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A PRACTICAL MODIFICATION FOR THE TRANSMISSION LINE CHARACTERISTICS

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SUMMARY

Now, the generated power is large and it may be concentrates at a point with large blocks. Then, the transmission of such large blocks of power must be transmitted through overhead transmission lines. In this case transmission losses will increased so that a new concept in decreasing the transmission losses should be considered.

It must be noted that the elements of a power network may be subjected to voltages and currents in wide range of frequency under switching operations . In this moment the transmission line parameters will be frequency dependent due to earth return effect. Then, the earth path can be investigated in order to improve the characteristics of transmission lines.

An improvement factor for decreasing the value of the transmission line series reactance is suggested. This factor is correlated to the other line parameters, e.g. capacitance.

A formula for the improvement factor as a function of the ratio between the conductor height above ground and its radius is derived. This factor assumes high values for the case of cables while low for the case of overhead transmission lines.

The effect of the improvement factor on the voltage, the reactive power, transmission efficiency, the attenuation factor and power factor at constant voltage at the receiving end are investigated.

The improved characteristics of transmission line in the power system can be realised by choosing a suitable value of the improvement factor. The effect of earth resistivity is neglected due to the appeared new earth zero sequence current path.

The proposed concept is applied to a small percentage of line length at its middle part. The results are presented for different lengths of a transmission line. The PI-equivalent circuit for two port network is considered. A mathematical expression for the modified series impedance of a transmission line is deduced.

KEY WORDS :

Transmission lines, parameters, line chart, steady state, zero sequence, power limit.

INTRODUCTION :

In electrical power systems, the low power factor means a high current for the same active power, and this has three important factors. First, the line losses are proportional to the reciprocal of the square of the power factor. Secondly, the ratings of the generators and transformers are proportional to the reciprocal of the power factor, larger generators and transformers are thus required. Thirdly, low power factors are usually lagging, and this causes a large voltage drop, i.e. extra regulating equipment is therefore required [1].

It is already been known that the power factor can be improved by static and synchronous condensers [2]. The supply authorities use the synchronous condensers for voltage control and power factor improving to keep a high power factor through a tariff arrangement. The consumer also is encouraged to improve the power factor of his plant by the tariff, and this may be realized up to the economic limit. The calculations of the cost of any scheme is often difficult, as the cost varies considerably with time, tariff conditions and even with convention [1].

Both static and synchronous condensers are used to compansate the reactive part of power consumed in the power network. This reactive power is appeared due to the inductive and capacitive reactances of the power system elements such as generators, transformers and transmission lines.

In large power systems, the cost of the synchronous or static condensers which compansate for the reactive power consumed is increased considerably. This reactive power is decided by the inductive and capacitive reactances of its elements such as generators, transformers and transmission lines. It is known that the transmission line as the largest reactance in comparison with the other elements of the power system.

The rating of the condensers can be minimized by reducing the inductive reactance of transmission lines. This enhances the importance of studying the transmission line reactance.

PROBLEM FORMULATION :

The largest part of the inductive reactance is generated in the power system by the transmission line and so the return ground path parameters. Thus one of the most important elements in the power system is the overhead transmission lines [3]. They are basically circuits with distributed parameters.

It is erroneous to describe the transmission line parameters as being functions of time. Moreover the capacitances are voltage dependent when corona occurs [3]. In practice some of the salient features of these parameters are influenced by the geological structure and electrical properties of the earth in the neighbourhood of the line. The inductive parameters of the line over a homogeneous conducting earth with unit relative permeability can be considered [4]. However, in driving the earth resistivity from resistance measurements, the value of earth resistance is sometimes found to depend markedly on the electrode separation. This variation indicates a stratified earth [3].

Further investigation seems to be necessary before the effect of corona can be taken into account in calculations, particularly on the line, in which each phase consists of a bundle of separate conductors in parallel. However, it is customary to treat the capacitance as being independent of voltage and to neglect the earth conductance [3].

The conductor diameters are small in comparison with their separation so that the assumption that displacement currents within the earth are negligible, the capacitances can be considered as frequency independent [5].

It must be remarked that for switching operations in power system the circuit elements are subjected to voltages and currents containing a wide frequency range which may extend from 50 Hz to the region of 100 kHz. Over such a range the values of the system parameters and earth path are not constant but vary with frequency [3]. Transients in power system depend to a great extent on the properties of transmission lines (overhead and underground cables) and earth path parameters. The earth resistance is the most complicated element in calculations of transients and also unbalanced steady state loading.

For the above two reasons, choise of new earth path, free from the ground parameters, is needed. This new path must be the earth wires. It may be on the level above earth and under the phases of the overhead transmission line. These earth wires are considered to be at zero potential throughout its length, the order of parameter matrices (resistance, capacitance and inductance) can be reduced by matrix manipulation to that of the number of phases [3].

