Application of Proposed Distribution Network Planning Rules on Fast Developing Countries

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Abstract: With the ever increasing need to electric energy and the fast development of loads in many countries especially in the fast developing ones such as the GULF countries, the load growth as well as the forecasted loads, are highly increased depending on new and arising factors and conditions. In turn, Electricity Companies build rapidly generating plants, transmission and distribution networks to meet the rapid load demand. Usually, power system expansion follows the load growth which may exist at random locations. This adds to the absence of prior proper planning, especially medium and long term planning, resulting in network configurations that do not match with optimum siting and sizing planning rules. Operation of such networks faces several problems that may sacrifice the power quality. Thus, proper planning of new networks, expansion or rehabilitation of existing ones should be based on most accurate and proper planning rules. This calls for the investigation of a new exact cost function for optimum sizing and siting of network substations, and hence the H.V. feeds (incoming) and the M.V. distribution (outgoing) feeders. Therefore, this paper presents a newly proposed methodology that takes into consideration the capital costs of all electrical components, losses in these components, operation and maintenance costs. The inflation rate can be also taken into consideration. This methodology gives important results, which conclude that the optimum distance between substations and hence the optimum number of substations, greatly depends on different factors that were not taken into consideration before, for example : the kWh price, cost of the HV incoming feeders (66-110 kV feeders) besides the cost of the MV outgoing feeders (6.6-22 kV feeders), cost of the distribution substations (MV/LV), cost of losses in transformers, cost of losses in all feeders, incoming and outgoing, Operation and maintenance costs ….etc. [Journal of American Science. 2010;6(11):327-]. (ISSN: 1545-1003).

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1- Introduction:

On the application of the proposed cost function to re-plan, expand and rehabilitate the network of Jeddah City, as an example of a fast developing network, the obtained results in this paper present the most important conclusion that the today number of substations in a fast developing network can be kept optimally the same without increase till year 2023, but only needs the increase of the substation capacity, and the enforcement of the H.V. and M.V. lines, according to the forecasted loads and the given rate of load growth.

In the planning of transmission, sub-transmission and distribution networks of an electric power system, cost plays a major role and is a main deciding factor. From the technical point of view, there are always several alternative designs that can satisfactorily fulfill the objectives of the system, namely; continuity, voltage level and power losses. Then, the cost will be the deciding factor on differentiating between the best technically selected plans [1], hence deciding the optimum sites and sizes of the network elements, especially the network substations.

Therefore, since early of the second half of the 20^{th} century, investigations of cost functions supporting the appropriate system plans have been attempted [1-11]. In this respect, authors considered only the capital costs of the network elements, believed to be most effective, and ignored those thoughts to be non-effective. This rendered most of the previously proposed cost functions to be approximate. This becomes very clear when dealing with fast growing loads in fast growing countries and with heavy load densities, where, on application, can lead to misleading plans. Therefore, this paper has been devoted to propose an accurate cost function that takes all cost factors into consideration. Comparing with the results obtained using previous approximate formulae, important results are obtained.

2- Review of Previous Related Investigations :

Ponnavaikko [2] proposed an optimal planning solution aimed at optimizing the substation feed area, load carrying limit of the feeders and the conductor size for feeders. Pannavianko considered that the substation cost is a function of the substation size and the number of feeder bays provided at the substation.

From the point of view of energy conservation, Swedan [3] suggested that the system network, which is required to be built in such a way that the power distributed to the load center can take place at minimum cost, may be achieved by evaluating an objective function in terms of the annual energy losses costs.

Considering that the best distribution system planning could be achieved using the best size and location of substations, EBASCO [4] proposed that such achievement could be realized by finding the least annual cost of the sum of the fixed, charges on substations and feeders. Operation, maintenance and losses costs were neglected.

Since the formula presented by EBASCO [4] is believed to be commonly used for optimum siting and sizing of network substations, however being approximate, it is worthy to present here in some details, and to be compared with the present proposed cost function.

Increasing the number of substations for a given load density tends to increase total cost. However, increasing the number of substations reduces the cost of feeders. Clearly then, the least total annual cost is a function of substation and feeder costs, capacity of feeder and load density.

