Use Series Compensation in Distribution Networks 33 KV

Dr. Al-Zohuariali M. Kathim[1], Majeed R. Zaidan[2]

[1]The Ministry of Municipalities, Water Directorate of Diyala province – Iraq, +96407729725904
[2]Lecturer, Baqubah Technical Institute, Middle Technical University, Baghdad, Iraq, +96407707896466

Majeed Rashid Zaidan, Lecturer, electrical Technical department, Baqubah Technical Institute, Middle Technical University, Baghdad, Iraq) E-Mail: majeed6466[at]gmail.com

Abstract: ***Series Capacitors (SC) Device is "placed in the middle of the" transmission line is used to decrease the reactive power in the "distribution networks 33KV and the powerful capability of series line compensation "to control the transmitted power can be used" much more effectively "to increase the transient stability limit" and provide power oscillation damping.***

Keywords: Series Capacitors, Distribution Networks, Series Compensation, varistor

1. Series Capacitors (SC)

"Series capacitor" is not only a capacitor in series with the line. For appropriate functioning, series compensation requires control, protection and surveillance facilities to enable it to perform as an integrated part of a power system". Also, since the "series capacitor" is operating at the same voltage level as the remnant of the system, it needs to be fully insulated to ground.

The Basic "circuit diagram of a best of the art series capacitor is shown" in Figure (1). The "basic vital protective device a varistor", usually the ZnO type, that limiting the voltage across the "capacitor to assure values in conjunction with system faults giving rise to huge short circuit currents" passing through the line [1].

A spark gap is used in many cases, to qualify "by-pass of the series capacitor in a status" where the varistor is not sufficient to absorb the "overflowing current during a fault sequence". There are different bypass solutions available now like spark gap, high power plasma switch, power electronic device, etc.

Lastly, a "circuit breaker is incorporated in the scheme to enable bypassing" of the series capacitor for more extended periods of time as the need may be. Likewise needed to turn off the spark gap, or, without a "spark gap, for bypassing the varistor in conjunction with faults close to the series capacitor" (so-called internal faults).

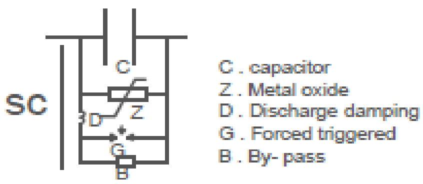

Figure 1: basic "configuration of a Series Capacitor"

Reactive shunt compensation is very effective in preserving "the required voltage profile along the transmission line interconnecting two busses of the Ac system" and providing support to the end voltage of radial lines in a confrontation increasing power demand. "Shunt compensation", when utilized or used at completely close intervals through the line, could theoretically make it probable to transmit power up to the thermal limit of the line. Shunt compensation is ineffective" in controlling the real transmitted "power which, at a defined transmission voltage, is eventually" determined by "the series line impedance" and the angle "between the end voltages of line".

Series capacitive compensation was acquainted decades ago "to cancel a section of the reactive line impedance and thereby increase the transmittable power" series compensation is very effective in both controlling power flow in the line and in consolidate stability"[2].

The influence of "series compensation on the basic factors, determining attainable "maximal power transmission", steady-state power transmission limit, transient stability, voltage "stability and power oscillation damping", will be tested.

2. Concept of Capacitive Compensation

The main intended of using series capacitive compensation is to decrease the overall effective series transmission impedance "from the sending to the receiving ends", (Figure 2).

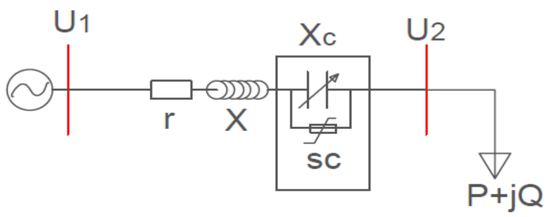

Figure 2: model transmission line with series Capacitor

$$p = \frac{V_1 V_2}{X} \sin \delta$$

The "effective transmission impedance" X_{eff} with the "series capacitive compensation" is specific by

$X_{eff} = X - X_c$

Or

$X_{eff} = (1-k)X$

where (**k**) "is the degree of series compensation"

$k = X_C/X$ $0 < k < 1$

Supposing $V_s = V_r = V$

The "current in the compensated line, and the corresponding actual power transmitted, can be derived" in the forms below:

The line is overcompensated if **x <xc** shown relationship between the voltage and series capacitor appears In Figure (3-a), while Figure (3-b) relationship between line voltage side with series capacitor and length of line from another side [3].