TRANSMISSION LINE PARAMETERS :

The new path of the earth current is considered. It must be a good earth along the line. This can be realized using sufficient number of tower footing resistances along the line [6]. The new path should be at a mean value of height (H) to give a constant separation between the phase conductor and the path as shown in Fig. 1. This figure shows the new and old pathes of earth current. Considering that the new path at zero potential the mirror effect is calculated. From Fig. 1. it is seen that :

$$h'_m = h_m + H \quad , \quad h'_n = h_n + H$$

$$D^2_{nm} = (h_n + h_m)^2 + d^2_{nm} - (h_n - h_m)^2, \quad D'^2_{nm} = (h'_n + h'_m)^2 + d^2_{nm} - (h'_n - h'_m)^2$$

It is known that the self and mutual potential coefficients obey the formula

$$\alpha_{nm} = 18 \text{ Ln } \frac{D_{nm}}{d_{nm}} \quad , \quad \alpha_{nn} = 18 \text{ Ln } \frac{2h_n}{r_{nn}}$$

where (r_{nn}) is the radius of the conductor. Also the self and mutual inductances are :

$$L_{nm} = 2 \times 10^{-4} \text{ Ln } \frac{D_{nm}}{d_{nm}} \quad ; \quad L_{nn} = 2 \times 10^{-4} \text{ Ln } \frac{2h_n}{r_{nn}}$$

We have now two cases : First, the new earth path and second, the old one, i.e. the ground path. The ratio of the parameter of the second case to the same parameter of the first case is defined as improvement factor (B).

The Improvement Factor :

The ratio of the two self parameters will take the form :

$$B = \frac{\text{Ln } (2k)}{\text{Ln } (2k - 2y)} \tag{1}$$

where $k = h/r$ and $y = H/r$

This equation can be rewritten as :

$$(0.5)^{B-1} \cdot (k - y)^B = k \tag{2}$$

It is cleared from equation (2) that the ratio of the earth conductors height to the radius of the phase conductor is a function of the ratio of the phase height to the conductor radius. This relation is calculated for different values of the suggested improvement factor (B) and the results are shown in Fig. 2. From Fig. 2 it is seen that the high values of the improvement factor, such as 1.5 or more can not be applied. That is the spacing between phase and ground wire will be less than the permissible limit.

The relation between the suggested height for the earth wires (H) and the improvement factor (B) is computed and drawn in Fig. 3. It is shown that the curves are saturated for all values of the ratio (k). Thus the required values of the improvement factor should be in the region up to B = 1.2, i.e. in the linear zone of the curves. Also, it is important to say that the maximum limit of the linear part is increased as the value of the ratio (k) is decreased. As the improvement factor is increased the power limit of the transmitted power will also increased due to the increased shunt capacitive reactance of the transmission line at constant sending end voltage. This means a saving in the costs of the required synchronous or static condensers at the end of the line.

The vector diagram for the short transmission line, neglecting the capacitive reactance is given in Fig. 4. It is locused for different values of the improvement factors.

From the vector diagram (Fig. 4) the efficiency of the transmitted power through the line can be calculated. This efficiency (η_k) is increased as the improvement factor is increased. The transmission efficiency excess is the ratio of the transmission efficiency with and without the improvement factor. It can be driven in the form :

$$\eta_k = \frac{\cos \phi_{2k}}{\cos \phi_2} \cdot \left[\left(1 - \frac{I_1}{V_1} \sqrt{R^2 + \frac{\omega^2 L^2}{k^2}}\right) / \left(1 - \frac{I_1}{V_1} \sqrt{R^2 + \omega^2 L^2}\right) \right] \qquad (3)$$

where ($\cos \phi_{2k}$) is the power factor at the receiving end for the factor (k) ;

(I_1) and (V_1) are the current and voltage at the sending end, respectively; and (R, L, ω) are the resistance, inductance and the angular frequency of the system.

The conductor height to its radius ratio (k) is a function of the improvement factor. This relation is drawn in Fig. 5 which gives the curves for constant receiving end conditions such as the 1/4, 1/2, 3/4 and full load currents. From equation (3) and Fig. 5, the relation of the ratio of the sending end voltage at with and without the improvement factor for different values of currents can be computed. This relation must be a function of the improvement factor (B). The results of calculations are shown in Fig. 6, where (V_{sk}/V_s) ratio as a function of factor (k). The most important factor (power factor) is given in Fig. 7 as a function of the improvement factor.

APPLICATION :

The proposed idea can not be implemented along all length of a transmission line. The economic criteria will prevent such use. On the other hand, the application of the given technique along a small length of a line may produce good results.

Using the concept of equivalent circuit of the two port network for the electrical representation of a transmission line, the equivalent circuit of a studied overhead line can be given as shown in Fig. 8. In this figure the middle PI-circuit represents the small section of a line, under which the earth path must be implemented. Its length is given as β as a percentage value of the total length of the studied transmission line. The other two PI-terminal parts are the equivalent circuit for the remainder length of a line.

The shown equivalent circuit of Fig. 8 must be simplified to its equivalent single PI-circuit as drawn in Fig. 9. The series impedance of equivalent PI-network will be expressed mathematically in the form :

$$\frac{Z}{R + j\omega L} = X + j\,F \tag{4}$$

where Z : the series impedance of modified transmission line,

R+jωL: the series impedance of the original transmission line without any modification.

X : the real port for the increased value of series impedance due to the application of proposed idea.

F : the imagenary part for the increased value of series impedance due to the application of given technique.

