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REDUCTION OF ENERGISATION OVERVOLTAGES ON CABLE/OVERHEAD-LINE SYSTEMS USING SHUNT REACTIVE COMPENSATION

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Abstract:

The waveshapes and magnitudes of overvoltages produced by the energisation of cable/line transmission systems depend on the relative position of the cable and the overhead line with respect to the energising source as well as, on the value of the source inductance. The effects of these two factors are investigated using a computer program on a three-phase basis. Under some circumstances, the overvoltages produced may be far more severe than those produced in transmission circuits consisting of overhead lines alone. The use of shunt-reactive compensation has proved to be advantageous, particularly in these cases where a cable/line system is being energised from a highly-inductive source. Moreover, it is found that the reduction in overvoltages is further increased for the same compensation value, when shunt reactors are distributed at both ends of the transmission system than when they are cocentrated at one end only.

1. INTRODUCTION:

For many years the problem of overvoltagee caused by switching of transmission systems has been given much attention[1,2,3,4]. Once the maximum operating voltage of a system is established, the insulation requirements are basically determined by overvoltages that may occur on the system, especially those caused by energisation operations. It is therefore of great importance to system designers and engineers, to experience the conditions under which dangerous energisation overvoltages may occur on the system and to have the means for assessing, and consequently reducing, their magnitudes.

However, most the work carried out in this field[1,2,3,4,5] was directed towards systems involving overhead lines only. Yet, underground-cable/overhead-line systems are commonly used in power systems to transmitt bulk electrical power at nearly all voltage levels[6,7]. Energisation of such systems[8,9] has nevertheless not received the attention that has been devoted to simple overhead-line systems. Though, under certain conditions, the overvoltages produced may be far more severe.

The first objective of this paper is to present a computer study based on the lattice-diagram method[10] into the magnitudes and waveshapes of overvoltages caused by energising underground-cable/overhead-line systems, and to illustrate the effect of interchanging the cable and line positions in the system. Three-phase systems are considered and the effect of varying source-inductance value on these overvoltages is also investigated. The second objective of the paper is to demonstrate the effect on these overvoltages of applying shunt reactive-compensation at either the sending-end or both ends of the transmission system. For all cases, the three phases are assumed to be energised simultaneously.

2. THE ENERGISATION OF UNDERGROUND-CABLE/OVERHEAD-LINE TRANSMISSION SYSTEMS:

When a circuit is being energised, the actual instant of energisation may occur when the voltage across the circuit-breaker is at or about its maximum value and results in the application of a voltage step of the order of peak phase-to-neutral voltage, to the circuit being energised[1,2,4,8]. In the case of a cable-line combination this step of voltage is applied to the first circuit (cable or line) of the combination and produces a transient voltage in this circuit which may exceed the original step by a considerable margin. The first circuit then acts as a source and its transient voltage is applied to the second circuit (line or cable) of the combination to produce an even larger transient voltage in that circuit. This phenomenon is sometimes referred to as "surge magnification" and under some conditions much larger overvoltages are produced than if one of the circuits is energised on its own. The magnitude of the overvoltage produced depends upon the energy interchange between the two circuits which in turn depends upon the values of their parameters.

2.1 Effect of cable and line position in the energised system:

Consideration of the conditions at the junction of the line and cable will show that because the surge impedance of the line is much larger than that of the cable, the associated transmission coefficient[2,10] at the junction will have a value greater than unity and may approach a value of 2.0. Consequently, if the system is energised (as a single unit) at peak voltage from the cable end, a travelling wave of almost 2.0 p.u. will occur at the junction and a voltage approaching 4.0 p.u. will be received at the open-circuited end of the line.

On the other hand if the system is energised from the line end, the transmission coefficient for waves coming from the line to the cable is much less than unity with the result that the voltage at the open-circuited end of the cable will have a much slower wavefront than in the previous case.

The voltage waveforms obtained in the first case are shown in Fig.1 and those of the second case are shown in Fig.2. In both cases, the system losses are included which resulted in overvoltage values slightly lower than those mentioned above.

