Mansoura Engineering Journal

Volume 12 | Issue 1 Article 3

6-1-2021

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Recommended Citation

Shebl, K. and Abou El-Ela, A. (2021) "A Simple Approach to Optimal Conductor Sizing for a Radial Distribution Feeder with Laterals.," *Mansoura Engineering Journal*: Vol. 12 : Iss. 1 , Article 3.
Available at: https://doi.org/10.21608/bfemu.2021.173728

Mansoura Engineering Journal (MEJ), VOL.12,No.1,June 1987

A SIMPLE APPROACH TO OPTIMAL CONDUCTOR SIZING FOR A RADIAL DISTRIBUTION FEEDER WITH LATERALS

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(Received May 9, 1987, accepted June 1987)

الخلاصة :-

يقدم هذا البحث طريقة مقترحة جديدة وبسيطة للحصول على التدرج الأمثل للمقاطع المستعرضة لمغذى تيار يستخدم فى نظم التوزيع الكهربية. وتعتمد هذه الطريقة على الحل التكرارى للاختيار الأمثل للمقطع المستعرض المناسب للتيار المار فى كل جزء من مغذى تيار شعاعى يحتوى على قضبان تحميل على مسافات مختلفة وبقيم مختلفة. ويتم إختيار المقاطع المستعرضة من بين مجموعة المقاطع المتاحة فى التصنيع.

وقد تم صياغة هذه المسألة رياضياً بإعتبار التكلفة الإجمالية هى الدالة المستهدفة لتكون قيمتها أصغر ما يمكن بما فيها التكلفة الثابتة للموصل والتكلفة المتغيرة والتى تمثل تكلفة الطاقة السارية والطاقة المستهلكة وتكلفة تعديل المقطع المستعرض بين جزئين من المغذى يحملان تيارين مختلفين. وقد تم وضع قيود على الدالة المستهدفة أهمها قيد على مقدار الخفض فى الجهد المسموح به عند طرف المغذى، وقيد لضمان عدم تعدى الحد الحرارى المسموح به فى المغذى عند تيار معين. كما تم عمل برنامج للطريقة المقترحة والتى تم تطبيقها على نظام شعاعى من نظم التوزيع يحتوى على ٣١ قضيب، ومغذى أساسى، وأربعة مغذيات إبتدائية، ومغذيين ثانويين. وتم الاختيار الأمثل للمقاطع من بين خمسة قيم متاحة فى التصنيع.

وتتميز هذه الطريقة ببساطتها فى التطبيق وسهولة كتابة برنامج حاسبى لها وأنها لاتستلزم كمية ضخمة من الحسابات ولاتحتاج ذاكرة تخزين ضخمة ولا حتى أجهزة كمبيوتر معقدة للحسابات حتى أنه يمكن إجراء الحسابات باستخدام جهاز كالكوليتور من ذوى البرمجة للحل بهذه الطريقة وبالذات فى حالة التطبيق على مغذى شعاعى مفرد فقط. وهذه الطريقة لها إمكانية دراسة تأثير التغيرات فى معدل نمو الأحمال أو معامل الحمل أو تكلفة وحدة الطاقة على نتيجة الحل الأمثل وذلك خلال سنوات فترة التخطيط المحددة.

ABSTRACT

This paper presents a new computational procedure for obtaining the optimum feeder grading solution. The procedure is extremely simple and does not involve the use of dynamic programmin. This is a major achievement as it eliminates (i) the bulk of computation, (ii) the need for large computation storage, (iii) the need for complex computer programming. The proposed procedure is so simple that all the required calculations can be done on a small programmable calculater specially in case of single radial feeder without laterals. Also, the procedure enables to handle the variations in the load growth rate, load factor, cost of energy, etc. over the planning period. The presented optimization problem minimizes the sum of feeder cost and the present worth of the feeder energy costs, while keeping the voltage regulation within a prescribed value.

I. INTRODUCTION

The distribution system constitutes a significant part of a total power system. The capital investment diployed in the distribution system forms about 40 % of the total amount spend in the entire power system. Also, the distribution system is responsible for about more than 85 % of the total power losses in the overall power system due to the low level of distribution system voltage. Therefore, the optimal design of distribution system is necessary to minimize the overall cost of the distribution system including the capital investment and the cost of energy losses.