The real term X can be finally formulated as

$$\begin{aligned} X = 1-\beta+\alpha\beta- \frac{\omega^2 CL}{4}\,\beta(1-\beta)\left(\frac{1-\beta}{2}+\alpha\beta\right)^2-\omega^2C^2(R^2+\omega^2L^2)\,\alpha\beta(1-\beta)^3 \\ \left(\frac{1-\beta}{2}+\alpha\beta\right) \end{aligned} \tag{5}$$

In this expression (5) the coefficient α means the ratio of the specific impedance of middle section to that of a transmission line without any modification. This may be written as :

$$\alpha = \frac{R_1}{R} = \frac{L_1}{L} = \frac{R_1 + j\omega L_1}{R + j\omega L} \tag{6}$$

Equation (6) is used in order to reduce the deduced formula and its application may be practically realized. On the other side, the imajenary term F for the ratio of series impedance is simplified by the form :

$$F = \frac{\omega^3 C^2 LR}{16}(1-\beta)^2 \alpha\beta\left(\frac{1-\beta}{2} + \alpha\beta\right) + \frac{\omega CR}{4}\beta(1-\beta)\left(\frac{1-\beta}{2} + \alpha\beta\right)^2 \qquad (7)$$

Now, the determined ratio of Z/(R+j L) should be analysied, for this reason, a 500 kV transmission line is considered. Its parameters for different value of line length are listed in Table 1.

Both expressions of real and imajency terms X and F of the ratio of impedance after modification to that before modification can be simplified in the form :

$$\begin{aligned} X &= 1-\beta+\alpha\beta-Q\beta(1-\beta)\left(\frac{1-\beta}{2}+\alpha\beta\right)^2 - S\alpha\beta(1-\beta)^3\left(\frac{1-\beta}{2}+\alpha\beta\right) \\ F &= M\alpha\beta(1-\beta)^2\left(\frac{1-\beta}{2}+\alpha\beta\right) + N\beta(1-\beta)\left(\frac{1-\beta}{2}+\alpha\beta\right)^2 \end{aligned} \qquad (8)$$

where Q, S, M and N are constants. Their values depend on the line length.

Using the parameters of a transmission line (Table 1) at each length, the constants Q, S, M and N can be computed. The results of calculations are tabulated in Table 2.

The real term X as well as the term F are evaluated for the given lengths. The results are drawn in Fig. 10 while it is seen that the term F can be neglected for all studied lengths. But is must be noted that its value is increased with increasing the line length. This means that the ratio between modified impedance Z and original series impedance (R + jωL) may be expressed accurately by

$$Z / R + j\omega L = X \qquad (9)$$

Now, different conditions for the percentage length β, in the region of 0.1 ÷ 0.3, with many values of coefficient α, in the range 1.1 ÷ 1.5, are considered. The results of calculations are shown in Fig. 11..

From Fig. 11, it is seen that good results may be acheived for smaller percentage length β with more higher coefficient α. Thus, smaller values of percentage length β such as 0.05 as well as 0.01 should be investigated. The coefficient α will be the same in this case. The results of calculations are presented in Fig. 12. It is seen that at line length of 100 km, the results for conditions β = 0.05, 0.1 and 0.2 are the same. This means that the modification can be realized by 5 or 10 or 20 km in 3 order to give the same results. It is clear now to modify only 5 km is better. On the other hand, the increase in the value of coefficient α can be realized by using the spiral conductors to give the required value. Also, the reduction in the percentage length means that the proposed solution is more economic. Although the modification for the parameters of a transmission line with larger length should be the best, the results prove that it is bad. For example at 100 km, the modification is larger then at 200 km and so on. This proves that the sectionalization for the overall length of a transmission line may be needed.

As this phenomena is appeared, the 5 km length can be devided into 5 parts, for example, in order to determine the same modified characteristics. Also, smaller percentage length β may be used so that an economic criteria for such a problem may be required. As the modified characteristics are improved with smaller percentage length β, the overall characteristics for all values of line length, especially for longer lines, are greatly modified.

Thus, if the above technique is applied to different sections of transmission lines by different values, a controlled parameter transmission line may be found. Otherwise, a certain defined parameters can be acheived by controlling the investigated technique. This phenomena may be utilized with the controlled type transmission lines [7].

CONCLUSIONS :

The use of ground wires principle gives a new reactive part of the transmission line impedance. Using the given idea the power factor can be improved. The transmitted power must be increased.

A formula for the improvement factor is derived. The inductance and potential coefficient of transmission line are increased with increasing the value of improvement factor.

The earth return effect can be neglected. This simplifies the process of transient calculations in transmission lines.

The proposed concept can be economically implemented at small sections of a transmission line. The smaller percentage modified length appears as the best.

The suggested technique is recommended for the design of transmission lines. The parameters of a transmission line can be controlled.

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Table 1.

The parameters of studied transmission lines

Length,km Parameter	100	200	300	400	500
Resistance, ohms	17.2	34.4	51.6	68.8	86.0
Inductance, H	0.218	0.436	0.654	0.872	1.09
Capacitance, μF	1.36	2.72	4.08	5.44	6.80

Table 2.