2.2 Effect of source impedance:

The above results are obtained with an infinite source, i.e. when the source is of zero impedance or of low resistance value. When energising from the cable end, this type of source results in more rapid changes of voltage than arise in the case of energising from an inductive source.

Fig.3 shows the effect of varying the source inductance on both the magnitudes and waveshapes of the received end voltage. Compared with the waveforms of Fig.1, it can be seen that the larger the source inductance the greater is the time constant of the ascillation and hence, the lower is the oscillation frequency which is superimposed on the source 50 Hz component. For example, the frequency of oscillation is over 1000 Hz for zero-inductance source, about 370 Hz for 0.034 H inductance, and decreases to about 62 Hz for the 1.0 H source.

Conditions are not so straight however, when the maximum overvoltage magnitudes are considered. Whereas the maximum value of overvoltage decreases with increasing values of source inductance, situations are reveresed with the larger values of source inductance. The reason is that, increasing the source inductance beyond a certain value drives the system to go into a series resonance with the source inductance. The result is a continuous increase in overvoltage magnitude as the frequency of oscillation approaches the 50 Hz value. This condition is much clarified when examining the waveforms of Fig.3(d) obtained for a 1.0-H source inductance.

3. REDUCTION OF OVERVOLTAGES BY THE USE OF SHUNT-REACTIVE COMPENSATION:

Shunt-reactive compensation, particularly inductive, have been successfully used to reduce the magnitudes of energisation overvoltgaes occuring on overhead lines[2,5]. To the authors' knowledge, however, the application of shunt-reactor compensation to perform the same duty on composite cable/line transmission systems has been given none or little attention. Provided that the reactors are connected to the transmission system at the time of energisation, it is found that a reduction in overvoltage magnitudes is brought about. Their use is found to be particularly advantageous when the natural frequency of the source inductance and the cable/line system approaches the supply frequency value. This is illustrated by Figs.4&5 where shunt reactors of value 5.093 H each, corresponding to 100 MVAr rating on 400-kV basis, are connected at the sending-end and at both sending and receiving ends, respectively. Comparison with the results of Fig.3(d) shows that the maximum overvoltage value is reduced from over 3.6 p.u. for no compensation to about 2.79 p.u. for 100-MVAr compensation connected at sending end, and to about 2.04 p.u. for 200-MVAr compensation distributed at both ends.

The reduction in maximum overvoltage is illustrated further by the curves of Figs.6 & 7, which show the variation of maximum overvoltage, as a percentage of that obtained without compensation, with the source inductance for the same composite transmission system considered before. The curves of Fig.6 are obtained when the whole compensation MVAr value is applied at the sending-end alone. Those of Fig. 7 are for the case when the compensation MVAr value is divided equally between the sending and the receiving ends of the energised system.

As it has already been pointed out, the curves of Figs. 6 and 7 show that the maximum overvoltage magnitude is reduced considerably for the larger values of source inductance; i.e. for the cases when the dominant frequency of the transient voltage approaches that of the power-frequency value. Also, for all cases considered, the percentage reduction in maximum overvoltage increases almost linearly with source inductance. Moreover, it may be seen that, for the same value of MVAr compensation, larger decrease in overvoltage values are obtained when the shunt reactors are distributed equally at both ends rather than connected at one end alone. This fact is realised when the bottom curve of Fig. 6 is compared with the top curve of Fig. 7, where the total compensation for each case amounts to 200 MVAr.

4. CONCLUSIONS:

It is clear now that energisation of a cable/line transmission system as a single unit, can lead to the production of overvoltages which may under some circumstances be far more severe than those produced in transmission circuits consisting of overhead lines alone. Conditions may greatly be improved if energisation is taken place from the line end of the energised system which suggests that there is a best end from which to energise the system. This may however not always be possible in practice, in which case shunt-reactor compensation will offer the remedy.

The results of this study show that the presence of shunt reactors becomes increasingly important as the parameters of the source, from which the cable/line system is being energised, together with those of the system itself, are of values such that resonance conditions are being approached. In these cases, the reduction effect imposed by the shunt-reactive compensation on the magnitudes of energising overvoltages becomes considerable.