Incremental increase in capital cost may be easily offset by saving in energy losses over the life span of the elements in use especially the transformers. Another capital investment which may significantly reduce energy losses is in the use of distribution feeders with cross-sectional areas greater than those necessary to carry the expected current. An increase in cross-sectional area results in lower resistance and thus reduced losses. The extra capital cost associated with the larger cross-sectional area conductor may be paid for by the savings in losses. The latter opportunity has received some attention [1-3], but not as much as might be warranted by the potential benefits.

In most of the distribution system planning methods [4-6], the distribution feeders have been assumed to be of uniform cross-sectional area. But most of the distribution networks are of radial type. Therefore, the loads carried by different feeder segments are different. The segment closest to the transformer carries the maximum load and the segment at the tail-end of the feeder carries the minimum load. The load carried by the feeder segments increases as one moves from the tail end towards the transformer end. This inherent feature of the radial distribution feeders can be exploited while designing the feeder by using different conductor sections for different feeder segments.

Funk Houser and Huber [7] have proposed a method of optimal conductor grading. This method, however, cannot be used in general as it is based on the assumption of uniform load distribution for the feeders. T.H.Fawzi et. al. [8] presented an optimization problem solution of obtaining the most economical design of primary rural distribution feeders compatible with the required quality of service and which includes the choice of the cross-sectional areas as well as the topology of the feeders has been considered. They used the linear programming as the tool for the problem solution to manipulate the order of magnitude increase in the number of variables.

Ponnavaikko and Prakasa Rao [9] have proposed a comprehensive model for grading radial feeders with non-uniform loading. Their PPR model is realistic, flexible and considers the conductor grading problem as an optimization one. They used the dynamic programming as a tool to obtain the solution of their model. Very recently, Nangendra Rao [10] presented a computational procedure for obtaining the optimum conductor grading policy using the same PPR model of reference [9]. However, the procedure does not involve the use of dynamic programming.

This paper presents a new computational procedure for obtaining the optimum feeder grading solution. The procedure is extremely simple and does not involve the use of dynamic programmin. This is a major achievement as it eliminates (i) the bulk of computation,(ii) the need for large computation storage, (iii) the need for complex computer programming. The proposed procedure is so simple that all the required calculations can be done on a small programmable calculater specially in case of single radial feeder without laterals. Also, the procedure enables to handle the variations in the load growth rate, load factor, cost of energy, etc. over the planning period. The presented optimization problem minimizes the sum of feeder cost and the present worth of the feeder energy costs, while keeping the voltage regulation within a prescribed value.

2. MATHEMATICAL MODEL FORMULATION

The primary distribution feeder is represented by many mathematical models such as the feeder voltage drop, thermal current carrying capacity, emergy loss cost, growth factor, energy cost and feeder cost. The following assumptions has been made in formulating the mathematical models:

(i) All the consumers are having the same maximum demand and power factor.
(ii) The system is balanced under steady-state operating conditions having no loss or no voltage drop in the neutral wire.
(iii) All the feeders are of radial type.
(iv) The reactance per unit length of distribution conductor with different cross sectional areas is constant.

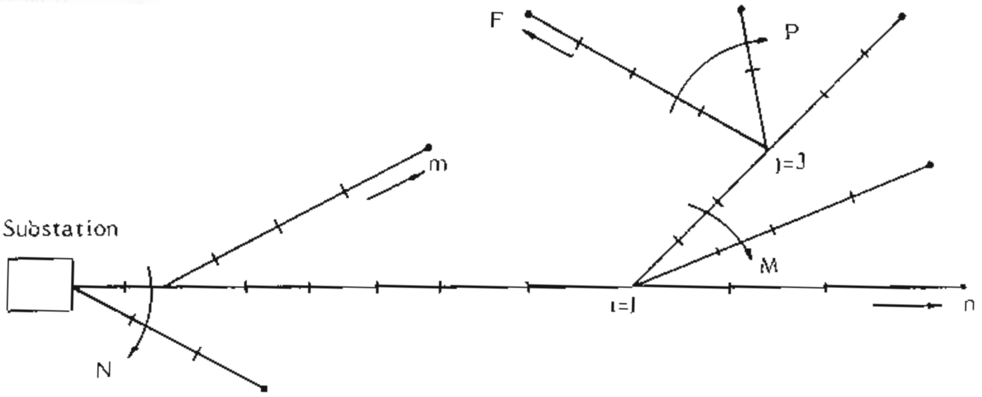

Fig.1 Notation system of single line diagram for a general radial distribution system

