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ANALYSIS OF POSSIBILITIES OF USING SERIES COMPENSATION FOR CONSEQUENCES ELIMINATION OF DRIVING LONG TRANSMISSION LINES

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Subject review

The paper analyzes the problem of long transmission lines drive and the possibility of applying of capacitive series compensation. It deals with the voltage on the lines and the influence of the degree of compensation to the transmission capacity and the stability of the steady state network voltage. The first aspect of the analysis is the problem of increased transmission line load when there is a necessity to relieve the load from the reactive power in order to convey as much real power through the line, reduce losses and maintain voltage within limits. Another aspect of the analysis is very small load or idle line, when the Ferranti effect leads to an extremely high voltage at the end of the line.

Key words: *long transmission line, reactive power compensation, the serial capacitor*

Analiza mogućnosti korištenja serijske kompenzacije za otklanjanje neželjenih posljedica pogona dugih prijenosnih vodova

Pregledni članak

U radu se analizira problematika pogona dugih prijenosnih vodova i mogućnost primjene serijske kapacitivne kompenzacije. Razmatraju se naponske prilike na vodovima te utjecaj stupnja kompenzacije na prijenosnu moć i na stabilnost napona u stacionarnom stanju mreže. Prvi aspekt analize je problematika povećanog opterećenja voda kada postoji nužna potreba rasterećenja voda od jalove snage kako bi se vodom prenijela što veća djelatna snaga, smanjili gubici i održao napon unutar dopuštenih granica. Drugi aspekt analize je izrazito malo opterećenje ili prazan hod (PH), kada zbog Ferrantijeva efekta dolazi do izrazito visokog napona na kraju voda.

Ključne riječi: *dugi prijenosni vod, kompenzacija jalove energije, serijski kondenzator*

1 Introduction
Uvod

Much of the high voltage transmissions lines, in the modern power system, due to the increase in demand for electricity are highly loaded most of the time. Problems are related to the construction of new transmission lines leading to the reduction in the number of newly built high voltage power lines, and an increasing number of lines that run close to the margin of static and dynamic stability. The method of compensation using series condenser described in this paper can be used to increase stability and to increase the transmission capacity of high voltage lines. Capacitor connected in series with transmission line reduces the effective reactance of line, thus affecting the improvement of voltage circumstances on the line. In many cases, compensation with serial capacitor on transmission lines proved to be a more economical solution than building new transmission lines, and so the temporary or permanent suspension of construction of new lines is enabled.

2 Uncompensated transmission line parameters
Parametri nekompenziranog prijenosnog voda

For a long transmission line distributed parameters along the line must be taken into account: resistance R, inductance L, capacitance C and the generalized parameters of line $\underline{A}$, $\underline{B}$, $\underline{C}$, $\underline{D}$. These parameters can be expressed by serial impedance $\underline{z}$ the length of the line and transverse admittance $\underline{y}$ per phase as follows:

$$\underline{z} = r + j \cdot \omega \cdot L \tag{1}$$

$$\underline{y} = g + j \cdot \omega \cdot C. \tag{2}$$

For a long transmission line, it is necessary to define the transmission constant $\underline{y}$ and characteristic impedance $\underline{Z}_c$.

$$\underline{\gamma} = \sqrt{\underline{z} \cdot \underline{y}} = \sqrt{(r + j \cdot \omega \cdot L)(g + j \cdot \omega \cdot C)}. \tag{3}$$

$$\underline{Z}_c = \sqrt{\frac{\underline{z}}{\underline{y}}} = \sqrt{\frac{(r + j \cdot \omega \cdot L)}{(g + j \cdot \omega \cdot C)}}. \tag{4}$$

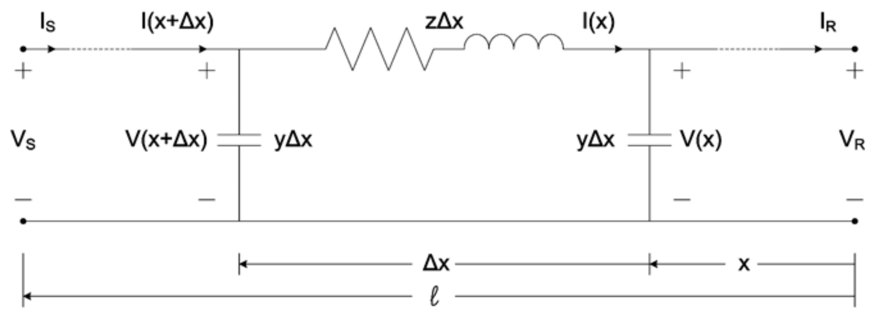

Figure 1 *Long transmission line with distributed parameters*
Slika 1. *Dugi vod s distribuiranim parametrima*