Moreover, the study shows that, for the same value of compensation MVAr, the reduction in overvoltage magnitudes is further increased, though slightly, in cases where shunt reactors are distributed at both ends of the transmission system than in cases having only one end shunt-compensated.

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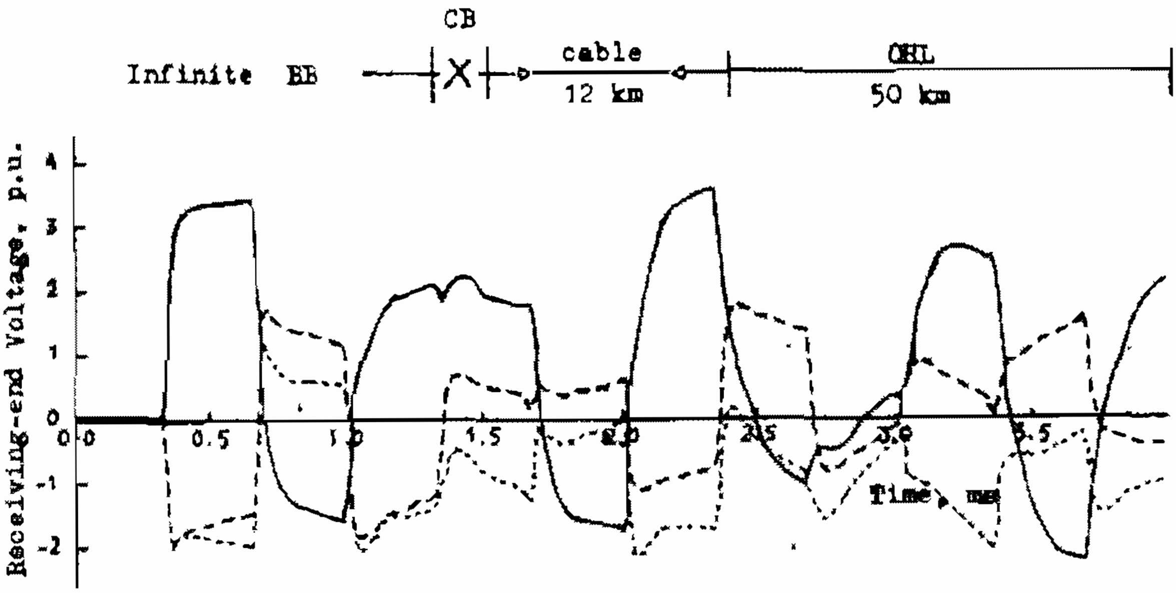


Fig. 1: Transient voltage at receiving end due to energisation at cable end. Maximum overvoltage = 3.453 p.u.