Fig.1 shows the single-line diagram representation of a general radial distribution system with a main, lateral and sublateral feeders. For such a system there is a clear need to represent the lateral and sublateral branching according to a certain notation system. The followings are the notation used to define the given system:

n = total number of segments along the main feeder,
N = number of main feeders radiating from the main substation,
m = total number of segments along the lateral feeder,
M = number of lateral feeders radiating from node i=I on the main feeder,
F = total number of segments along the sublateral feeder,
P = number of sublateral feeders radiating from node j=J on the lateral feeder,
Ni = subscription denoting the notation for the i-th segment in the N-th main feeder (i=1,2, ...,n),
IMj = subscription denoting the notation for the j-th segment in the M-th lateral feeder radiating from node i=I (j=1,2, ... ,m),
JPk = subscription denoting the notation for the k-th segment in the P-th sublateral feeder radiating from node J (k=1,2, ... ,F).

In order to study the optimal conductor sizing of a distribution system, some variable items must be mathematically modelled such as the voltage drop across the feeder, cost of energy losses, cost of energy, cost of feeder material and cost of area changing along the feeder.

2.1 Voltage Drop Across the Feeder

The well known approximate formula for voltage drop V, in volts in a simple radial feeder with n segments, feeding loads with lagging power factors can be written as:-

$$V = \sum_{i=1}^{n} (I_i . R_i \cos\theta + I_i . X_i \sin\theta) \qquad \text{... (1)}$$

where;
I_i = load current taken from the radial feeder at point i,
θ_i = power factor angle of the load current at point i,
R_i = resistance in ohms of segment i,
X_i = reactance in ohms of segment i,.

But, $$R_i = \rho \ell_i / a_i \qquad \text{..... (2)}$$

where;
ℓ_i = length of segment i in km,
a_i = cross-sectional area of segment i in mm²,
ρ_i = specific resistance of segment i in (ohm.mm²/km).

Also, $$X_i = x . \ell_i \qquad \text{.....(3)}$$

where x is the reactance per unit length of segment i for a cross-sectional area a_i.

The Egyptian standard tables of feeder's manufacture show that the reactance per 1 km of aluminum is 0.0951 Ω and 0.0816 Ω for cross-sectional areas of 30 and 95 mm² respectively. This shows the reactance slightly decreased with the decrease of cross-sectional area of feeder. Therefore, taking the reactance to be constant independent of the cross-sectional area of the segment does not affect the solution accuracy much.

Substituting from equations (2) and (3) in eq. (1), we get;

$$V = \sum_{i=1}^{n} [(C'_i / a_i) + C''_i] \qquad \text{.....(4)}$$

where; $$C'_i = I_i \ell_i \rho \cos\theta_i \qquad \text{..... (5)}$$
$$C''_i = I_i \ell_i x_i \sin\theta_i \qquad \text{..... (6)}$$

In case of distribution system with lateral and sublateral feeders, there will be more than end point for the system depending upon the unmber of lateral and sublateral feeders. In such a system, the number of end points in the system E, is given as;

$$E = N + L + S \qquad \text{..... (7)}$$

Where; N = total number of main feeders in the system,
L = total number of lateral feeders in the system,
S = total number of sublateral feeders in the system.

Then, the voltage drop along the main feeder, from the substation point to an end point is to be given as:

$$V_{Ni} = \sum_{i=1}^{n} [(C' / a)_{Ni} + C''_{Ni}] \qquad \text{..... (8)}$$

Also, the voltage drop between the substation and an end point on a lateral feeder radiating from node i=I on the main feeder is to be given as;

$$V_{IMj} = \sum_{i=1}^{I} [(C'/a)_{Ni} + C''_{Ni}] + \sum_{j=1}^{m} [(C'/a)_{IMj} + C''_{IMj}] \qquad \text{..... (9)}$$

The voltage drop between the substation and an end point on a sublateral feeder radiating fron node j=J on a lateral feeder that radiating from node i=I on the main feeder is to be given as;

$$V_{JPk} = \sum_{i=1}^{I} [(C'/a)_{Ni} + C''_{Ni}] + \sum_{j=1}^{J} [(C'/a)_{IMj} + C''_{IMj}] + \sum_{k=1}^{F} [(C'/a)_{JPk} + C''_{JPk}] \text{.....(10)}$$