The total cost of substations and feeders/ unit area is :

C_T = feeders Cost/ Unit Area (km^2) + s/s Cost

$$= \left(a + \frac{bS}{2}\right)\frac{D}{kVA_f} + \frac{c}{S^2} + dD \qquad (1)$$

Minimizing the above equation with respect to S results in the optimum substation size and site (represented by the distance between substations S) as follows:

$$S = 1.59\left[\frac{kVA_f . c}{bD}\right]^{0.333} km \qquad (2)$$

and the corresponding optimum substation size would be :

$$kVA_s = S^2 D = 2.52 D^{0.333}\left[\frac{kVA_f . c}{b}\right]^{0.666} \qquad (3)$$

Where :

D is the Load density in kVA per square kilometer (km^2).

kVA_s is the substation kVA capacity.

kVA_f is the feeder kVA capacity.

S is the distance in km between substations.

a is the fixed charges on feeder equipment and regulators in dollars per year.

b is the cost of feeders in US$ per km.

c is the part of substation cost not proportional to substation capacity.

d is the cost per kVA of the substation capacity required to carry the load in the area S^2

C_T is the total cost of substations and feeders per square km.

K.S. Hindi et al [5,6], Harley et al [7] and Adler et al [8] confined their investigations to problems related with low voltage networks, namely to radial layout of a distribution network [5,6], replacement of the transformers (dynamic design) with the growth of the load demands [7] and to a model focusing on the treatment of residential and light commercial service areas with time-varying load characteristics, including customer load profile changes, per customer load growth and service area population growth. Clearly, such investigations for related low voltage plans cannot be of effective use for HV/MV distribution network planning, where optimum siting and sizing of substations and hence HV incoming and MV outgoing feeders are the main objective.

Further, M. Kaplan, and A. Braunstein, [9] presented a contribution to the determination of the optimum site for substations. The method enables to limit the number of possible solutions and by using grapho-analytical methods to home on the optimum solution. The optimum site for a substation is the location which will result in minimum construction and operation costs.

Furthermore, G.L. Thompson, and D.L. Wall, [10] formulated a distribution planning model which considers existing and potential substation locations, their capacities and cost, together with the primary feeder network represented by small area demand locations to represent non-uniform loads, and feeder segments having variable distribution costs and limited capacities.

Ibraheim et al [11] presented an economic comparison between two suggested technical alternatives for an integrated network (composite distribution system comprising primary substations, distributions points, primary feeders connecting the distribution points, distribution transformers (kiosks) and feeder sections tying these kiosks (normally in the form of loops)). All such costs have been added by computation for various alternative plans of a distribution district. The most economical variant was recommended. To fulfill this, extensive data was necessary to be provided, arranged in tables and laborious computations were carried out, other than using a simple objective function.

Thus, it is thought that anyone of the preceding formulae has selected only several factors thought to be the effective ones, but ignored other factors that may be of cost effectiveness in planning. This called for the present investigation. The proposed cost function presented in this paper has taken into consideration even every minor factor of the many that have been ignored in the previous proposed cost functions, such as; the kWh price to account properly for the cost of losses, the main fixed charges on substations and feeders, the operation and maintenance costs, losses cost in all system elements, substation cost and the substation loading.

3- Proposed Cost Function:

In the present work it has been aimed to investigate a cost function that considers all affecting factors, including capital cost, costs of losses, operation and maintenance costs with only basic data required, where none of the factors, even having slight effect, is neglected such as done before [e.g. 2,3,4].

Since the loads of distribution networks in fast developing countries are characterized by high densities and high growth rates, distribution substations are fed by elevated voltages e.g. up to 110 kV, such as in Saudi Arabia networks, where the distribution substations are 110/13.8 kV substations. This means that the distribution networks in such countries comprises the 110 kV feeding network. This agrees with same generally accepted classifications of networks voltages. This calls to consider the cost of the substations incoming feeders. Consequently, in the presently suggested formula, all of the following factors are considered for optimizing the locations and capacities of the substations and hence, the incoming and outgoing feeders lengths and sizes defining the basic network plan. Thus, the taken factors are :

- Cost of the HV incoming feeders (66-110 kV feeders).
- Cost of the MV outgoing feeders (6.6-22 kV feeders).
- Cost of the HV/MV substations equipment (part of substation cost depending on its capacity).
- Cost of the HV/MV substation land, civil work, public works …etc (fixed part of substation cost).
- Cost of losses in transformers.
- Cost of losses in all feeders, incoming and outgoing.
- Operation and maintenance costs ….etc.

The following symbols will be used to determine the relationship of the above factors in deriving the equation of the total cost.