Notice: For all voltage waveforms the following identification applies

———— Phase 1 ·············· Phase 2 – – – – – – – – Phase 3

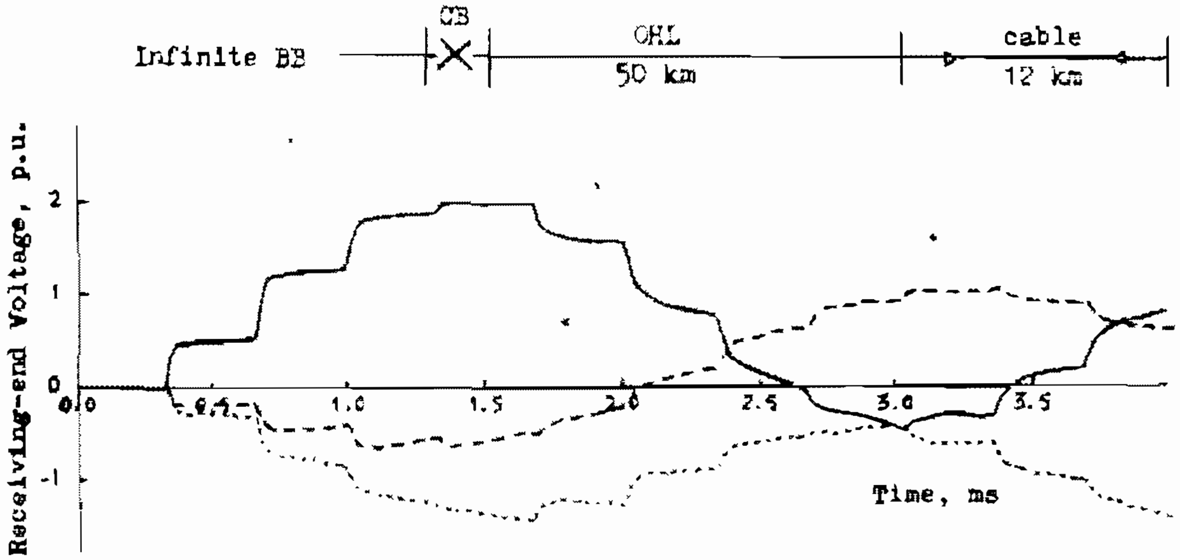
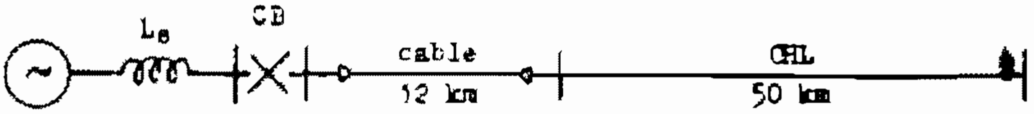
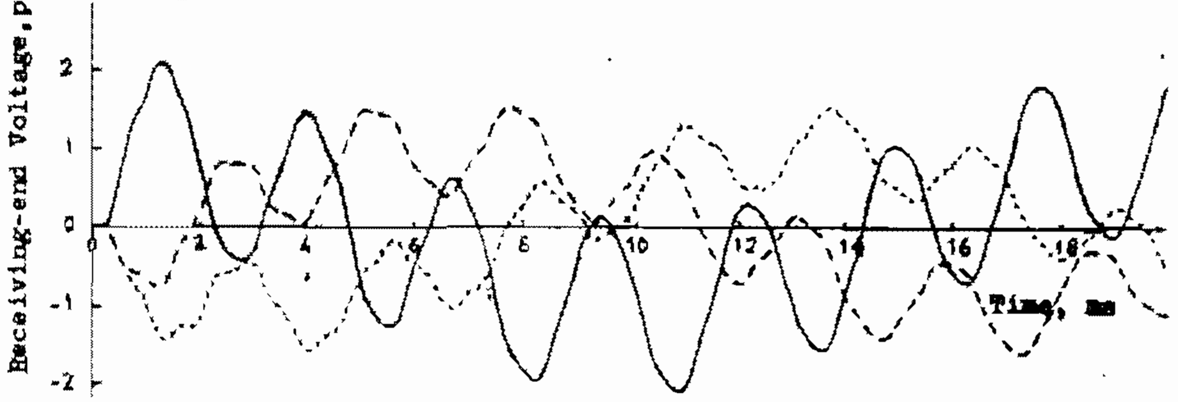
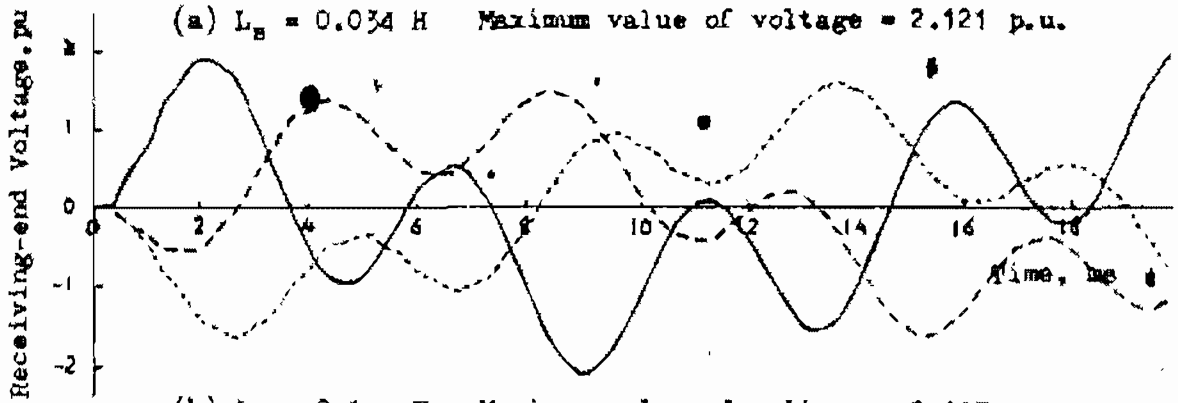