2.2 Cost of Energy Loss

For the main radial feeder, shown in Fig.1, having n segments, the energy loss across the n segemnts for the base year is given as;

$$P_L = \sum_{i=1}^{n} 3\ T\ 10^{-3}\ I_i^2\ R_i\ (LLF)$$

$$P_L = \sum_{i=1}^{n} 26.28\ I_i^2\ R_i\ (LLF) \qquad \text{..... (11)}$$

Where T is the number of hours per year (8760), and LLF is the loss of load factor which is a function of load factor (LF) and is defined [6] as;

$$LLF = A\ (LF)^2 + B\ (LF) \qquad \text{for } A + B = 1 \qquad \text{.....(12)}$$

The total energy loss is to be calculated on the basis of present worth cost for the period of conductor assumed life time (D years) for a discount rate of annual percentage r. It can be written as;

$$C_o = \sum_{i=1}^{n} 26.28\ I_i^2\ R_i\ (LLF)\ h \sum_{d=1}^{D} [1/(1+r)^d] \qquad \text{..... (13)}$$

where h is the cost of energy per KWH.

The effect of load factor on the LLF as given by eq.(12) and consequently its effect on the cost of energy C_o is discussed by Ponnavaiko [6]. To consider the effect of load growth, eq. (11) is to be multiplied by a factor $(1+g)^{2d}$, d=1,2,...,Y, where Y is the plan period up to which the feeder can take load growth, and g is the annual load growth rate. The effect of growth in load factor is given by Scheer [11] through obtaining the yearly value of LF, i.e. $(LF)_d$ within the planning period Y as;

$$LF_d = LF_u - (0.5)^{d/1.6}\ (LF_u - LF_p) \qquad \text{..... (14)}$$

where LF_u and LF_p are the ultimate and present values of load factors respectively.

In case of general distribution system containing E main, lateral and sublateral feeders the total energy loss is to be given as;

$$C_{oe} = \sum_{e=1}^{E} C_o \qquad \text{.....(15)}$$

2.3 Cost of Energy

The cost of energy is not constant as it always increasing with time as the cost of erection, labour, equipments and maintenance increases with time. Then the cost of energy per kwh, h in eq. (13) must be variable with time as h_d ($d=1,2,\ldots,D$). Substituting these factors in eq. (13), it becomes;

$$C_D = \sum_{i=1}^{n} 26.28\,(\ell_i\, I_i^2/a_i)\left\{\sum_{d=1}^{Y} (1+g)^{2d}(LLF)_d\, \acute{h}_d/(1+r)^d + (1+g)^{2Y}(LLF)_Y \sum_{d=M+1}^{D} \acute{h}/(1+r)^d\right\} \quad \ldots\ (16)$$

Equation (16) gives the cost function over the main feeder only. In case of general distribution system with laterals and sublaterals, the cost of eq. (16) is to be modified as;

$$C_{De} = \sum_{e=1}^{E} C_D \quad \ldots(17)$$

2.4 Cost of Feeder

The actual cost of the distribution feeder involves a fixed cost as well as a variable cost. The fixed cost component involves cost for conductor's pole, accessaries, labor and erection. The variable cost component reflect the cost of conductor material and is a function in cross-sectional area. For a radial feeder with n segments, the total cost over the life period of the feeder is to be written as:

$$C_f = \sum_{e=1}^{E} \sum_{i=1}^{n} (W_{1i}\, a_i + W_{2i})\, \ell_i \quad \ldots.\ (18)$$

where W_{1i} and W_{2i} are the cost constants of feeder per unit length (1 km).

2.5 Cost of Area Changing

Most of distribution feeders have different values of cross-sectional area as a result of economical gradation. Changing the area of a feeder for two adjacent segments will involve more cost. This excess cost involves the labor cost for welding or connecting the two different areas to each other. This cost can be expressed as:

$$C_w = H\, c_w \quad \ldots\ldots\ (19)$$

where C_w is the total cost for changing the areas along the feeder, H is the number of changing the areas across the feeder and c_w is the cost of one change in feeder area.