D is the load density in kVA/km2.
kVA_s is the substation MVA capacity.
kVA_{fi} is the incoming feeder kVA capacity.
kVA_{fo} is the outgoing feeder kVA capacity.
S is the distance in km between substations.
a_i is the fixed charges on incoming feeders equipment and regulators (cable ends, feeder cells, ….etc.).
a_o is the fixed charges on outgoing feeders equipment and regulators.
b_i is the cost of incoming feeder/km.
b_o is the cost of outgoing feeder/km.
c is the part of substation cost not proportional to substation capacity (land, civil work, building, …..etc.).
d is the cost per kVA of the capacity required to carry the load in the area S2
n_{fi} **is** the number of incoming feeders required/ km2.
n_{fo} is the number of outgoing feeders required/ km2.
C_s is the substation cost / km2.
C_{TC} is the total construction costs or expenses / km2.
x is the ratio between the value of power losses at full load of the substation transformer and its rating.
lf is the loss factor of a substation transformer.
C_{tr} is the cost of losses in substation transformers/ unit area.
I_i is the rated current of incoming HV feeder.
I_o is the rated current of outgoing MV feeder.
$C_{o\&m}$ is the expenses of substations operation and maintenance/ unit area.

To investigate the total costs and hence the cost function that is optimized to get the optimum spacing between substations and hence their sizes and feeder lengths, Using One Square km As a Unit Area, calculations have been carried out as follows :

3-1- Cost of incoming and outgoing feeders [12]:

No. of incoming feeders/ substation is normally 4 to 6 as a substation is usually fed from two or three different sources via double circuit lines or cables. The most common practice, a HV/MV substation is fed from two double circuit feeders.

So, the No. of incoming feeders per substation is equal to 4.

n_{fi} is the No. of incoming HV feeders/km^2= $\frac{4}{S^2}$

Cost / incoming feeder is given by : $a_i + b_i\frac{S}{2}$

Cost of incoming feeders to HV/MV substations / Unit area = n_{fi} * Cost / incoming feeder

$$= \frac{4}{S^2}\left(a_i + b_i\frac{S}{2}\right) \qquad (4)$$

Similarly, the cost of outgoing feeders required/km^2

$$= n_{fo}\left(a_o + b_o\frac{S}{2}\right) = \frac{D}{kVA_{fo}}\left(a_o + b_o\frac{S}{2}\right) \qquad (5)$$

3-3- Cost of substations:

The cost of a substation comprises that part of cost that does not depend on the substation capacity (c) which includes the land, the building and civil work and as such in addition to the part that depends on the substation capacity which is given by d*kVA_s.

Where :

d is the cost/ kVA of the capacity required to carry the load in the area S^2.

kVA_s is the substation capacity or size= S^2.D

Using one square km as a unit area for calculations.

C_s = substation cost/ km^2 $= \frac{c}{S^2} + dD$ (6)

3-3- Cost of losses [12]:

3-3-1- Losses in substation transformers [12]:

Let the ratio between the value of power losses of the substation transformer and its rating be x, where x, i.e.

$$x = (1-\eta)$$

where :

η is the transformer efficiency percentage/100.

Transformer losses in a substation at full load= $x(kVA)_s$

and transformer losses in substations/ unit area (km^2)

$$= \frac{x(kVA)_s}{S^2}$$

Then, the cost of losses in substation transformers per unit area is equal to:

$\frac{x(kVA)_s}{S^2}$* transformer operation age * loss factor (lf) * PF *cost of energy/kWH

where the loss factor is the ratio between the averaged value of power losses of a transformer and its rating which depends on its load curve.

$$\text{Loss Factor (lf)} = \sum_{hour1}^{Hour24} \frac{(kVA_{actural})^2 / 24}{(kVA_{rating})^2}$$

∴ Cost of losses in substation transformers/ km^2 is :

$\frac{x(kVA)_s}{S^2}$* 25 (years)* 8760 (hours/ year)* loss factor (lf)* PF* \$/kWH= $\frac{k_s(kVA)_s}{S^2}$

Where :

k_s = x * 25 * 8760 * loss factor (lf) * PF * \$/kWH (7)

x = 1% = 0.01

Cost of losses in substation transformers/ km^2 (C_{tr}) is :

$$\frac{k_s(kVA)_s}{S^2} = \frac{k_s * S^2 D}{S^2} = k_s D \quad (8)$$

3-3-2- losses in H.V. incoming and outgoing feeders [12]:

Similarly, cost of losses in incoming feeders =Losses cost = loss/ feeder at rated current * No. of incoming feeders/ unit area * loss factor * life duration in hours * cost/ kWH

$$= \frac{I_i^2 \left(R_i/km\right)}{1000} * \frac{S}{2} * \frac{4}{S^2} * 25 * 8760 * lf * \$/kWH$$

$$= \frac{I_i^2 \left(R_i/km\right)}{1000} * \frac{2}{S} * 25 * 8760 * lf * \$/kWH \quad (9)$$