The derived constants for studied lines

Constant Line length	Q	S	M	N
100	7.3079×10^{-3}	28.389×10^{-6}	13.419×10^{-6}	1.836×10^{-3}
200	29.23×10^{-3}	454.22×10^{-6}	215.499×10^{-6}	7.345×10^{-3}
300	65.77×10^{-3}	2.2995×10^{-3}	1.08697×10^{-3}	0.0165
400	0.1169	7.268×10^{-3}	3.435×10^{-3}	2.938×10^{-3}
500	0.1827	0.0177	8.387×10^{-3}	4.59×10^{-3}

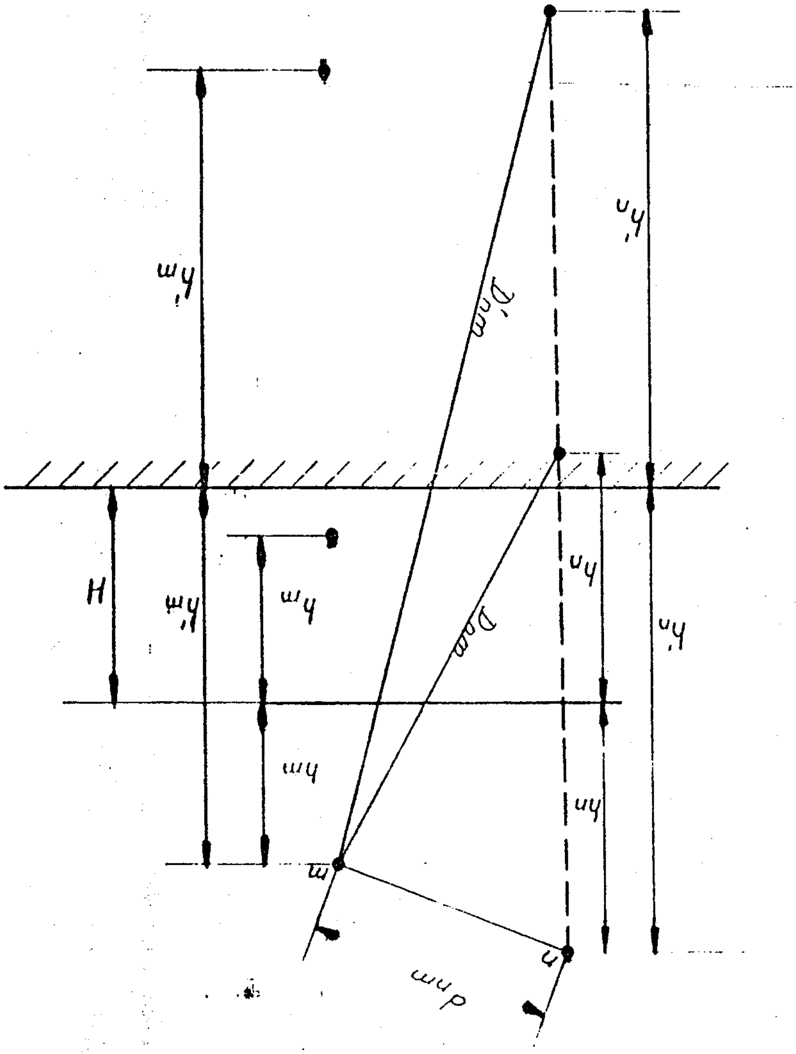


Fig. 1. Conductor geometry with new earth wire path.