3. OBJECTIVE FUNCTIONS

The objective function in our problem is to minimize the total present worth expenditure containing the energy loss cost and the conductor costs given by equations (16) and (18) respectively. This total combined cost will be written as:

$$C_T = \sum_{e=1}^{E}\left\{\sum_{i=1}^{n} (W_{1i}\, a_i + W_{2i})\ell_i + \sum_{i=1}^{n} (26.28/a_i)\ell_i\, I_i^2\left[\sum_{d=1}^{Y} (1+g)^{2d}(LLF)_c\, \acute{h}_d/(1+r)^d + (1+g)^{2Y}\, (LLF)_Y \sum_{d=M+1}^{D} \acute{h}_d/(1+r)^d\right]\right\} \quad \ldots.\ (20)$$

The minimization of the objective function (20) may results a cross-sectional areas that may lead to either high values of voltage drops across the feeder segments, that decreases the service quality and/or high thermal current carrying capacity that may disrupt the service. Therefore, the feeder voltage drop and the thermal current carrying capacity must be decided in a priori as constraints on the minimization of the objective function.

3.1 Voltage-Drop Constraint

The voltage level at the consumer in the distribution system is the main constraint in distribution system planning. The distribution voltage level is a function of two variables. One is dependent on the equipments in use such as transformers, its tap settings and the voltage level received from the generating stations. The othe is the voltage drop in the feeder segments [10]. The voltage drop in the distribution feeder depends on the choice of its cross-sectial areas, loading level, power factor and circuit operating voltage.

The choice of high value of feeder voltage drop leads to less conductor size and consequently less investment and higher system losses. On the contrary, small value of feeder voltage drop leads to higher conductor size and consequently more investment and less system losses. Therefore, the choice of the optimal economical value of feeder voltage drop is a trade-off between the capital investment and the annual recuring expenditure due to energy losses.

3.2 Thermal-Limit Constraint

The maximum allowable conductor temperature at which the conductor can be operated is called the thermal limit or thermal rating of that conductor. For a given feeder loading, the thermal current carrying capacity sets a lower limit on the conductor cross-sectional area A_{min} [12], i.e.,

$$a_i \geqslant A_{min} \qquad \text{...... (21)}$$

3.3 Conductor-Size Constraint

The cross-sectional areas of the conductors vary in a discrete manner and there are only a few standard sizes used in practice. Therefore, the feeder areas are assumed in a priori. Due to the discrete values of the conductor size, the following constraint is to be adopted here:

$$a_i > 0 \qquad \text{..... (22)}$$

Hence, the optimization problem can be formulated as to minimize the objective function given by equation (20) subjected to the three constraints of voltage drops, thermal limit and conductor size given by equations (4), (21) and (22) respectively.

4. SOLUTION TECHNIQUE

Consider a simple distribution system with a radial feeder that has three segmants as shown in Fig.2. The solution technique can be explained by the following steps:

1) assume any appropriate standard cross-sectional area A_1 for all the feeder segments. Determine the overall cost function C_1 of the whole feeder and the total voltage drop across the feeder.
2) If the voltage drop constraint is satisfied, all the segmants except the first one are to be given a smaller standard area value such as A_2. The total cost C_2 and the voltage drop are determined.
3) In any step, if the voltage drop constraint is not satisfied or the cost $C_2 > C_1$, the area of the segment at that step is to be given a higher standard area value.