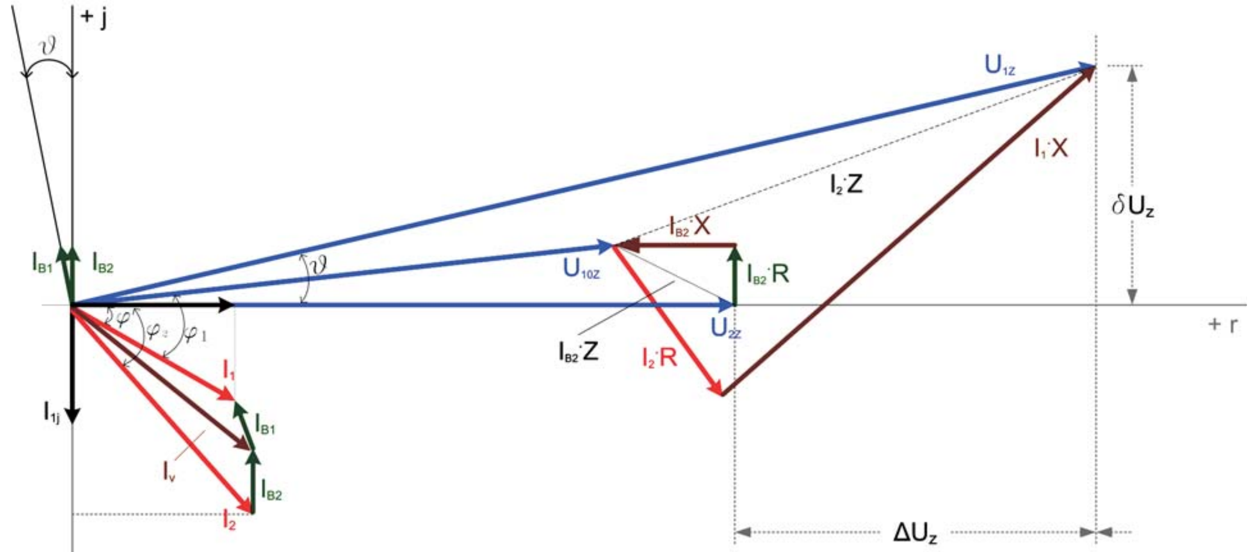

Figure 2 *Vector diagram of the transmission line at higher loads*
Slika 2. *Vektorski dijagram prijenosnog voda kod većeg opterećenja*

Generalized parameters $\underline{A}$, $\underline{B}$, $\underline{C}$ and $\underline{D}$ of uncompensated long transmission line are:

$$\underline{A} = \underline{D} = \cosh\left(\underline{\gamma} \cdot l\right), \tag{5}$$

$$\underline{B} = \underline{Z}_c \cdot \sinh\left(\underline{\gamma} \cdot l\right), \tag{6}$$

$$\underline{C} = \sqrt{\frac{\sinh(\underline{\gamma} \cdot l)}{\underline{Z}_c}}. \tag{7}$$

By using serial or parallel compensation we can achieve significant improvement of transmission capacity within the acceptable voltage limits. For this purpose, we used the following expressions to determine the parameters $\underline{A}$ and $\underline{B}$ for compensated long line.

$$\underline{A} = 1 + \left(\frac{\underline{Y} \cdot \underline{Z}}{2}\right) + \left(\frac{\underline{Y}^2 \cdot \underline{Z}^2}{24}\right) + \left(\frac{\underline{Y}^3 \cdot \underline{Z}^3}{720}\right). \tag{8}$$

$$\underline{B} = \underline{Z} \cdot \left[1 + \left(\frac{\underline{Y} \cdot \underline{Z}}{6}\right) + \left(\frac{\underline{Y}^2 \cdot \underline{Z}^2}{120}\right) + \left(\frac{\underline{Y}^3 \cdot \underline{Z}^3}{5040}\right)\right]. \tag{9}$$

3 Loaded and unloaded transmission line voltage profile

Naponske prilike neopterećenog i opterećenog voda

Vector diagrams are graphically presenting conditions on unloaded or loaded transmission line. Current I_v on the line is shown in the diagram as a result of the load current I_2 and the capacity current (half) of line I_{B2}, where

$$I_{B2} = U_{2z} \cdot \frac{B}{2}. \tag{10}$$

The voltage at the beginning of the line is:

$$U_{1z} = \sqrt{\left(U_{2z} + \Delta U_z\right)^2 + \left(\delta U_z\right)^2}\,, \tag{11}$$

where the longitudinal and transverse voltage difference is defined as:

$$\begin{aligned} \Delta U_z &= -I_{B2} \cdot X + I_2 \cdot R \cdot \cos\varphi_2 + I_2 \cdot X \cdot \sin\varphi_2 = \\ &= I_{r2} \cdot R + \left(I_{x2} - I_{B2}\right) \cdot X, \end{aligned} \tag{12}$$