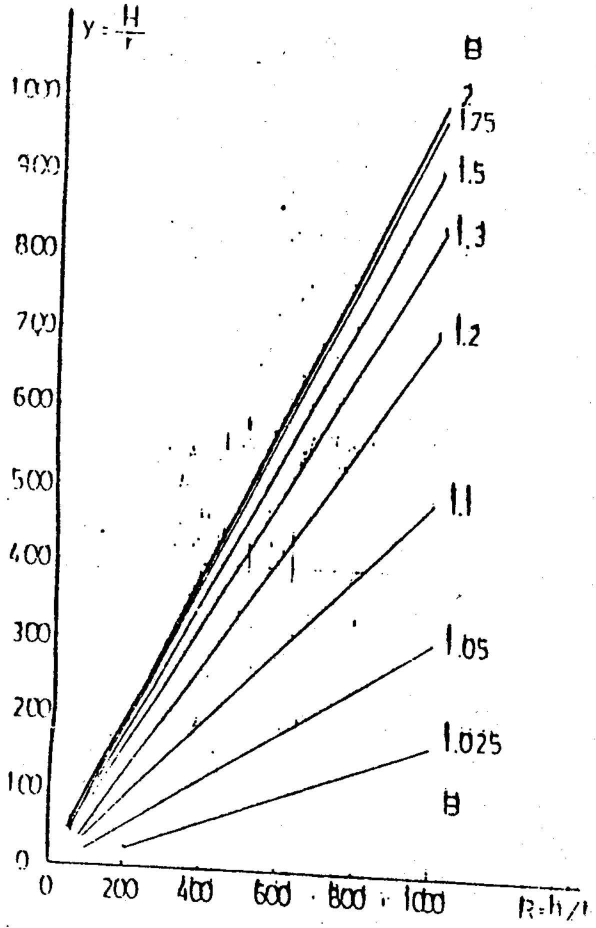


Fig 2. Earth wire height to phase coductor height relation

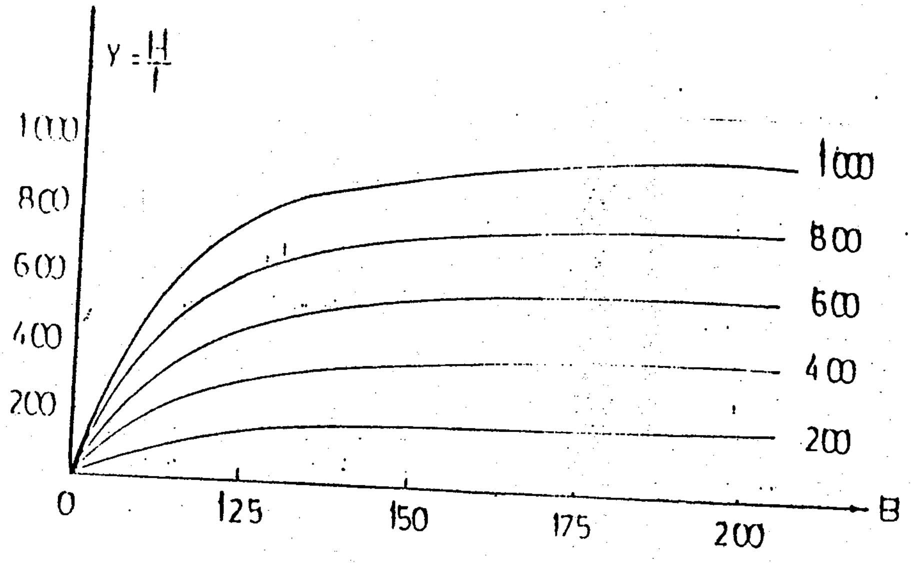


Fig 3. Earth wire hight improvment factor relation

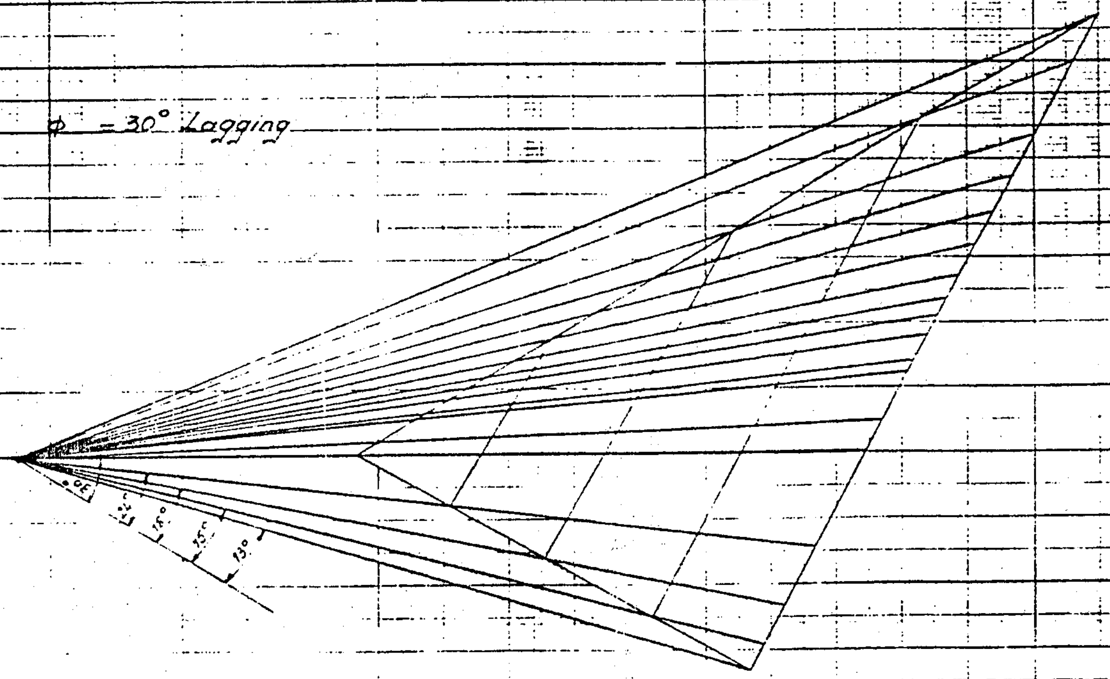
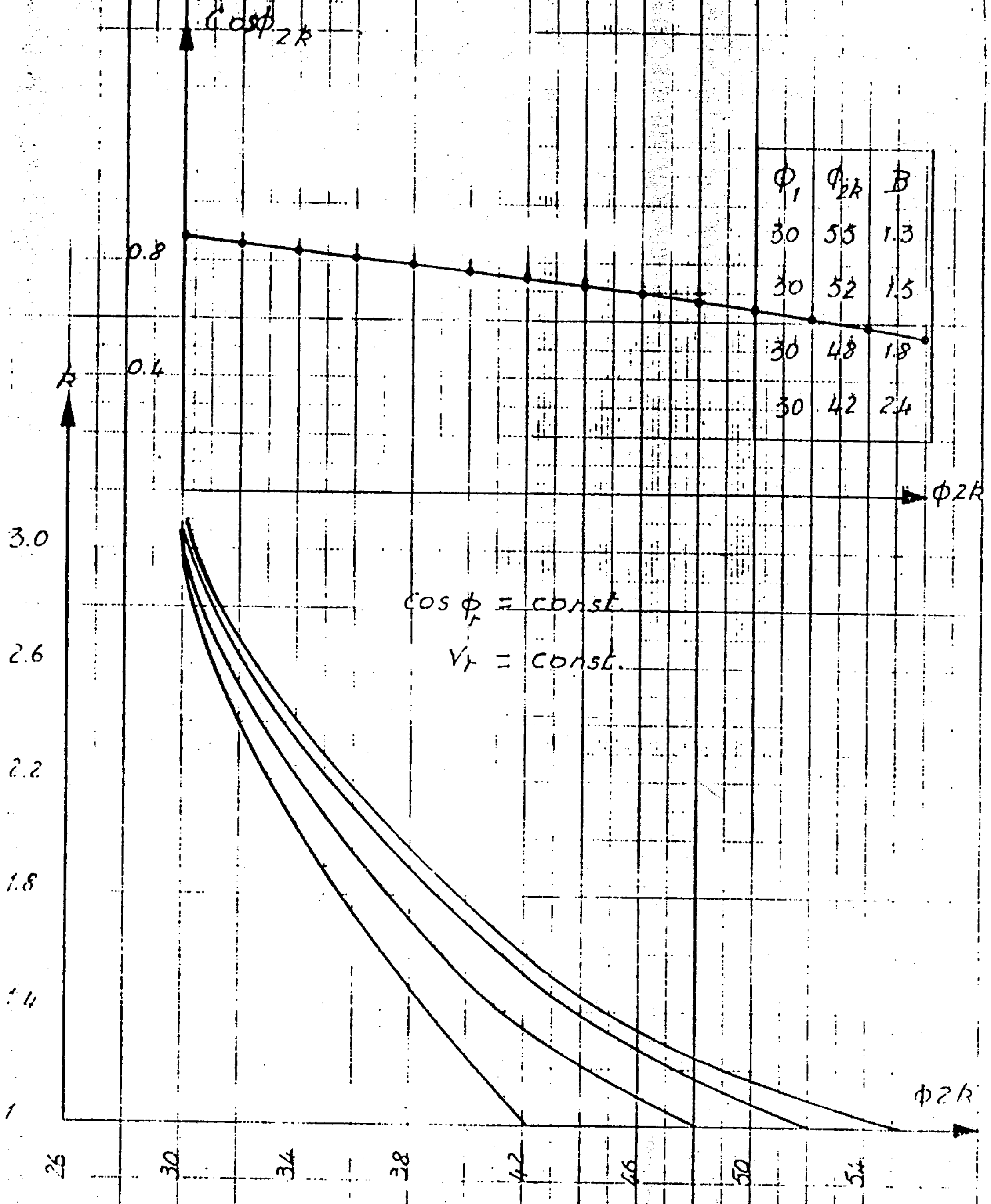