Also, energy losses in the MV outgoing feeders and their cost over the life time of cables (assumed 25 year)/ unit area can be calculated as follows [12] :

Energy Losses cost in MV outgoing feeder = loss/ feeder at rated current * No. of outgoing feeders/ unit area * loss factor * life duration in hours * cost/ kWH =

$$= \frac{I_o^2 \left(R_o/km\right)\frac{S}{2}}{1000} * n_{fo} * 25 * 8760 * lf * \$/kWH$$

$$= \frac{I_o^2 \left(R_o/km\right)}{1000} * \frac{S}{2} * \frac{D}{(kVA)_{fo}} * 25 * 8760 * lf * \$/kWH \quad (10)$$

3-4- Operation and maintenance costs :

The expenses of operation and maintenance of substation equipment may considerably affect the cost function and hence the optimization of the substations sites and sizes. In an independent study of the operation and maintenance expenses of a substation, the authors could conclude that these costs over the substation life add to approximately the total substation capital (construction) costs [12].

Therefore, the cost of operation and maintenance/ unit area can be estimated as:

$$C_{o\&m} = \frac{s/s \cos t}{S^2} \quad (11)$$

3-5- Suggested exact cost function:

From the above detailed analysis of the costs of a system including substations, incoming feeders, outgoing feeders, system energy losses, operation and maintenance costs, the believed most exact cost function suggested in the present work can be formulated by the additions of costs given in equations (4) to (11) as follows :

$$C_T = \left(\frac{c}{S^2} + dD\right) + \frac{4}{S^2}\left(a_i + b_i\frac{S}{2}\right) + \frac{D}{(kVA)_{fo}}\left(a_o + b_o\frac{S}{2}\right) + \quad (12)$$

$$k_s D + k_f \frac{2I_i^2 R_i / km}{1000S} + k_f \frac{2I_o^2 R_o S}{2000} * \frac{D}{(kVA)_{fo}} + \frac{s/s\cos t}{S^2}$$

Where :

$$k_s = 25*8760*lf * PF * \$/kWH$$
$$= 2.19x\,10^5 * lf * PF * \$/kWH$$

and

$$k_f = 25*8760*lf * \$/kWH$$
$$= 2.19x\,10^5 * lf * \$/kWH$$

In order to minimize the total cost : $\frac{dC_T}{dS} = 0$

$$\frac{dC_T}{dS} = \frac{-2c}{S^3} + 0 - \frac{8a_i}{S^3} - \frac{4b_i}{2S^2} + 0 + \frac{b_o D}{2kVA_{fo}} + 0$$

$$-\frac{2k_f I_i^2 R_i / km}{1000\,S^2} + k_f \frac{I_o^2 R_o}{2000}\frac{D}{(kVA)_{fo}} - \frac{2x(s/s\cos t)}{S^3} = 0$$

$$\frac{dC_T}{dS} = \frac{-1}{S^3}(2c + 8a_i + 2*(s/s\cos t))$$

$$-\frac{1}{S^2}\left(2b_i + \frac{2k_f I_i^2 R_i / km}{1000}\right) + \left(\frac{b_o D}{2(kVA_{fo})} + k_f \frac{I_o^2 R_o}{2000}\frac{D}{(kVA)_{fo}}\right) = 0$$

Multiply by S^3

$$S^3\left(\frac{b_o D}{2(kVA_{fo})} + k_f \frac{I_o^2 R_o}{2000}\frac{D}{(kVA)_{fo}}\right) - S\left(2b_i + \frac{2k_f I_i^2 R_i / km}{1000}\right)$$
$$-(2c + 8a_i + 2*(s/s\cos t)) = 0$$

or

$$\alpha S^3 - \beta S - \gamma = 0 \quad (13)$$

Where :

$$\alpha = \frac{b_o D}{2(kVA)_{fo}} + \frac{k_f I_o^2 R_o}{2000}\frac{D}{(kVA)_{fo}}$$

$$\beta = 2b_i + \frac{2k_f I_i^2 R_i}{1000}$$

$$\gamma = 2c + 8a_i + 2*(s/s\cos t)$$

Solving equation (13) for S gives the optimum distance between substations and feeders length for minimum cost.