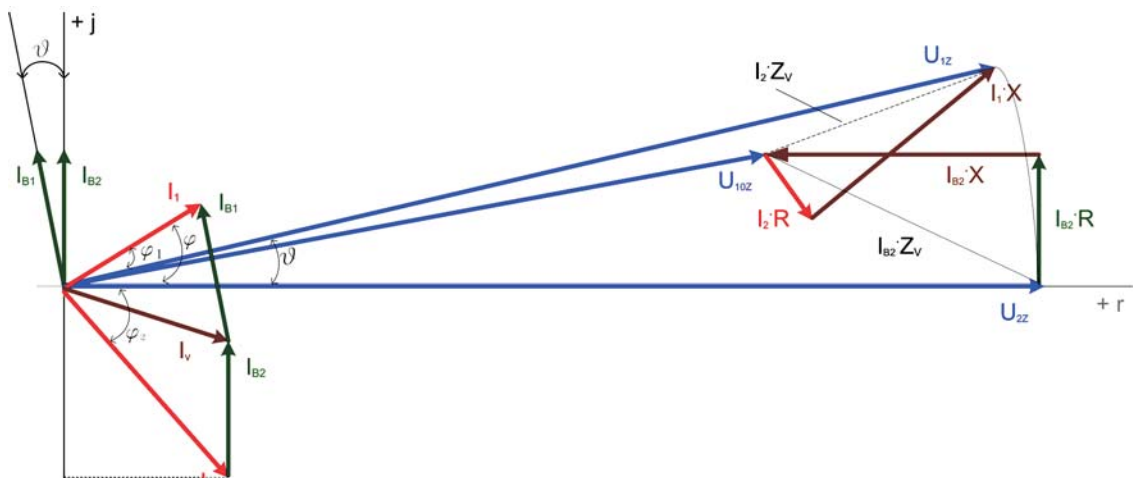

Figure 3 *Vector diagram of the transmission line at small load*
Slika 3. *Vektorski dijagram prijenosnog voda kod malog opterećenja*

$$\delta U_z = I_{B2} \cdot R - I_2 \cdot R \cdot \sin\varphi_2 + I_2 \cdot X \cdot \cos\varphi_2 = \\ = I_{r2} \cdot X - \left(I_{x2} - I_{B2}\right) \cdot R . \tag{13}$$

The introduction of voltage drops components according to diagram the voltage at the beginning of line:

$$U_{1z} = \sqrt{\begin{aligned}&\left[U_{2z} + I_{r2} \cdot R + \left(I_{x2} - I_{B2}\right) \cdot X\right]^2 + \\ &+\left[I_{r2} \cdot X - \left(I_{x2} - I_{B2}\right) \cdot R\right]^2 .\end{aligned}} \tag{14}$$

Using phasor relation we can extract an approximate but quite accurate value as follows:

$$\underline{U}_{1z} = U_{2z} + \Delta U_z + j \cdot \delta U_z \;\Rightarrow \\ U_{1z} = U_{2z} + \Delta U_z + \frac{\left(\delta U_z\right)^2}{2U_{2z}} . \tag{15}$$

The angle between the voltage phasor at the beginning and end of the line is calculated by:

$$\mathrm{tgn}\,\vartheta = \frac{\delta U_z}{U_{2z} + \Delta U_z} . \tag{16}$$

The current at the beginning of the line is determined by its active and inductive components:

$$I_1 = \sqrt{\begin{aligned}&\left(I_2 \cdot \cos\varphi_2 - I_{B1} \cdot \sin\vartheta\right)^2 + \\ &+\left(I_2 \cdot \sin\varphi_2 - I_{B2} - I_{B1} \cdot \cos\vartheta\right)^2\end{aligned}} = \\ = \sqrt{I_{r1}^{\,2} + I_{x1}^{\,2}} . \tag{17}$$

According to the diagram the angle of voltage phase shift and current at the beginning of line:

$$\varphi_1 = \vartheta + \varphi , \;\; \mathrm{tgn}\varphi = \frac{I_{x1}}{I_{r1}} , \tag{18}$$

and here φ is the angle between voltage at the end and current at the beginning of the line.