Fig. 2: Transient voltage at receiving end due to energisation at line end. Maximum overvoltage ≅ 2.0 p.u.

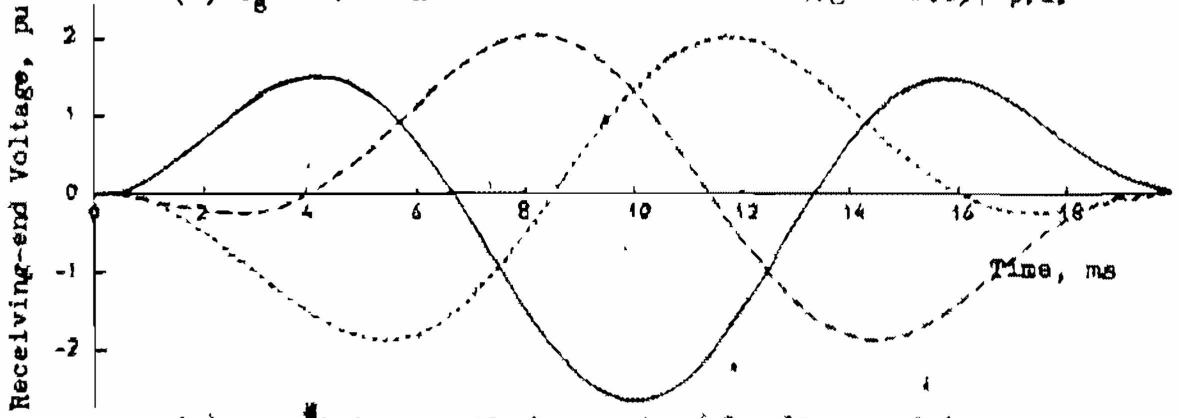




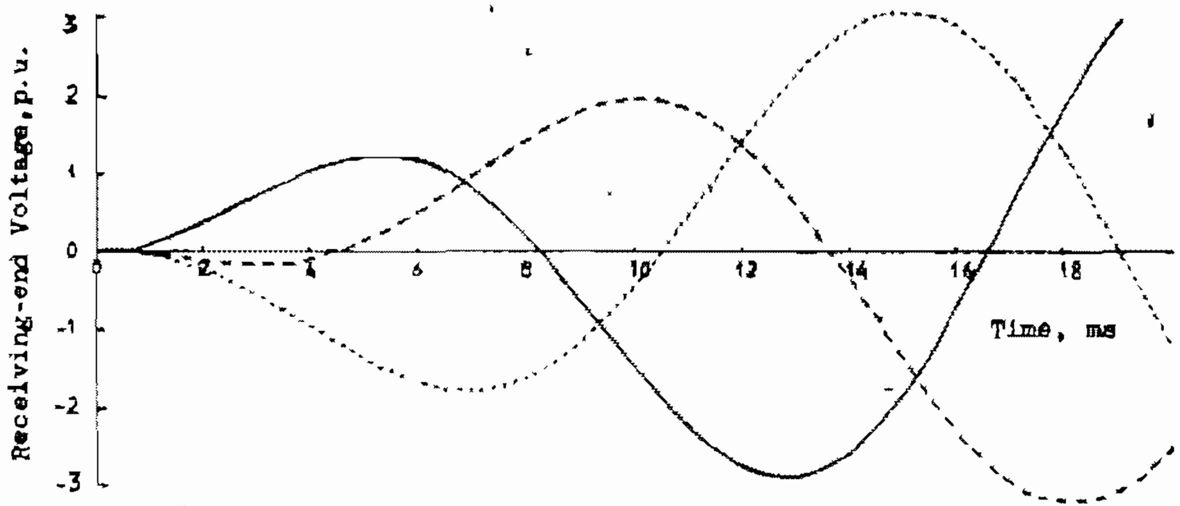
(a) L_s = 0.034 H Maximum value of voltage = 2.121 p.u.