Then, the optimum substation size is given by

$$(kVA)_s = S^2 D$$

Solving equ. (13); S and $(kVA)_s$ are obtained :

4- Sample Results of Application of the Proposed Cost Function to the Planning of an Actual Network In A Fast Growing Country And Analysis of Results:

In order to verify the benefits from using the proposed cost function, calculations have been carried out to obtain the optimum sites and sizes of the 110/13.8 kV substations and incoming and outgoing feeders of Jeddah 110/13.8 kV networks, for the sake of optimum networks planning and/or rehabilitation. Calculations were also carried out for the same network using the simplified approximate cost function [4] commonly used, for comparison, where high economical and technical benefits will be shown by using the proposed cost function in the present work.

Load forecast for Jeddah area based on a new approach for load forecast in fast developing countries is presented in the authors' paper [13]. Considering the forecasted load density over the years, as presented in Figure (1), sample results are presented in figure (2) for the variation of the optimum distance (S) between substations with the years under the given otherwise conditions. These are compared with the results obtained by the approximate formula. Fig. (2), shows that the optimum distance between substations that decrease with the years (as the load and load density increase, Fig. (1)), is larger when using the investigated (proposed) cost function than using the approximate one, while, the number of required substations is less. Thus, it is required to use less number of substations but with larger capacities. This is an excellent advantage in fast growing countries since at the beginning, substations are built everywhere to meet the loads at various locations. Just increasing the capacities of the existing substations will meet the future loads (up to year 2023 in the studied case). This will save high costs of building new substations (as given by the approximate formula) where the cost of land becomes excessively high as well as saving new routes for the feeding (HV incoming) feeders and the distribution (MV outgoing) feeders.

Further, Figs. (3) presents the same as in Figs. (2), but increasing the cost of energy \$/kWH. Figures (2), (3) indicate that as the cost of electric energy/kWH increases i.e. as the costs of feeders losses increase, it is appropriate to increase the number of substations i.e., decrease the distance between substations. The losses of feeders here play an effective role.

Furthermore, expressive results are shown in Fig. (4), where the calculated optimum distances between substations are presented when varying the fixed part of the substation cost (c) using the proposed cost function compared with the approximate one, under the given conditions. Figure shows clear dependence of the optimum distance between substations on the fixed part of the substation cost.

More and above Figure (5), shows the comparison between the calculated distance between substations dependence on the kWh prices (0.05, 0.08, 0.11, 0.2, 0.27 $), When I_o= 300 Amp, I_i= 600 Amp, and c= 6.7 M $, with the use of the newly investigated (proposed) methodology compared with the approximate one. It can be seen that the increase of the kWh price decreases the distance between substations with the use of the exact proposed formula while no effect is seen when using the approximate formula. This is quite clear as being due to ignoring the losses costs in the approximate formula.

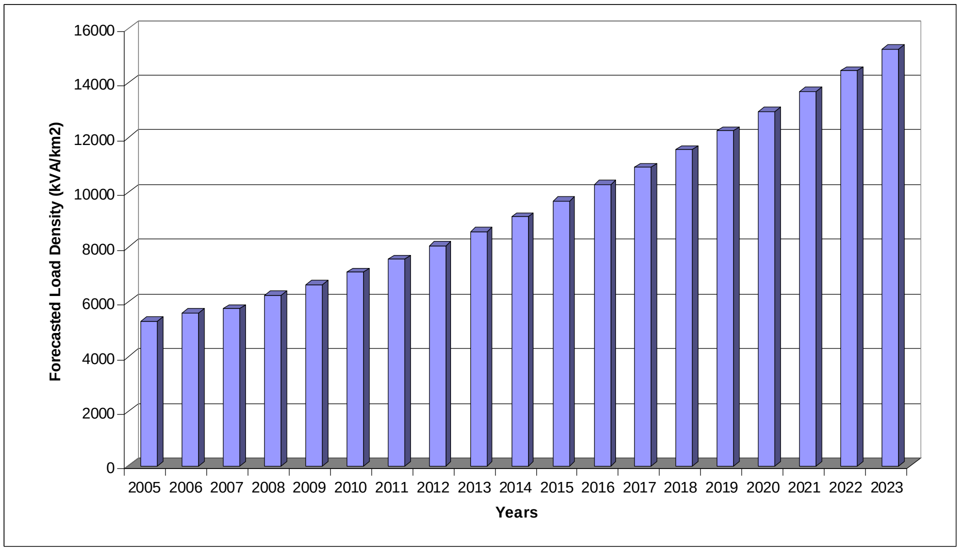

Fig. 1: The forecasted load density for Jeddah area.

