Transmission Efficiency Optimization for the operation of double-circuit Overhead Lines (OL)

by

Thales M. Papazoglou
Electric Power Systems Lab (EPSL)
Electrical Engineering Department
The Technological Educational Institute of Crete

1. Abstract

The question of improving efficiencies of operation is nowadays more than ever considered a very critical issue. This is because losses have acquired recently an extra cost that of the CO_2 release penalty. It is well known that a good portion of the electricity required to operate a power grid is spent as Overhead Line (OL) power losses. In this paper the key points of the theory of maximum OL transmission efficiency are reviewed. The OL loading corresponding to the maximum transmission efficiency is given. Then by means of a case study it is shown how to optimize the transmission efficiency of double-circuit overhead lines for the periods of off-peak loading of the lines. The transmission efficiency vs. line loading curves of the OL are presented and the change of character from capacitive to inductive with increasing load of the OL is illustrated. The potential gains in percentage points of the transmission efficiency are calculated.

2. Introduction

It is well-known that about 3% of the power generated at anyone time in an Electric Power System (EPS) is lost in transmission (while about 6 % are distribution losses). About half of the transmission power loss is due to Overhead high-voltage Line (OL) losses. These losses are included as operating cost by the Transmission Companies (TRANSCO). Nowadays, the pressure to reduce electric power losses is greater because of the constraints of the deregulated market as well as the extra costs due to the additional CO_2 release penalty.

The efficiency of a transmission line depends on its loading. It can vary from zero, when the OL is energized but has no load, to a maximum value. Under nominal load the OL efficiency is quite high. As it will be clarified in the next section, for a given OL line there is a certain characteristic load that corresponds to the maximum efficiency of the line. Therefore, the greater the difference between the actual load of the line and the characteristic one, the greater the efficiency margin between the actual and the maximum transmission efficiency.

In the case of a light-to-medium loaded double-circuit OL, as we will see in section # 4, one can increase the transmission efficiency by either dividing the load between the two circuits or concentrating the load into the one circuit depending on the relation of the actual load and the characteristic load of the line for maximum efficiency.

3. Some elements of the theory of maximum transmission efficiency

In 1994 the author formulated comprehensively the theory of maximum transmission efficiency of OL [1]. Here, I will review the elements needed herein. Starting from the well-known equations of a long transmission line having '1' as sending end (or line-start) and '2' as receiving end (or line-end):

$V_1 = AV_2 + BI_2$

$I_1 = CV_2 + AI_2$

where: V is the phase voltage of the line and I the line current, and where A, B, C are the so-called generalized circuit constants of the symmetrical line – having the following expressions:

$$A = \cosh(\gamma l)$$

$$B = Z_0 \sinh(\gamma l)$$

$$C = \frac{\sinh(\gamma l)}{Z_0}$$

expressed in terms of the parameters of the overhead line, i.e. the line characteristic impedance: Z_0, the propagation constant: γ, and the line length: l.

The maximum efficiency of the transmission line is computed by the formula:

$$\eta_{\max} = |A|^2 + \mathrm{Re}(BC^*) - \sqrt{4\,\mathrm{Re}(AC^*)\mathrm{Re}(BA^*) - \mathrm{Im}^2(BC^*)}$$

where: "| |" denotes the magnitude of a complex number, Re and Im denote the real and imaginary parts of a complex number, and the asterisk "*" is used to denote the complex conjugate.

This maximum transmission efficiency occurs when the load of the OL corresponds to an equivalent impedance with a magnitude of:

$$\zeta = \sqrt{\frac{\mathrm{Re}(BA^*)}{\mathrm{Re}(AC^*)}}$$

and, with a phase-angle θ such that:

$$\sin\theta = -\frac{\mathrm{Im}(BC^*)}{2\sqrt{\mathrm{Re}(AC^*)\mathrm{Re}(BA^*)}}$$

Now, if we let V_L be the line voltage at the load, then the line load corresponding to the condition of maximum transmission efficiency is:

$$P_e = V_L^2 \frac{|A|^2 + \mathrm{Re}(BC^*) - \eta_{\max}}{2\,\mathrm{Re}(BA^*)}$$

As it turns out this characteristic load P_e of the OL, which is computed solely from the electrical parameters of the line, regardless of the actual load coefficient, indicates where the transmission efficiency is maximized.

4. The transmission efficiency curves

Now, I will consider as case study a 220 kV line of 250 km length with the following parameters:

$$\gamma l = 0.2756\angle 85°$$

$$Z_0 = 408.25\angle -4° \quad ohm$$

$$A = 0.963\angle 0.387° \quad , \; B = 111.044\angle 81.13° \; ohm \quad , \; C = 6.66x10^{-4}\angle 89.13° \; S$$

For this line, the maximum transmission efficiency is: 97.13 %, which is computed by the formula given in the previous section. It means that, regardless of load this value for the transmission efficiency is the highest possible. As the line is loaded to its capacity, the transmission efficiency drops (see figure 1). The characteristic load P_e, for this line (corresponding to the maximum transmission efficiency), is:

P_e= 41.31 MW

For a double-circuit this will correspond to a total of 82.62 MW. So that, it turns out that, if a double-circuit line of the specifications above, at a given instant, has more than 83 MW to deliver, clearly sharing this load into two equal halves between the two circuits increases the transmission efficiency. This is regardless of the load coefficient as it can be seen from the following Transmission Efficiency Curves (TEC) of figure 1.