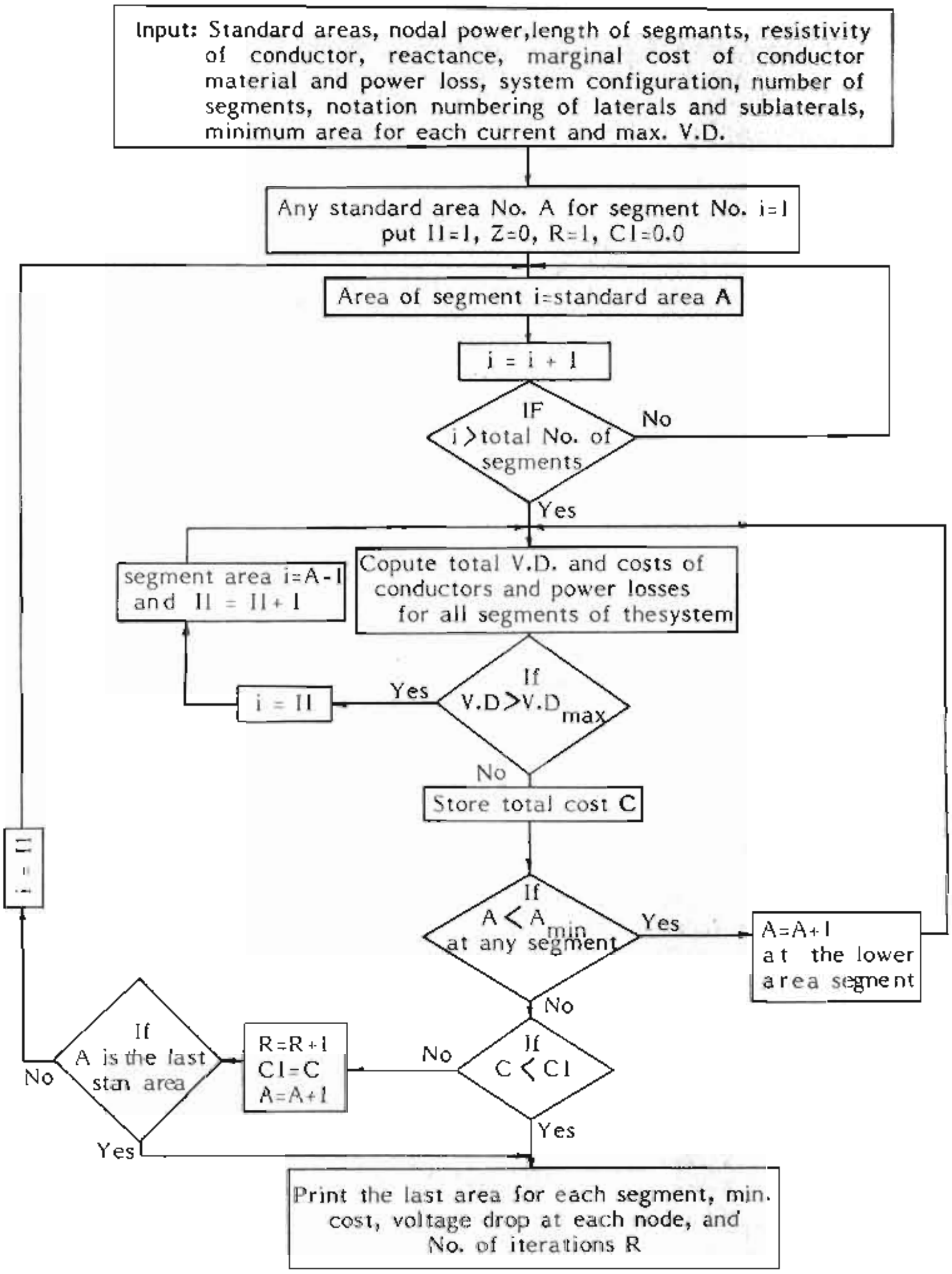

Fig.3 Flow chart of the presented technique

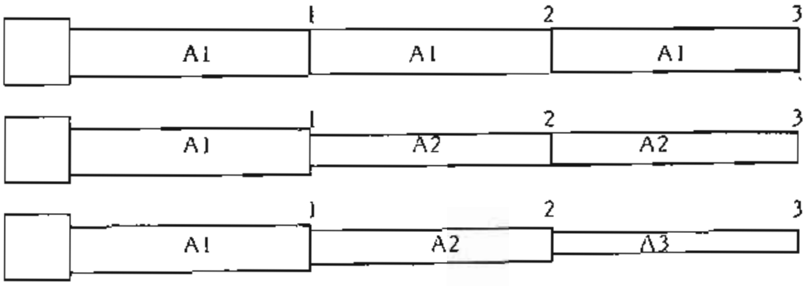

Fig.2 Fundamental steps of the solution technique.

4) The steps are repeated as long as the new cost is decreasing and the voltage drop constraint is satified.

5) The process is terminated when the total cost C starts to increase always and/or so the voltage drop constraint.

Fig.3 illustrates the detailed flow chart for the solution technique presented here.

5.APPLICATION ON NUMERICAL EXAMPLE

5.1 Test System

In order to test the proposed procedures for the optimal conductor sizing for a distribution system with laterals, an 11-KV realistic distribution system of feeders with thirty one segmants, one main feeder, four lateral feeders and two sublateral feeders is used. The single line diagram of this system is shown in Fig.4. The corresponding segment length, node-loading power and the minimum allowable area for each corresponding segment current are illustrated in Table 1. The minimum allowable area is decided according to the thermal current carrying capacity in each segment. The segment is defined by its two terminal nodes, e.g. x-y and y-z are the numbering system for two adjacent segmants. The node y belongs here to the segment x-y and not to the segment y-z.