Pay attention to how the voltage at the beginning of the line changes under the influence of capacitive current. On the vector diagram in Fig. 3 is shown that the capacitive current I_{B2} decreases the size of the longitudinal and increases the size of transverse components of the total voltage drop on the line. Because of this voltage difference reduces and phase shift ϑ between voltage at the beginning of the line and voltage at the end of the line increases. If we reduce the load on the line from its nominal value to zero, it can happen that when load is very small, voltage difference on the line is equal to zero.

The difference of voltage due to inductive character voltage drop is compensated by the negative voltage difference resulting from capacitive currents on the line. With further lowering of the line load, i.e. reducing the voltage drops triangle, the difference in voltage due to load will become smaller than the differences due to the negative capacitive current and the voltage at the beginning of the line will be lower than the voltage at the end of the line. At the end with the disappearance of the load current, only capacitive currents of line itself will remain on the line and also the largest negative difference voltage on the line. Diagram of the unloaded transmission line can be seen in Fig. 4.

The capacitive current has a positive impact in large and medium-sized loads on the line. At low load and at idle, this current can act negatively as increasing voltage to the end of the long line which can achieve illicit values. Total losses in power transmission on the line are composed of active and reactive power losses and are given by the equations:

$$\Delta P = 3 \cdot \left(\frac{S}{\sqrt{3} \cdot U}\right)^2 \cdot R = \left(\frac{S}{U}\right)^2 \cdot R \tag{19}$$

respectively $\Delta P = \dfrac{P^2 + Q^2}{U^2} \cdot R,$

$$\Delta Q = 3 \cdot \left(\frac{S}{\sqrt{3} \cdot U}\right)^2 \cdot X = \left(\frac{S}{U}\right)^2 \cdot X , \tag{20}$$

respectively $\Delta Q = \dfrac{P^2 + Q^2}{U^2} \cdot X .$

4 The impact of series compensation on line impedance
Utjecaj serijske kompenzacije na impedanciju voda

There are two methods by which we can raise the upper limit of the transmission capacity of a line, and also to maintain voltage within the allowed limits. The first method is to increase the operating voltage in the transmission network. Of course, this would lead to increased costs of the generators operation. Another method is to reduce the characteristic impedance of line that is generally achieved by either increasing the line size or adding a capacitor in series with the line, which is the subject of discussion in this paper. Size of the line is not practical or affordable to increase because it affects the characteristic impedance of line in only small proportion. Thus, the addition of capacitors in series with the line, which is series compensation, is the best available method for reducing the characteristic impedance of line. Capacitors connected in series with the line are used to reduce series reactance between the 'ends' of line, but adding a serial inductor increases characteristic impedance, and reduces transmission capacity. Therefore, the shunt reactor is connected in parallel and at the time of small loads to reduce Ferranti effect.

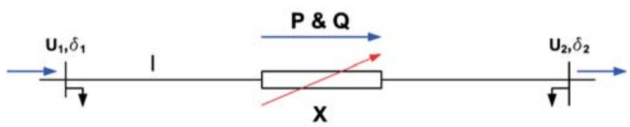

***Figure 5** Changing of the line impedance value*
***Slika 5.** Promjena vrijednosti impedancije voda*

Changes in the value of the impedance X as in Fig. 5, will increase or decrease the flow of active power for the same angle, or change the angle for the same power flow. Series compensation can be concentrated or distributed. When comparing the two types of compensation, a concentrated version gives better results than distributed from the standpoint of achieving the maximum transmission capacity, and can be seen in Fig. 6.

Reactive power compensation is associated with the appearance of higher harmonics, because the regulation and reactive power compensation must be reckoned with loads that can be a source of higher harmonics. Compensation entered into the system elements (capacitors and inductors) can easily lead to problems with harmonic resonance, which certainly should be avoided. Therefore, in practice adequate filters should be used. However, except in principle, the problem of resonance is coming out of topics and scope of this paper.

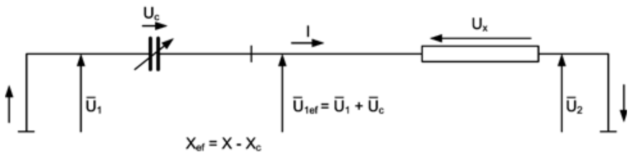

Figure 6 *Series capacitive compensation on line*
Slika 6. *Serijska kapacitivna kompenzacija na vodu*

5 Analysis of transmission line with serial capacitive compensation
Analiza prijenosnog voda sa serijskom kapacitivnom kompenzacijom

In Fig. 7 there is a single-phase transmission line equivalent length L with series compensation. Capacitors for compensation are located at a distance $K_F L$ from the beginning of the line, and for K_F apply $1 \geq K_F \geq 0$. If l_e, r_e, c_e and g_e are series inductance of transmission line, resistance, capacitance and conductance per unit length of the line, a generalized transmission parameters of the transmission system elements from Fig. 7 are given as:

(a) Section length of transmission line length $K_F L$

$$\begin{aligned} \underline{A}_1 &= \cosh\left(K_F \underline{\gamma} L\right), \\ \underline{B}_1 &= \underline{Z}_c \sinh\left(K_F \underline{\gamma} L\right), \\ \underline{C}_1 &= \frac{1}{\underline{Z}_c} \sinh\left(K_F \underline{\gamma} L\right), \\ \underline{D}_1 &= \cosh\left(\underline{\gamma} K_F L\right). \end{aligned} \tag{21}$$

(b) Serial connected capacitors

$$\begin{aligned} \underline{A}_2 &= 1 + j\,0 \cdot 0, \\ \underline{B}_2 &= -\,jX_C, \\ \underline{C}_2 &= 0 + j0, \\ \underline{D}_2 &= 1 + j\,0. \end{aligned} \tag{22}$$

(c) Section of transmission line length $\left(1 - K_F\right)L$

$$\begin{aligned} \underline{A}_3 &= \cosh\left[\underline{\gamma}\left(1 - K_F\right)L\right], \\ \underline{B}_3 &= \underline{Z}_c \sinh\left[\underline{\gamma}\left(1 - K_F\right)L\right], \\ \underline{C}_3 &= \frac{1}{\underline{Z}_c} \sinh\left[\underline{\gamma}\left(1 - K_F\right)L\right], \\ \underline{D}_3 &= \cosh\left[\left(1 - K_F\right)\underline{\gamma} L\right]. \end{aligned} \tag{23}$$

In equations (21) and (23), $\underline{Z}_c$ and $\underline{\gamma}$ and relate to the characteristic impedance and propagation constant of the line, and are defined as:

$$\underline{\gamma}^2 = \left(r_e + j\omega l_e\right)\left(g_e + j\omega c_e\right), \tag{24}$$

$$\underline{Z}_c{}^2 = \frac{\left(r_e + j\,\omega\, l_e\right)}{\left(g_e + j\omega c_e\right)}. \tag{25}$$

The chain matrix with generalized parameters of the complete transmission system is given as:

$$\begin{bmatrix} \underline{A} & \underline{B} \\ \underline{C} & \underline{D} \end{bmatrix} = \begin{bmatrix} \underline{A}_3 & \underline{B}_3 \\ \underline{C}_3 & \underline{D}_3 \end{bmatrix} \begin{bmatrix} \underline{A}_2 & \underline{B}_2 \\ \underline{C}_2 & \underline{D}_2 \end{bmatrix} \begin{bmatrix} \underline{A}_1 & \underline{B}_1 \\ \underline{C}_1 & \underline{D}_1 \end{bmatrix}. \tag{26}$$

Individual generalized parameters, nodes of this matrix:

$$\left|\underline{A}\right| \angle\alpha = \underline{A}_1 \underline{A}_2 \underline{A}_3 + \underline{A}_1 \underline{B}_2 \underline{C}_3 + \underline{B}_1 \underline{C}_3, \tag{27}$$

$$\left|\underline{B}\right| \angle\beta = \underline{A}_1 \underline{A}_3 \underline{B}_3 + \underline{A}_1 \underline{D}_3 \underline{B}_2 + \underline{B}_1 \underline{A}_3, \tag{28}$$

$$\left|\underline{C}\right| \angle\delta = \underline{C}_1 \underline{A}_2 \underline{A}_3 + \underline{C}_1 \underline{C}_3 \underline{B}_2 + \underline{D}_1 \underline{C}_3, \tag{29}$$

$$\left|\underline{D}\right| \angle\sigma = \underline{C}_1 \underline{A}_2 \underline{B}_3 + \underline{C}_1 \underline{B}_2 \underline{D}_3 + \underline{D}_1 \underline{D}_3. \tag{30}$$

Voltage and current at the beginning of the line are associated with voltage and current at the end of the line with the following equation:

$$\underline{V}_S = \underline{A}\underline{V}_R + \underline{B}\underline{I}_R, \tag{31}$$

$$\underline{I}_S = \underline{C}\underline{V}_R + \underline{D}\underline{I}_R. \tag{32}$$

Finally, the degree of compensation with series capacitor C_F is given as:

$$C_F = \frac{X_C}{X_L}, \tag{33}$$

where X_L is the total reactance of line.