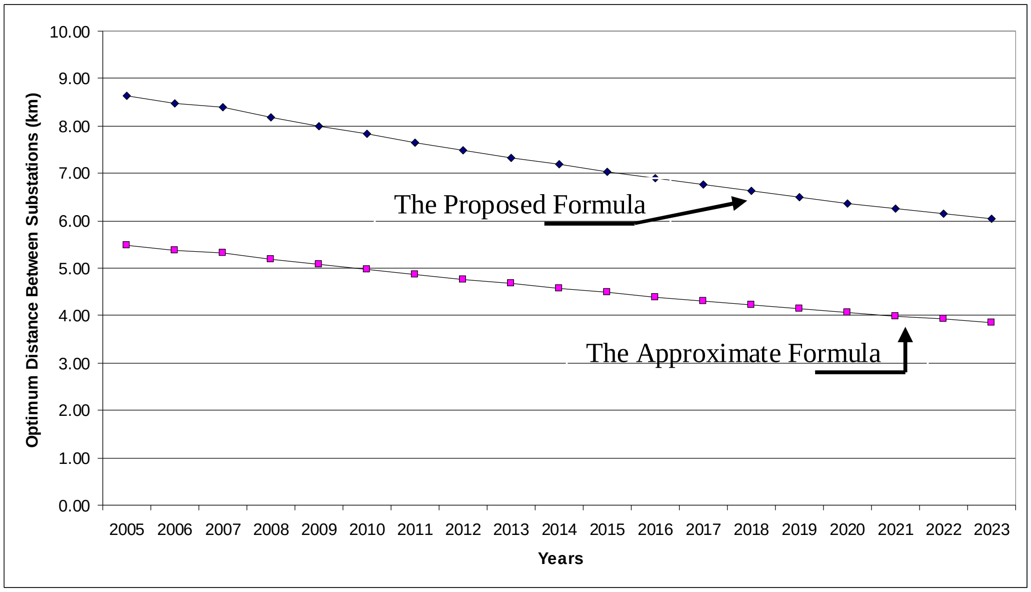

Fig. 2: The calculated distance between substations dependence on the different calculated methodologies, When the I_o= 200 Amp, I_i= 400 Amp, the kWh price is 0.05 $, and the fixed part of substation cost (c) is 4M $.

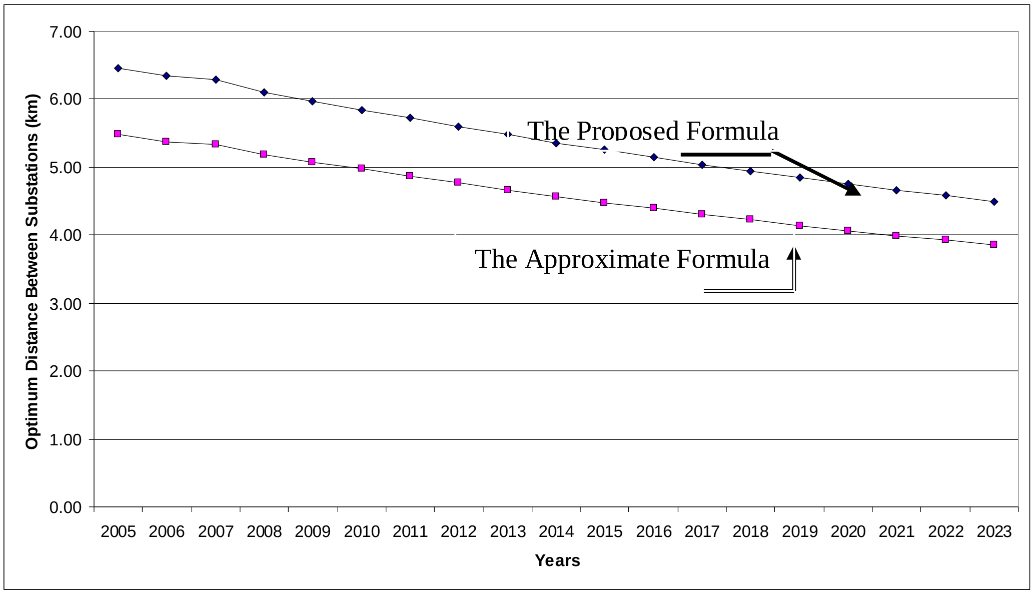

Fig. 3: The calculated distance between substations dependence on the different calculated methodologies, When the I_o= 200 Amp, I_i= 400 Amp, the kWh price is 0.27 $, and the fixed part of the substation cost (c) is 4M $.