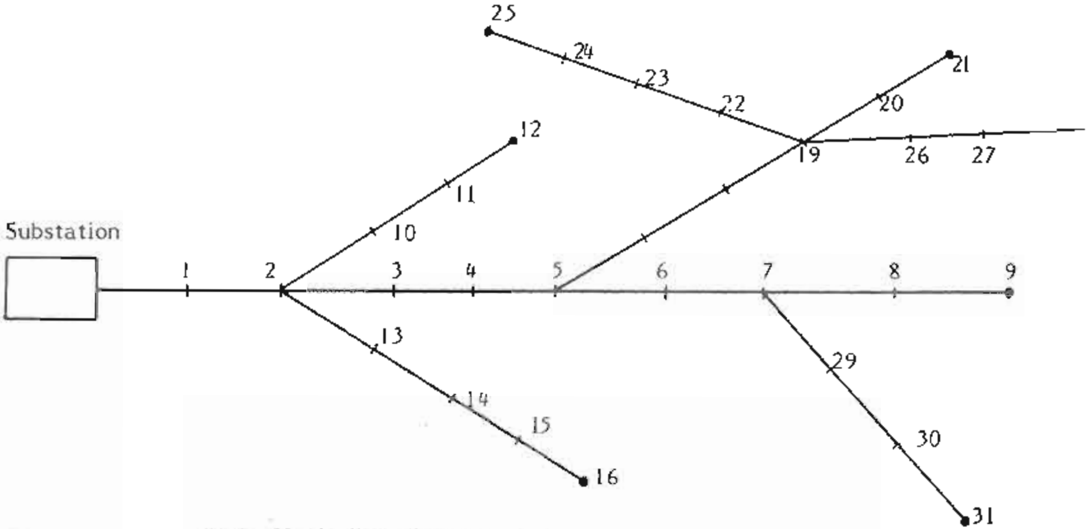

Fig.4 Single-line diagram of the 31-bus distribution system

The other important data that are used here are given in the following:

1. Resistivity of Aluminium	29.75 ohm.mm^2/km
2. Constant reactance for the distribution feeder	0.0951 ohm/km
3. Annual load growth	0.12
4. Power factor	0.8
5. Discount rate	0.1
6. Present load factor	0.2
7. Maximum load factor	0.4
8. Life period of distribution feeder	20 Years
9. Load growth period	8 Years
10. Variable cost of feeder	170 L.E./mm^2/km
11. Energy cost	0.03 L.E./Kwh
12. Cost of area changing	20 L.E./one
13. Maximum allowable voltage drop on the main feeder	285 Voltas
14. Maximum allowable voltage drop to node 12.	120 V
15. Maximum allowable voltage drop to node 16.	146 V
16. Maximum allowable voltage drop to node 21.	405 V
17. Maximum allowable voltage drop to node 31.	315 V
18 Maximum allowable voltage drop to node 25.	375 V
19. Maximum allowable voltage drop to node 28.	365V
20. Available standard areas for feeders at 11 Kv	95, 50, 40, 14 and 10 mm^2

Table 1. Main data for the distribution test system

segment No.	segment length (km)	node Loading power (k.w)	minimum allowable area (mm^2)
0 - 1	1.0	80	50
1 - 2	0.9	--	50
2 - 3	1.1	80	50
3 - 4	1.0	90	40
4 - 5	0.9	--	40
5 - 6	0.8	70	10
6 - 7	0.7	--	10
7 - 8	0.8	70	10
8 - 9	0.9	60	10
2 - 10	0.9	70	10
10 - 11	0.7	60	10
11 - 12	1.0	50	10
2 - 13	0.9	50	10
13 - 14	0.8	60	10
14 - 15	1.0	50	10
15 - 16	0.6	60	10
5 - 17	1.0	50	14
17 - 18	0.8	40	10
18 - 19	1.2	--	10
19 - 20	1.0	60	10
20 - 21	0.9	50	10
19 - 22	1.0	40	10
22 - 23	0.8	60	10
23 - 24	0.7	50	10
24 - 25	1.2	40	10
19 - 26	0.8	60	10
26 - 27	0.6	40	10
27 - 28	0.7	50	10
7 - 29	1.1	60	10
29 - 30	0.8	50	10
30 - 31	0.8	60	10