(b) L_s = 0.1 H Maximum value of voltage = 2.097 p.u.



(c) L_s = 0.5 H Maximum value of voltage = 2.644 p.u.



(d) L_s = 1.0 H Maximum value of voltage = 3.616 p.u.

Fig. 5: Effect of varying the source inductance on receiving-end transient voltage.

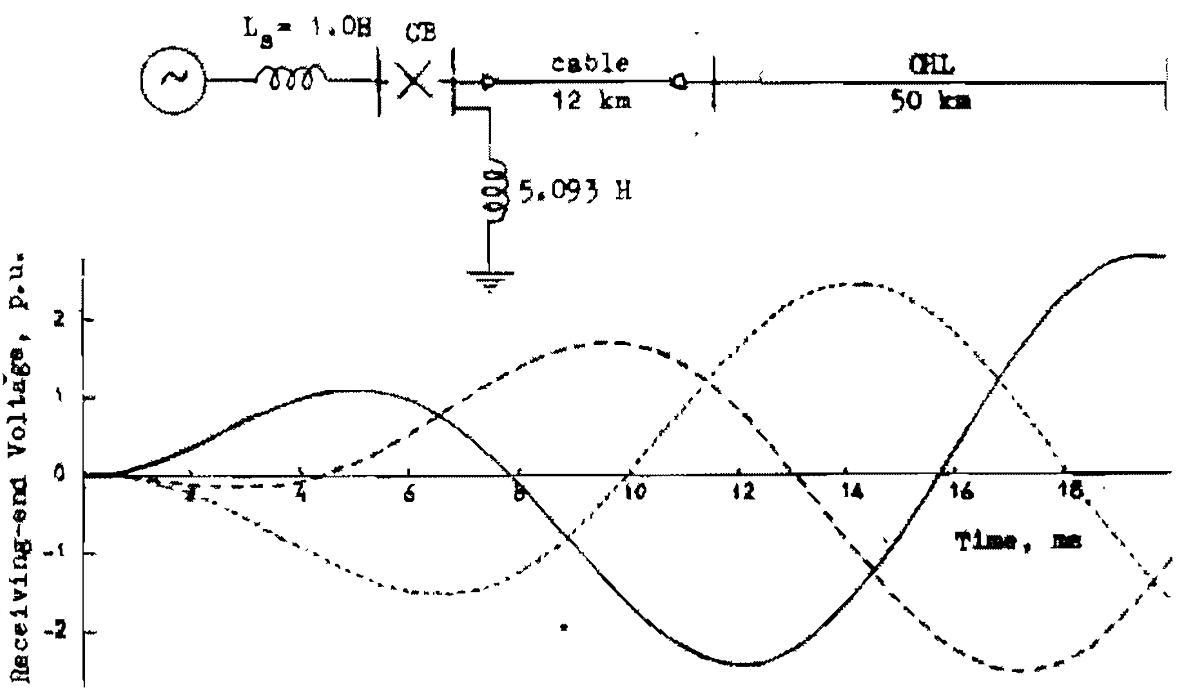


Fig. 4: Effect of shunt-reactor compensation at sending-end on the receiving-end voltage. Maximum value = 2.792 p.u.