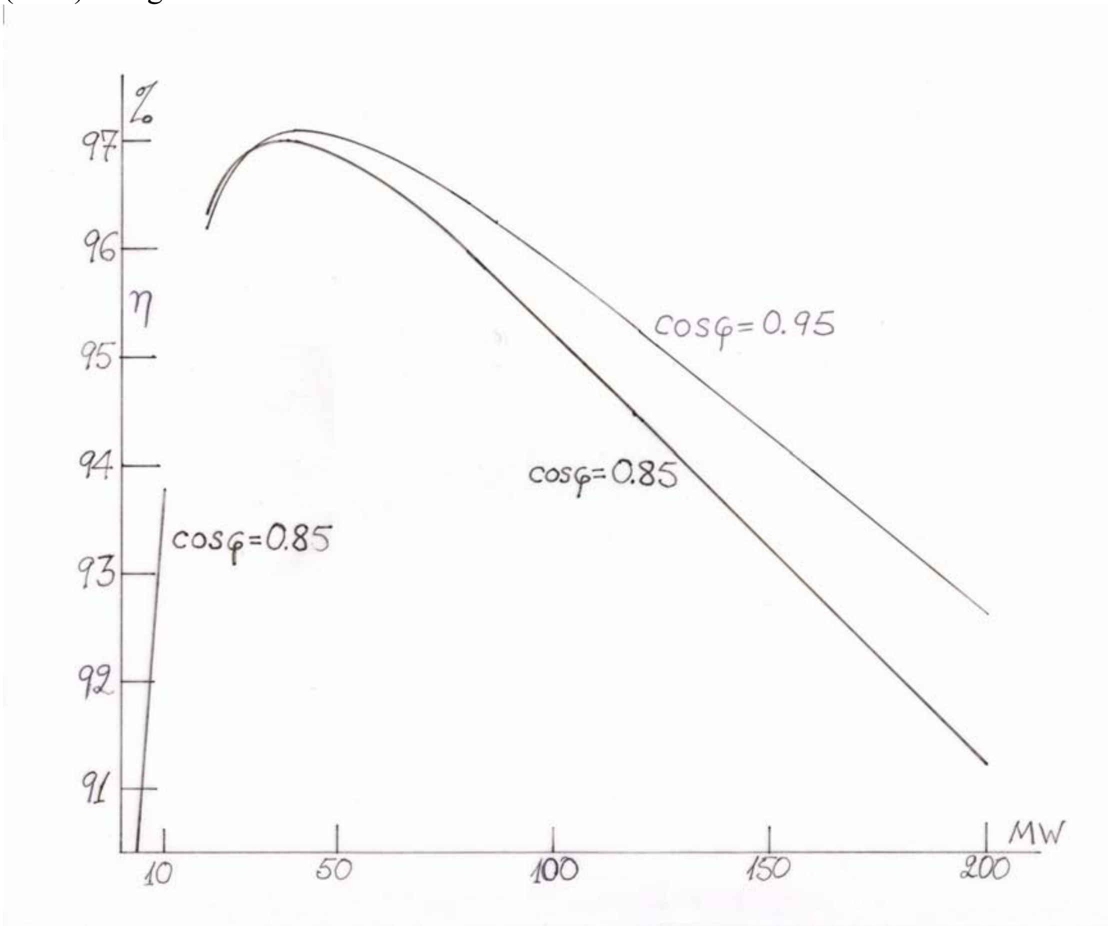

Figure 1. Transmission Efficiency Curves (TEC)

The TEC of figure 1 have been drawn for one single line of this case study. Each TEC corresponds to one load coefficient (0.85, or 0.95 inductive as indicated in the figure). So, if the load to be served is 200 MW at 0.85 load coefficient, serving this load with one circuit one will achieve a 91.24 % transmission efficiency, while if the same load is served with both circuits (100 MW each) one will have a 95.21 % transmission efficiency (roughly a 4 % transmission efficiency increase). However, if one has 40 MW to transmit, then, if it is left divided in the two circuits (20 MW each) it will have a transmission efficiency of 96.32 %, while if it is transmitted by just one circuit the transmission efficiency will be 97 % (very near the maximum).

5. Transmission line change-of-character curves

The character of a transmission line changes from capacitive to inductive as the line is loaded from light loads to heavy loads. In the particular case-study herein, this change of character is illustrated by the following OL Change-of-character Curves (OLCC) in figure 2.