.2 Results and Discussions

Table 2 illustrates the step-by-step results when applying the proposed procedures [illegible] optimal conductor sizing on the main feeder of the test system. The allowable voltage [illegible] along that feeder is 285 V. In the first step, all the segments assumed to have [illegible] area of 95 mm^2, and the voltage drop shows small value as 149.3 volts due to [illegible] large area where the cost shows a high value of 29913 L.E. which is mainly due [illegible] the material cost of feeder. The second step decreases all segments areas to 50 mm^2 where the cost decreased to 28295 L.E. and the voltage drop becomes more worest [illegible] V. Then, any further decrease in any segment area will violate the voltage drop constraint. Then the area of the first segment takes a larger value of 95 mm^2 and the

Table 2. Step-by-step results of gradation of the main feeder

Segment No.	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	Total V.D. (V)	Material cost (L.E.)	Energy loss cost (L.E.)	Total cost (L.E.)
Steps	cross-sectional area (mm^2) at each step												
1	95	95	95	95	95	95	95	95	95	149.3	20776	9137	29913
2	50	50	50	50	50	50	50	50	50	275.0	10935	17360	28295
3	95	50	50	50	50	50	50	50	50	245.3	12150	14788	26938
4	95	95	50	50	50	50	50	50	50	220.0	13243	12694	25937
5	95	95	95	50	50	50	50	50	50	197.0	14580	11277	25857
6	95	95	95	40	40	40	40	40	40	222.0	13203	12407	25610
7	95	95	95	50	40	40	40	40	40	212.0	13473	11818	25291
8	95	95	95	50	50	40	40	40	40	203.3	13716	11373	25089
9	95	95	95	50	50	14	14	14	14	263.3	11469	12261	23730
10	95	95	95	50	50	10	10	10	10	300.3	11124	12806	23930
11	95	95	95	50	50	14	10	10	10	283.9	11210	12491	23701
12 Optimal solution	95	95	95	50	50	14	14	10	10	272.2	11286	12308	23594

Table 3. Optimum conductor gradation for the lateral and sublateral feeders

Segment No.	Area (mm^2)	Total cost & voltage drop
2 - 11	14	C_t = 1140.2 L.E. V.D. = 1.02 % Allowable V.D. = 1.1 %
10 - 11	10	
11 - 12	10	
2 - 13	14	C_t = 1719.4 L.E. V.D = 1.3 % Allowable V.D. = 1.33 %
13 - 14	14	
14 - 15	10	
15 - 16	10	
5 - 17	40	C_t = 6408.6 L.E. V.D. = 3.34 % Allowable V.D. = 3.70 %
17 - 18	14	
18 - 19	14	
19 - 20	10	
20 - 21	10	
19 - 22	14	C_t = 1680.2 L.E. V.D. = 2.72 % Allowable V.D. = 2.90 %
22 - 23	14	
23 - 24	10	
24 - 25	10	
19 - 26	14	C_t = 869.9 L.E. V.D. = 3.38 % Allowable V.D. = 3.41 %
26 - 27	10	
27 - 28	10	
7 - 29	14	C_t = 1302.3 L.E. V.D. = 3.16 % Allowable V.D. = 3.32 %
29 - 30	10	
30 - 31	10	

voltage drop improved to 245.3 V and the cost decreased to 26938 L.E. This procedure continues up to 12 steps and stops at the optimal solution for a minimum cost of 23594 L.E. and a voltage drop of 272.2 V. To Take the cost of changing area into account, the number of area changing is to be considered in the last two steps which is found to be 3 times. Then the cost of area changing is found to be 60 L.E. (the cost/one area changing is 20 L.E.). This cost is to be added to the total cost in order to compare the final optimal cost which, in our case, is the case of step 12. The addition of the cost of area changing may change the optimal solution to another step.

Table 3 illustrates the optimum gradation for the other four lateral feeders and the two sublateral feeders. The minimum cost and voltage drop is given for each feeder.

6. CONCLUSIONS

A very simple conductor sizing procedure for radial feeders in distribution system is presented. It is based on an iterative technique to obtain the optimum area of each segmant of a radial feeder at a minimum cost and subjected to maximum allowable voltage drop. The objective cost involves the constant cost of conductor, the variable cost of energy loss and the cost of area changing between two adjacent segments. The current carrying capacity for each segment is considered to avoid high temperature rise in conductors. The proposed technique considers the load factor, load growth rate and discount rate for the present worth cost. In case of ignoring these parameters, as usual for approximation, the technique becomes more simple and can be done using a programmable calculator with convenient results. This technique needs very simple program that can be constructed and used easily by any system planner.

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