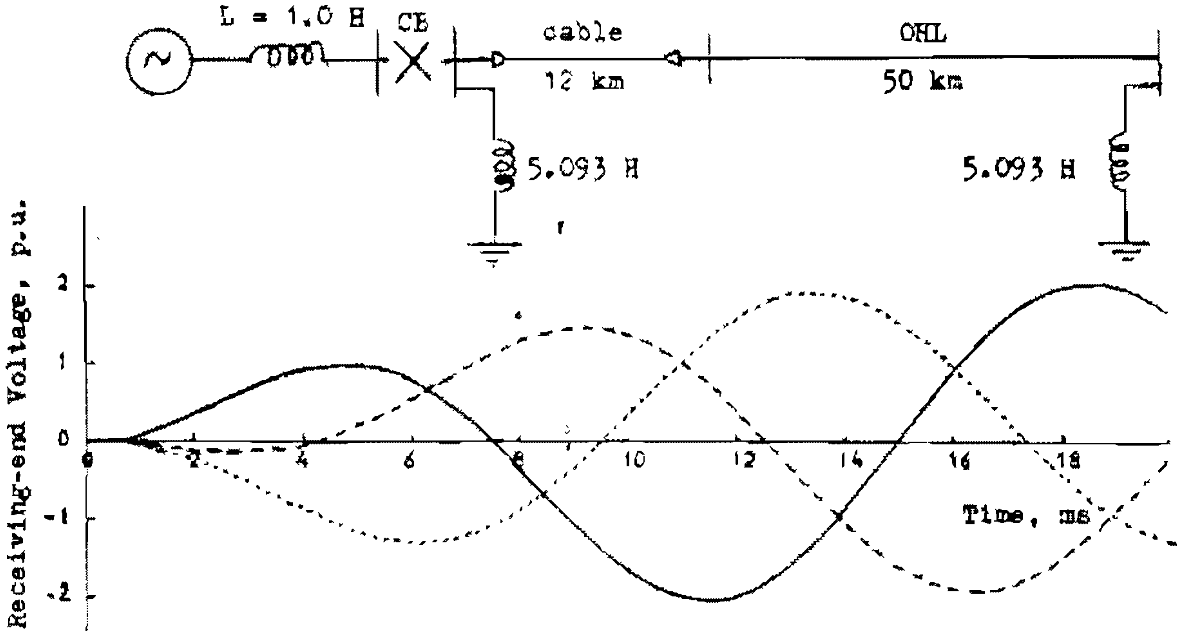


Fig. 5: Effect of shunt-reactor compensation at both sending and receiving ends on the receiving-end voltage. Maximum value = 2.044 p.u.