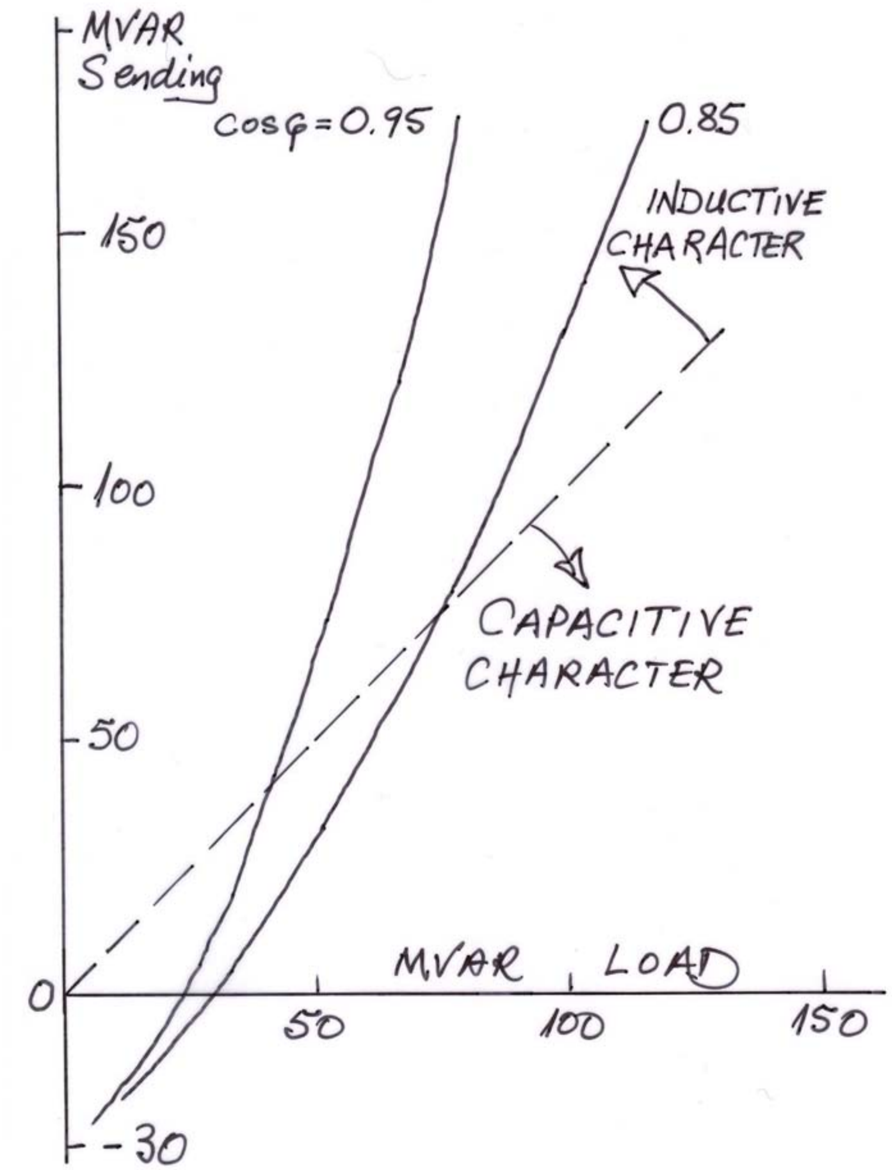

Figure 2. Overhead Line Change-of-character Curves (OLCC)

Each OLCC corresponds to one load coefficient. Here two OLCC are presented one for 0.95 and the other for 0.85 inductive load coefficients. The characteristic of the OL to be capacitive for light loads and turn to inductive character as it is loaded more, is clearly seen in the OLCC. The dashed line is the OL Neutral Line (OLNL) on which the OL has neutral character. For example, for load coefficient 0.85 the crossing of the OLCC with the OLNL corresponds to a line load of about 120 MW (a bit higher than the surge-impedance loading of the line: P_{SIL} ~ 119 MW) for which: sending Mvars, and the load Mvars are both equal to about 74.5.

6. Further investigations

Managing the environmental impact of existing OL is a valid present concern. Therefore, OL electrical losses and carbon additions to the atmosphere constitute a valid subject for investigation. Ways to minimize this environmental impact could be found in investigating compensation (series, or shunt) strategies of OL in order to reduce operating losses.

7. Conclusions

The very important issue of Transmission Line efficiency has been studied. Elements of the theory of maximum transmission efficiency have been reviewed in summary. It is shown how to select options, to share or not power delivery between single lines for off-peak loaded double-lines, in order to obtain higher transmission efficiencies. Potential gains in transmission efficiency are shown to be substantial. The change-of-character from capacitive to inductive depending on the size of load has been illustrated. Related further investigations are proposed.

8. References

[1] T. M. Papazoglou, Maximum efficiency of interconnected transmission lines, IEE Proceedings Generation Transmission Distribution, Vol. 141, No. 4, pp. 353-356, July 1994

9. Author's address:

Professor Thales M. Papazoglou
P.O. Box 1427
710 01 Iraklio
Crete, Greece.

Emails: tmpapa@teiher.gr, thales@teemail.gr
Fax: + 30 2810 259253
Tel.: + 30 2810 379701
Cell: + 30 6977 765782.