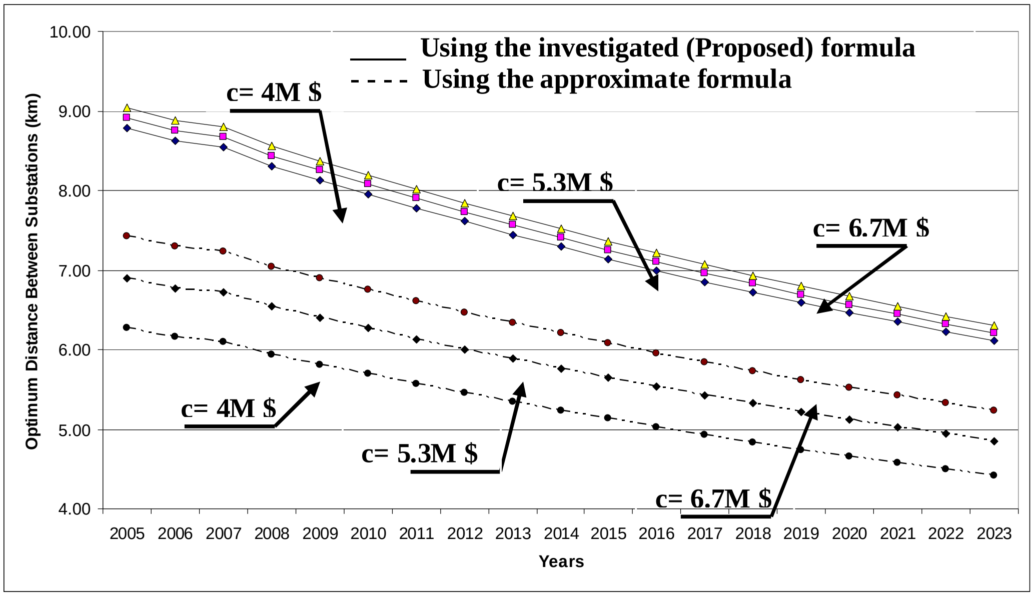

Fig. 4, Comparison between the calculated distance between substations dependence on the fixed part of substation cost (c= 4, 5.3, 6.7 M $),
When the I_o= 300 Amp, I_i= 600 Amp, the kWh price is 0.05 $, using the proposed cost function compared with the approximate one.

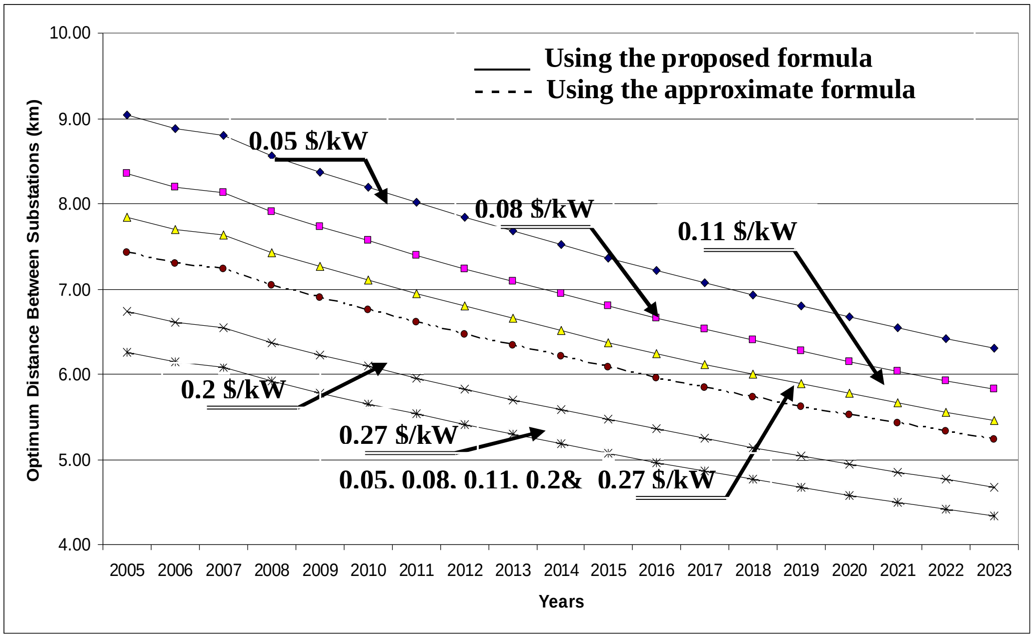

Fig. 5, Comparison between the calculated distance between substations dependence on the kWh prices (0.05, 0.08, 0.11, 0.2, 0.27 $/kWH),
When the I_o= 300 Amp, and the fixed part of substation cost c= 6.7 M $, using the proposed cost function compared with those using the approximate formula.