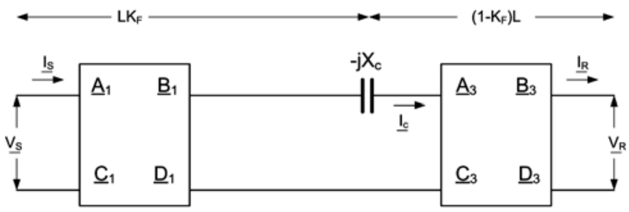

Figure 7 *Single-phase equivalent of transmission line with series compensation*
Slika 7. *Jednofazni ekvivalent prijenosnog voda sa serijskom kompenzacijom*

6 Capacitive compensation and the impact on the maximum transmission capacity
Kapacitivna kompenzacija i utjecaj na maksimalnu prijenosnu moć

Active and reactive power at the end of the line is given as:

$$P_R = \frac{\left|\underline{V}_S\right|\left|\underline{V}_R\right|}{\left|\underline{B}\right|} \cos\left(\beta - \Theta_S\right) - \frac{\left|\underline{A}\right|\left|\underline{V}_R\right|^2}{\left|\underline{B}\right|} \cos\left(\beta - \alpha\right), \tag{34}$$

$$Q_R = \frac{\left|\underline{V}_S\right|\left|\underline{V}_R\right|}{\left|\underline{B}\right|} \sin\left(\beta - \Theta_S\right) - \frac{\left|\underline{A}\right|\left|\underline{V}_R\right|^2}{\left|\underline{B}\right|} \sin\left(\beta - \alpha\right). \tag{35}$$

Similarly, for the beginning of line active and reactive power is:

$$P_S = \frac{|\underline{A}||\underline{V}_S|^2}{|\underline{B}|}\cos(\beta-\alpha) - \frac{|\underline{V}_R||\underline{V}_S|}{|\underline{B}|}\cos(\beta+\Theta_S), \tag{36}$$

$$Q_S = \frac{|\underline{A}||\underline{V}_S|^2}{|\underline{B}|}\sin(\beta-\alpha) - \frac{|\underline{V}_S||\underline{V}_R|}{|\underline{B}|}\sin(\beta+\Theta_S). \tag{37}$$

In equations (34) to (37), Θ_S is the voltage angle at the beginning of line in relation to the reference value at the end of the line. Active power at the end of the line is maximal when $\Theta_S = \beta$ is true, if there is sufficient reactive power. If voltage at the beginning and at the end of the line is constant, the maximum power at the end of the line can be summarized by the following equation:

$$P_{R\max} = \frac{|\underline{V}_S||\underline{V}_R|}{|\underline{B}|} - \frac{|\underline{A}||\underline{V}_R|^2}{|\underline{B}|}\cos(\beta-\alpha), \tag{38}$$

where $|\underline{A}|$ and $|\underline{B}|$ are the generalized parameters. This will be the maximum amount of power that can be transferred to the end of the line, which we get by inserting values $|\underline{A}|$, $|\underline{B}|$, β and α in equation (38) and using the diagram in Fig. 8. In terms of maximum power in Fig. 8, it was assumed that there is the same voltage at the beginning and the end of the line. The following equations give the current, and three-phase rated power of compensating capacitor Q_C, with the voltage at the end of the line $\underline{V}_R$ as a reference.

$$\underline{I}_R = \frac{P_{\max}}{V} + \frac{jAV\cdot\sin(\beta-\alpha)}{B}, \tag{39}$$

$$\underline{I}_C = \underline{D}_3\underline{I}_R + \underline{C}_3\underline{V}_R, \tag{40}$$

$$Q_C = 3I_C^2 X_C, \tag{41}$$

where:

$$I_C = |\underline{I}_C|. \tag{42}$$

To analyze the transmission line which is necessary to add series compensation, using the expression (43), which expresses the degree or percentage of series compensation. Defined as the quotient of the total series capacitive reactance compensator X_C, and the total inductive reactance of line X_L.