Fig. 4. The vector diagram



ϕ_1	ϕ_{2k}	B
30	55	1.3
30	52	1.5
30	48	1.8
30	42	2.4

Fig. 5. The calculated phase conductor height.

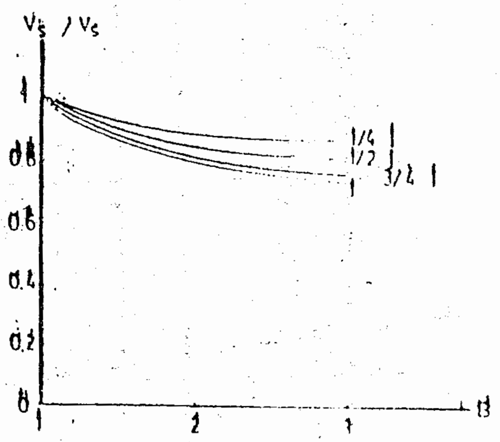


Fig. 6. Ratio of voltage increase with varying the value of improvement factor.

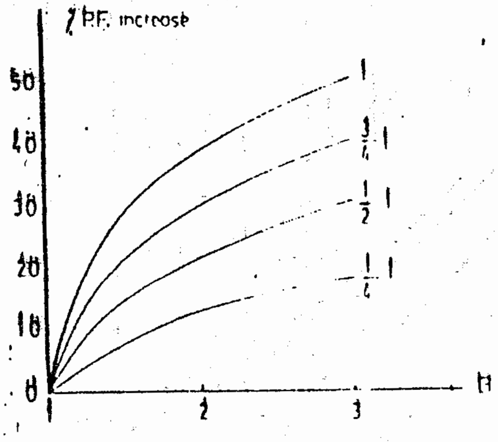


Fig. 7. The relation ship between power factor and improvement factor.

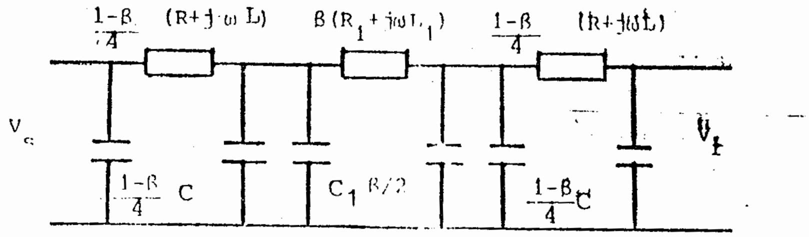


Fig. 8. The equivalent circuit for the proposed transmission line with modification.