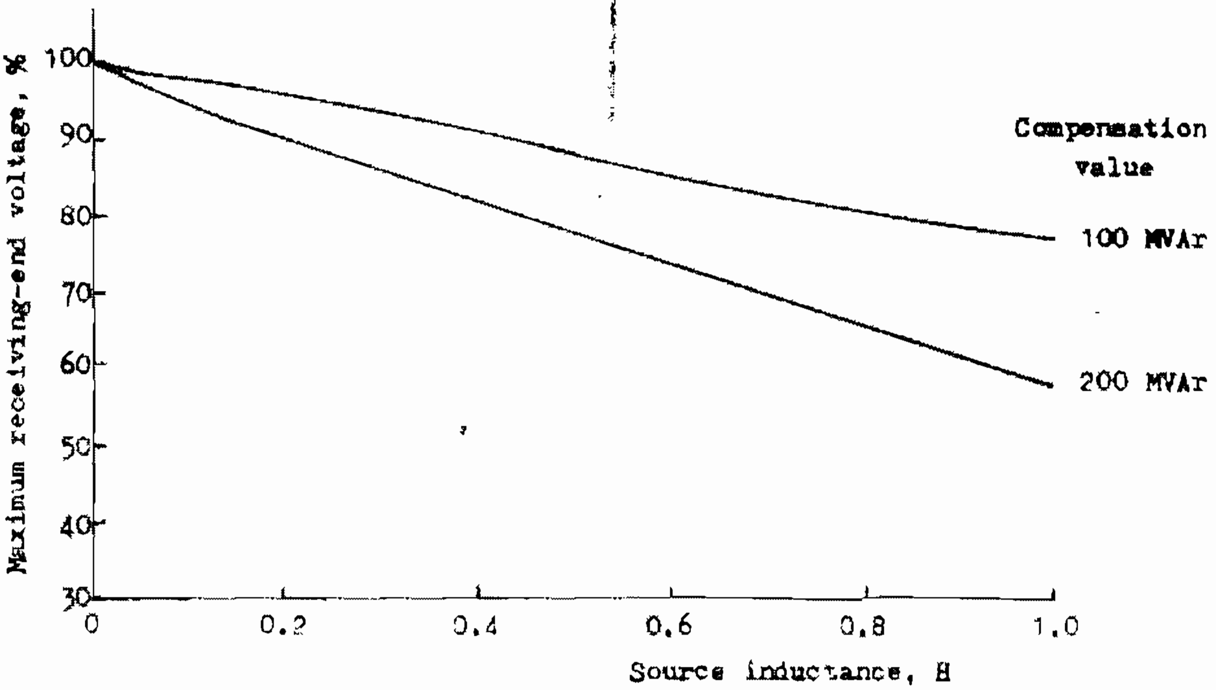


Fig. 6: Maximum overvoltage as a percentage of that without compensation. Shunt-reactor compensation connected at sending end.

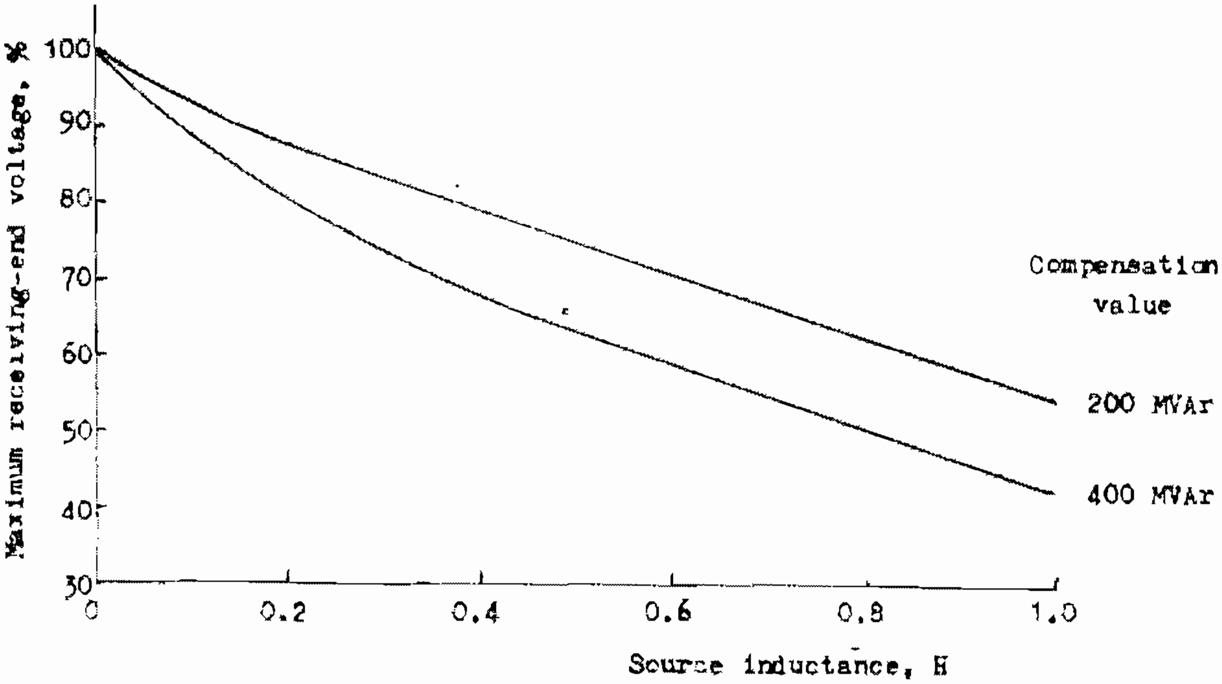


Fig. 7: Maximum overvoltage as a percentage of that without compensation. Shunt-reactor compensation distributed at both ends.