5. Conclusions and Recommendations:

The main conclusions of this paper can be summarized as follows:

1- The approximate cost functions commonly used nowadays may lead to misleading results for good network planning. The use of different methodologies will result in different distances between substations and hence different number of substations.
2- The proposed cost function in the present work yields realistic results, compatible with the best of experience in network planning, where the centers of loads are well served. It does take the costs of all the electrical components into consideration, their losses and their operation and maintenance costs.
3- For fast developing countries, where the loads are rapidly increasing and the load densities are high, the high voltage of the substations between 66 kV and 110 kV, actually and effectively serves as distribution voltage, as the high number of substations will consequently serve the load centers directly.
4- An important and vital recommendation for the rehabilitation and development of the 110/13.8 kV networks in fast developing countries, such as Jeddah Region Network, is to increase the capacity of the existing 110/13.8 kV substations, strengthen the 110 kV network by more 110 kV circuits between the substation to meet the growing loads, other than increasing the number of substations accompanied with so many difficulties, thus saving much cost of land and other costs.
5- The increase of the kWh cost results in decreasing the distance between substations (increasing the number of substations). The higher the substation cost the higher is the distance between substations.

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6. References:

1. N.S. Markushevich, I.C. Herejk and R.E. Nielsen, "Fundamental Requirements and Cost Benefit Study for Distribution Automation at B.C. Hydro", IEEE Trans. on Power Systems, Vol. 9, No. 2, May 1994.
2. M. Ponnavaikko and K.S.R. Prakasa, "Optimal Distribution System Planning ", IEEE Transactions on Power Apparatus and Systems, Vol. PAS-100, No. 6, June 1981.
3. M. Swedan, "Distribution Networks Planning From Electrical Energy Conservation Point of View", Report Ministry of Electricity – Egypt / Conference for Conservation of Production and Consumption of Electricity, November 1982.
4. Dewberry, P.E., R. A. EBASCO Services Incorporated, "Electric Distribution Systems Engineering", McGraw Hill, N.Y., Book, 1982.
5. K.S. Hindi and A. Brameller, "Design Low – Voltage Distribution Networks: A Mathematical Programming Method", Proc. IEE, Vol. 124, No. 1, January 1977.
6. K.S. Hindi, A. Brameller and Hamam, "Optimal Cable Profile of L.V. Radial Distribution - Two Mathematical Programming Methods", Proc. IEE, Vol. 123, No. 4, April 1976.
7. [7] R.G. Harley and E. Ben Dov, "Optimal Rating of a Transformer for a Growing Load Diagram", IEEE Transactions on Power Apparatus and Systems, Vol. PAS - 100, No. 12, December 1981.
8. R.B. Alder and W.G. Kim, "A Distribution System End User Cost Model", IEEE Transactions on Power Apparatus and Systems, Vol. PAS - 100, No. 7, July 1981.
9. M. Kaplan and A. Braunstein, "Contribution to the Determination of the Optimum Site for Substations", IEEE Transactions on Power Apparatus and Systems, Vol. PAS - 100, No. 5, May 1981.
10. G.L. Thompson, and D.L. Wall, "A Branch and Bound Model for Choosing Optimal Substation Locations", IEEE Transactions on Power Apparatus and Systems, Vol. PAS - 100, No. 5, May 1981.
11. A.S. Ibrahim, M. Swedan, M. Abd El All and S. El-Debeiky, "Evaluation of a Cost Function for Primary Distribution Network Planning", AUPTDE-CIRED International Symposium on Electricity Distribution in the ARAB Countries, Amman, Jordan, 3-6 June 1996.
12. M.A.A. Khafagy, "Reactive Power Compensation and Energy Conservation For Distribution System Planning In Fast Developing Countries", Ph.D. Thesis, Elec. Power & M/C Dept., Faculty of Engineering, Ain Shams University, 2009.
13. Salem M. Elkhodary, Hassan M. Mahmoud, Soliman El-Debeiky, Medhat Khafagy, and Abdul Rahman Twijry, "Spatial Features of Energy Forecast Methodology in Fast Growing Countries", MEPCON'08, The Twelfth Middle East Power Systems Conference, March 2008.

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