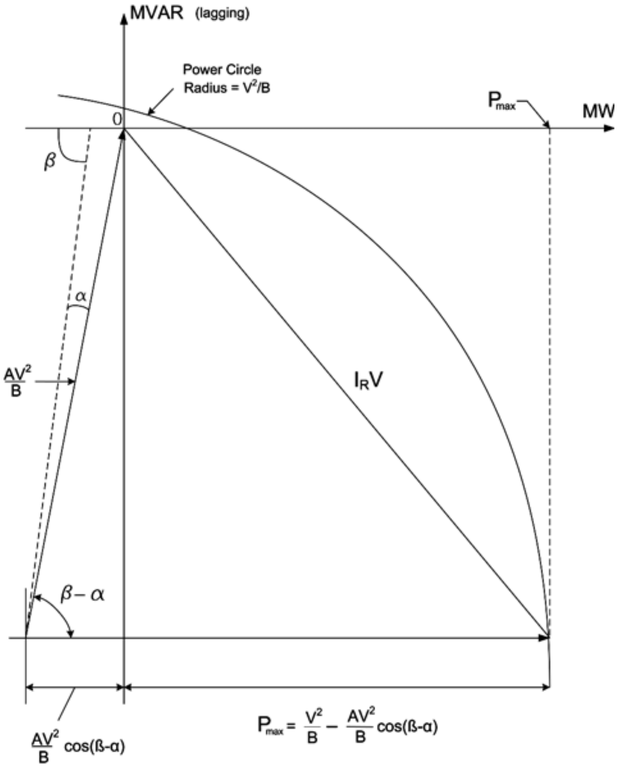

Figure 8 *Circuit diagram of power at the end of the line*
Slika 8. *Kružni dijagram snage na kraju voda*

$$k = \frac{X_C}{X_L}. \tag{43}$$

Since it is actually aimed to determine the size of the series-connected capacitors to the line, it will be necessary to define the degree of compensation k in the total impedance of line, which is:

$$\underline{Z} = R + j\left[X_L(1-k)\right]. \tag{44}$$

Effect of series compensation on transmission capacity [1, 3] can be seen in Fig. 9, where based on expression (38) it is shown by the curves. For fixed angle difference between voltages at the ends of the line $\Psi°$ transmission capacity of line increases as the degree or percentage of compensation increases. It is clearly demonstrated that with unchanged values of angular differences $\Psi°$ and with different values of the degree of compensation transmission capacity of line increases. Also, vice versa, for the same amount of transferred active power on the line angle the difference decreases as k increases, which is a measure to increase the

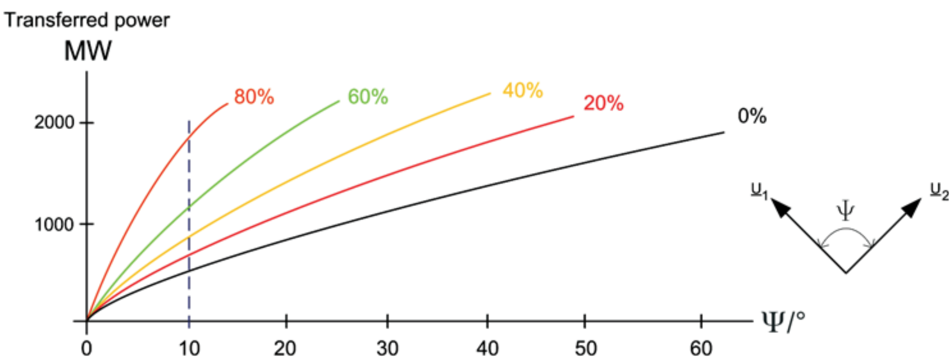

Figure 9 *Effect of series compensation on the line transmission capacity*
Slika 9. *Utjecaj serijske kompenzcije na prijenosnu moć voda*

dynamic stability of the transmission system.

If the serial capacitor is installed in order to increase transmission capacity, or increase the dynamic stability at a fixed power that line carries is only a matter of applying the compensation in any given case.

7 Voltage stability
Naponska stabilnost

Voltage dips are generally associated with voltage instability in the steady state of the network or where voltage angle stability is irrelevant. Without a control of voltage at the end of the line, we can reach the point when the load requirements can no longer be met. This results in an increased demand for reactive power, which still results in a gradual decline in voltage, for several minutes, until the voltage at the end of the line is reduced to the level that the line can no longer hold load. From equations (34) and (35), comes an expression that connects the power and voltage at the end of the line and is given by the equation (45).

$$V_R^4\left[\frac{|\underline{A}|^2}{|\underline{B}|^2}\right]+V_R^2\left[\begin{array}{l}\dfrac{2P_R|\underline{A}|}{|\underline{B}|}\cos(\beta-\alpha)+\\ \dfrac{2Q_R|\underline{A}|}{|\underline{B}|}\sin(\beta-\alpha)-\dfrac{V_S^2}{|\underline{B}|^2}\end{array}\right]+ \tag{45}$$
$$+P_R^2+Q_R^2=0.$$

When we define $K=Q_R/P_R$ and $x=V_R^2$ and so the equation (45) is reduced to

$$\frac{|\underline{A}|^2}{|\underline{B}|^2}x^2+x\left[\frac{2|\underline{A}|}{|\underline{B}|}P_R Z-\frac{V_S^2}{|\underline{B}|^2}\right]+P_R^2\left(1+K^2\right)=0, \tag{46}$$

where

$$Z=\cos\left(\beta-\alpha\right)+K\sin\left(\beta-\alpha\right). \tag{47}$$

Fig. 10 graphically shows the voltage at the end of the line as a function of active power for uncompensated transmission line. To each specific power at the end of the line correspond two voltages one of which is near the rated voltage and the other which is significantly reduced. If the voltage corresponds to a lower value, more current will flow through line, which is undesirable. As the load at the end of the line increases, we reach the point where only one of the voltages satisfies the equation (46). This point corresponds to the maximum load the line can handle. If the load exceeds this point there will be dipped voltage. If we compare the diagrams for different power factor it can be seen that the leading power factor has a higher maximum power value at the end of the line.