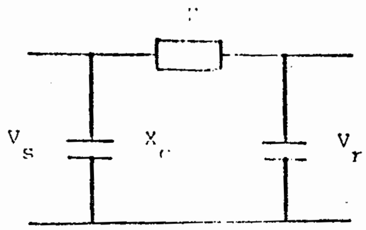


Fig. 9. The equivalent single PI-circuit of modified transmission line.

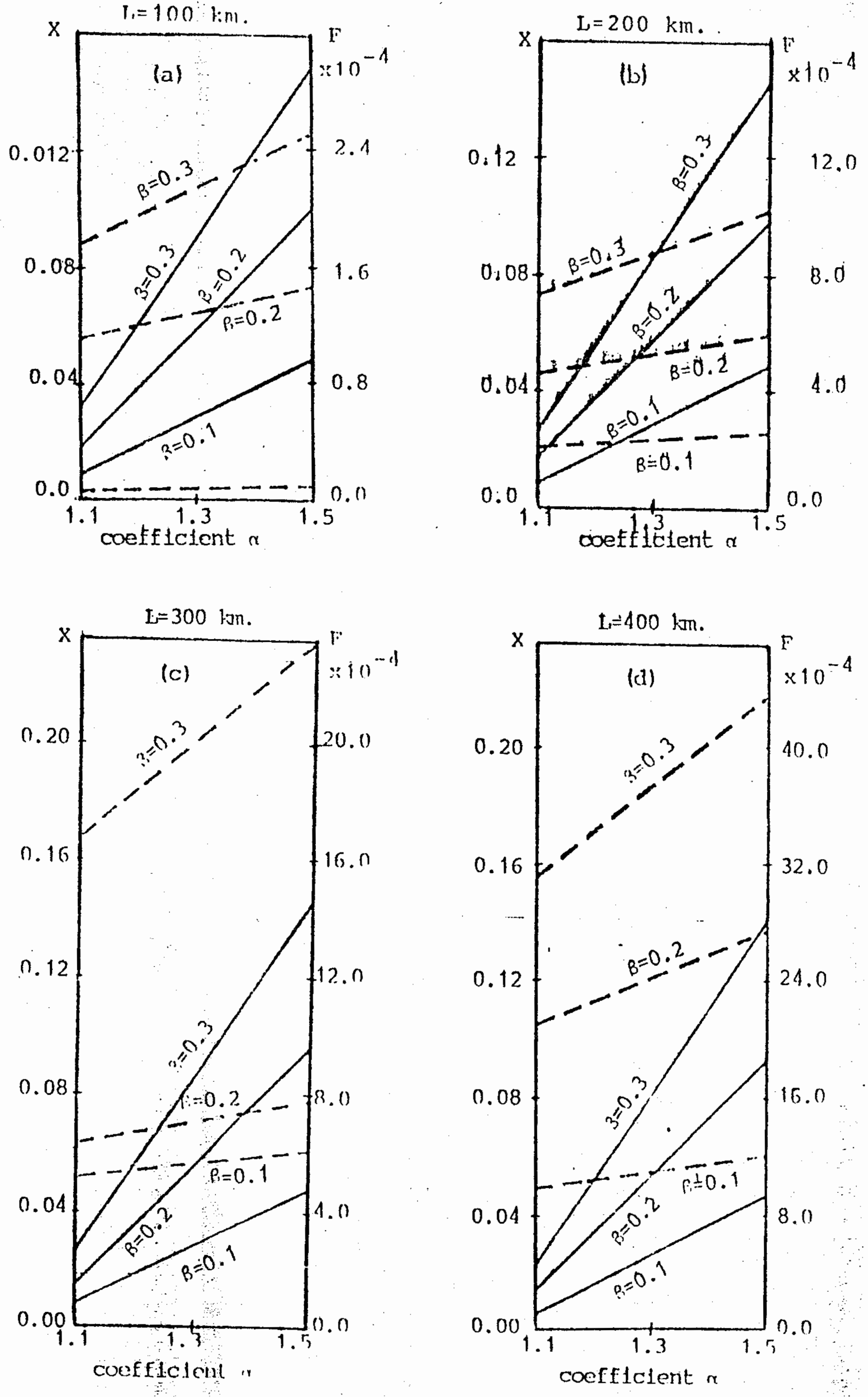


Fig.10. The calculated real and imagenary terms for the increase in the modified impedance.
——— X , ----- F

