + I_2$$

Hence,

$$\frac{\lambda}{2R_1} + \frac{\lambda}{2R_2} = 10 \tag{9}$$

Also note

R_1=1.2 Ω and R_2=1.8 Ω

Substitute the values of R_1 and R_2 into (9)

$$\frac{\lambda}{2\times 1.2} + \frac{\lambda}{2\times 1.8} = 10 \tag{10}$$

Solving (10) will give

$$\lambda = 14.4$$

From (7) and (8)

$$I_1 = \frac{14.4}{2\times 1.2} = 6\text{A}$$

$$I_2 = \frac{14.4}{2\times 1.8} = 4\text{A}$$

As can be seen, the Lagrange method confirms the simple method as described above that for minimum loss, Feeder 1 and Feeder 2 should be loaded 6 A and 4 A respectively. It is however important to note that the Excel method (the simple method) cannot be reasonably apply to complex distribution network. The Lagrange method is useful optimization tool that can be used to reduce technical losses in a complex distribution network [5].

III. Case Study

This case involves the use of Lagrange multipliers' concept to reduce technical losses in ECG distribution system. To determine the effectiveness of the method, a typical substation (substation B) in Tema with three outgoing 11kV feeders was modelled using the CYMEDIST software. The modelled network was simulated to assess the total losses. Losses recorded from the simulation was treated as a base case and compared to losses obtained using the optimization technique.

The modelled network is shown in Fig.1 below. Based on the size and the length of the feeders, the total DC resistance for each feeder was calculated.

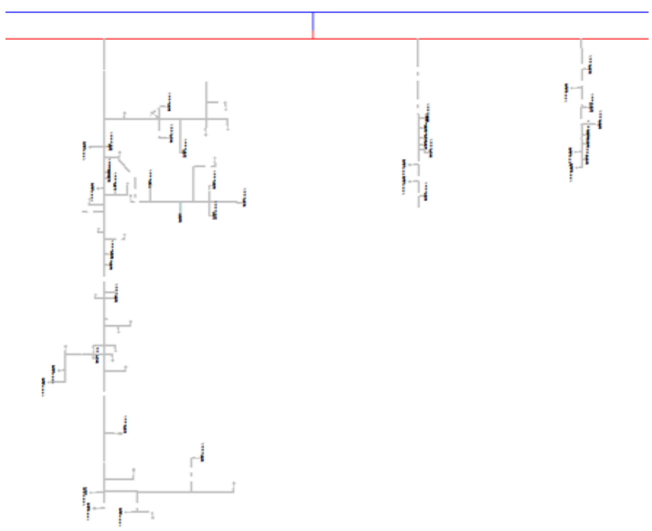

Fig. 1 Modelled Network

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A. Base Case Scenario

Note that feeder loads as given in this case study represent the actual feeder base loadings. Technical information from the Base Case are given as follows:

Line resistance:

- Total resistance of Feeder - B_{51} = 0.434 Ω
- Total Resistance of Feeder - B_{81} = 0.1851Ω
- Total Resistance of Feeder - B_{111} = 2.961 Ω

Feeder loading

- Feeder - B_{51} = 105 A
- Feeder - B_{81} = 150 A
- Feeder - B_{111}= 270 A

Power losses in the feeders

- P_{B51} = 4.78 kW
- P_{B81} = 4.16 kW
- P_{B111}= 215.9 kW

Total losses in the three feeders

- $P_{Total-1}$ = 225 kW

B. Application of the Optimization Approach

It is expected that the optimization approach will determine the optimum load distribution among the feeders to reduce the overall I^2R losses without varying the total load at the substation.

We know that for minimum power loss

$$\frac{d(P_{51})}{dI_{B51}} = \lambda$$

$$\frac{d(P_{81})}{dI_{B81}} = \lambda$$

$$\frac{d(P_{B111})}{dI_{B111}} = \lambda$$

Based on the values of the line resistances and computing for λ , it can be shown that

- Feeder - B_{51} = 149.7 A
- Feeder - B_{81} = 351 A
- Feeder - B_{111}= 21.95 A

For losses in the optimized scenario,

- P_{B51} = 9.7 kW
- P_{B81} = 22.8 kW
- P_{B111} = 1.5 kW

Therefore, the total losses in the optimized scenario,

- $P_{Total-2}$ = 34 kW

IV. Discussion

Comparing the total losses (225 kW) in the base case scenario to the losses (34 kW) in the optimized case scenario, we can see a significant loss reduction of about 85% when the load is optimally distributed among the feeders. It should be noted that the distances or the resistances of the feeders play very important role in the determination of the optimal loadings. The analysis presents a trend that seem to suggest that for a minimum loss, loads in long feeders (high resistance values) should be reduced and vice versa.

In practice, it is importance to use the optimization technique to first determine the optimal load distribution among the feeders. Once the optimal loadings have been found, the system can now be reconfigured using Ring Main Units (RMU) to either reduce or increase feeder length. In a situation where it is difficult to reconfigure the system due to the nature of the network or lack system flexibility, the method provides an opportunity to identify a strategic link in the network for cable connection to facilitate easy load transfer. It should be noted that the loads are not static, it changes with time. For this reason, it is important to consult load curves and use base load to estimate the optimal load distributions. It may not be economical to optimize the loadings during peak periods as peak periods generally have shorter durations.

V. Conclusion

Even though other options of system loss reduction exist, the Lagrange multipliers concept provides a powerful that can be used to optimize load dispatch and consequently reduce system losses in distribution system at the most cost effective way.

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