Maximum power at the end of the line $P_{\mathrm{Max}c}$ and the corresponding boundary voltage dips V_{Rc} are given as:

$$P_{\mathrm{Max}c}=\frac{V_S^2}{2|\underline{A}||\underline{B}|\left[Z^2-1-K^2\right]}\left[Z\pm\sqrt{\left(1+K^2\right)}\right], \tag{48}$$

$$V_{Rc}=\sqrt{\frac{\left(V_S^2-2|\underline{A}||\underline{B}|P_R Z\right)}{2|\underline{A}|^2}}. \tag{49}$$

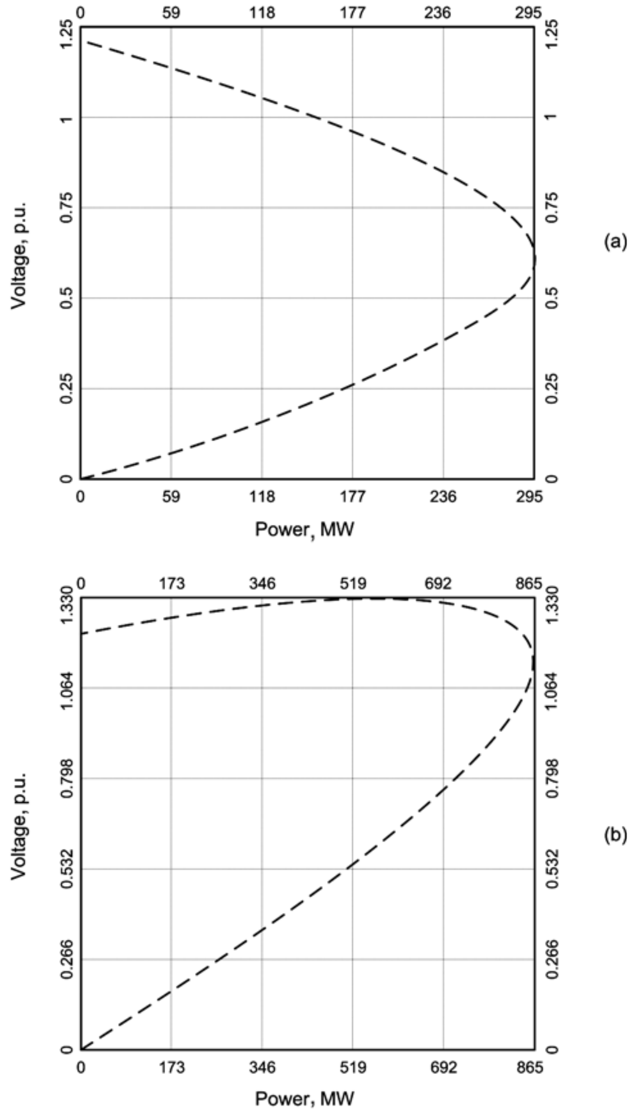

Figure 10 *Receiving end voltage for various receiving power for uncompensated lines: (a) 0,8 lagging power factor load; (b) 0,8 leading power factor load*
Slika 10. *Napon na kraju voda u ovisnosti o snazi za nekompenziran vod: (a) Zaostajući faktor snage 0,8; (b) Prethodeći faktor snage 0,8*

8 Conclusion
Zaključak

The paper gives an overview of the effects of capacitive series compensation on long transmission lines. The effect of compensation factor and location of capacitors to the maximum transmission capacity of line is described. Tendency of voltage dips on the line at high load is also questioned. The lines with serial capacitive compensation will have voltage dips at a significantly greater power at the end of the line than is the case with uncompensated line. Loads with leading power factor have better voltage stability limits compared to those with lagging and unique capacity factor. To transfer large amounts of electric power over long distances, especially when interconnections must take care of maintaining synchronism security and voltage stability, especially for cases of high load in the system, possibly in combination with behavioral disorders in the system. With series compensation, sustainable distance AC power transmission becomes large enough to eliminate problems with distance as a limiting factor for AC transmission in most cases.

9
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