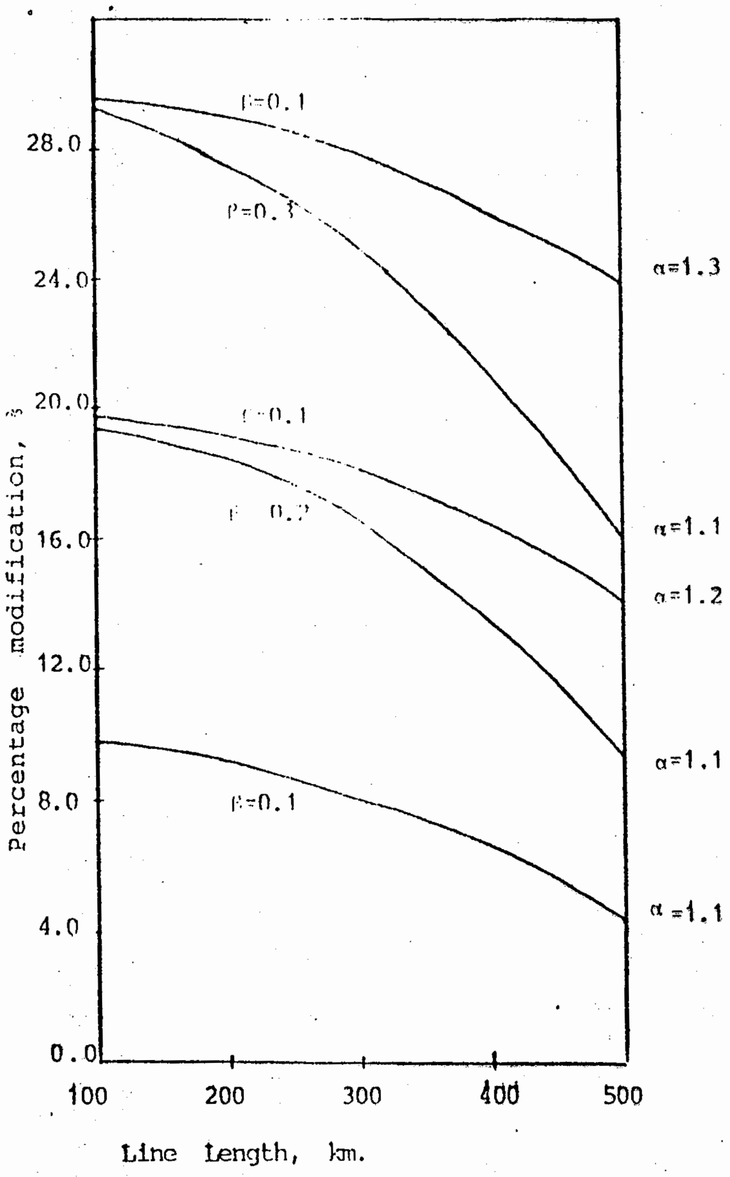


Fig.11. The relationship between the increase of modified impedance and line length.

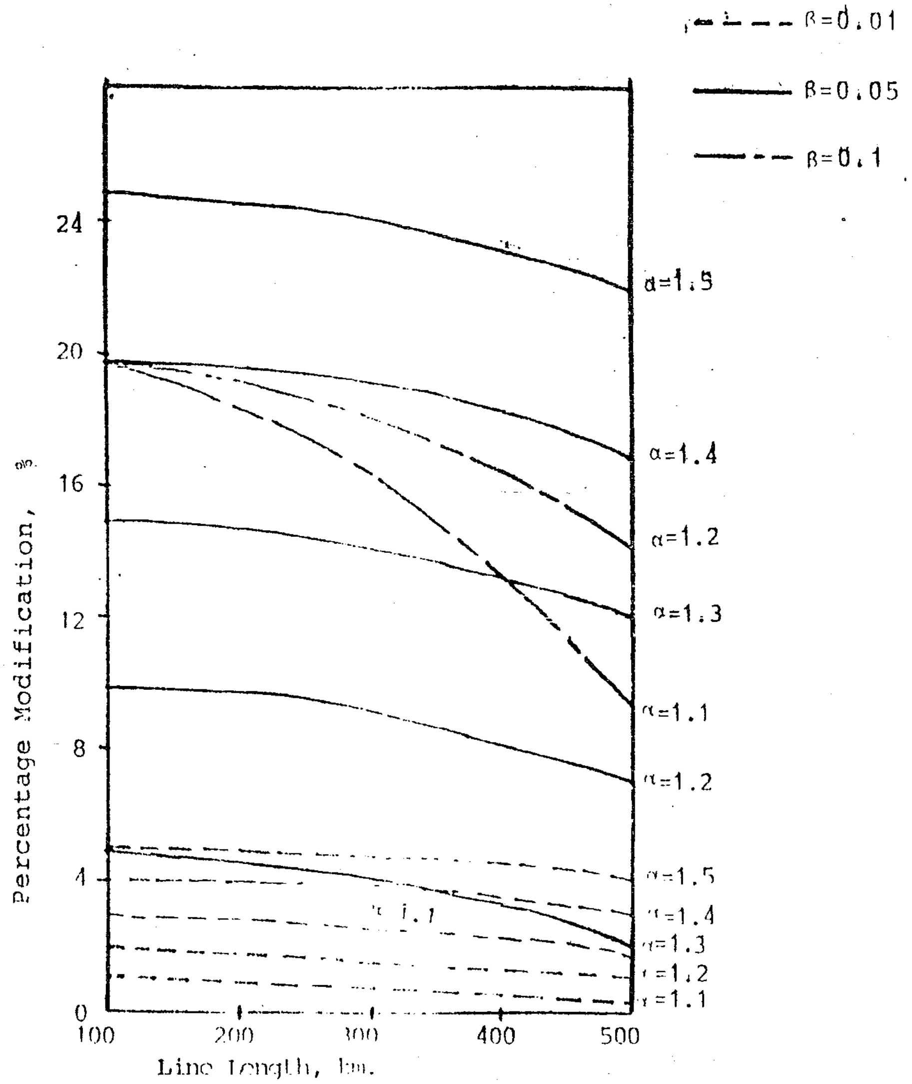


Fig. 12. The variation of modified impedance at different percentage values β and α,