The overcompensation is to be avoided in order to prevent the line from increasing ferro resonance phenomenon

$$p = V_M I = \frac{V^2}{(1-K)X} \sin\delta$$

The "reactive power supplied by the series capacitor can be represented" as the equation below

$$Q_C = I^2 X_C = \frac{2V^2 K}{X(1-K)^2}(1-\cos\delta)$$

The relationship between the "real power" **P**, "series capacitor reactive power" Q_C, and angle **δ** is shown plotted at large number of degree of series compensation" **k** in Figure (4). "It can be recognized that, clearly, the transmittable power rapidly increases with the degree of series compensation" (**k**). Similarly, the reactive power supplied by "the series capacitor increases sharply" with (**k**) and changes with angle (**δ**) in a same manner way as the line reactive power"[4].

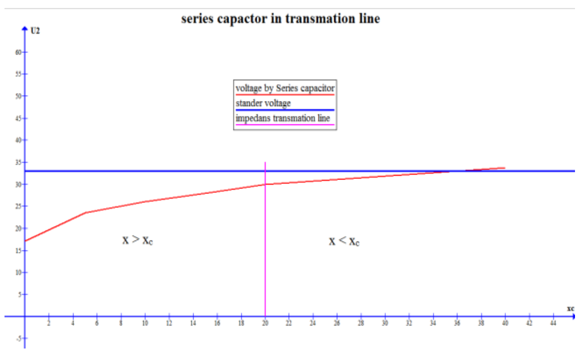

Figure 3-a: Relation "between the voltage and series capacitor"

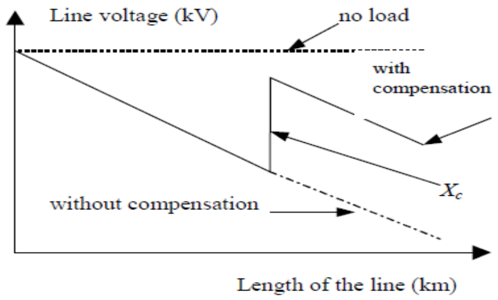

Figure 3-b: relationship "between line voltage with series capacitor" and length of line

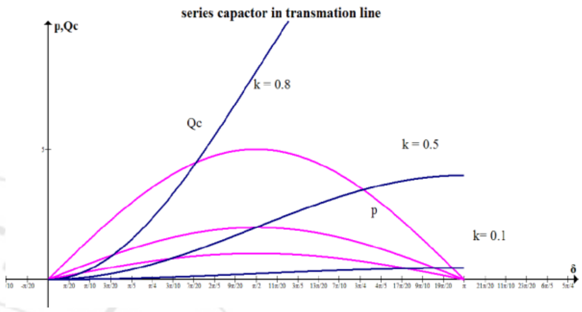

Figure 4: relationship "between the real power **P,** series capacitor reactive power $\boldsymbol{Q_C}$, and angle **δ**"

3. Chosen of Component Values

On first inspection "the chosen of component values appears to be difficult requiring inclusive modeling of each" specific status.

Capacitor µF chosen

To obtain "full compensation the capacitor value (C) should be slicked to give the same reactive impedance as the line inductance at the power frequency".

For "full compensation" $C = {}^{1}/_{(L\omega^2)}$

There are "stability advantages in designing for less than full compensation depending" on the actual design situation engineers may choose to not as much as fully compensate "for the inductive reactance" of the line[5].

Voltage Stability

Series capacitive compensation can likewise be used "to lessen the series reactive impedance to minimize the receiving-end voltage variety and the ability of voltage fall".

A "simple radial system with feeder line reactance X, series compensating" reactance Xc, and load impedance Z is appeared in Figure (5).

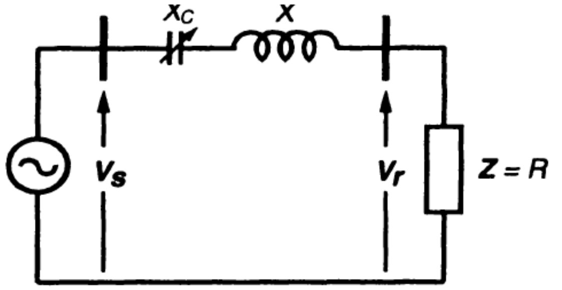

Figure 5: a simple radial system with feeder line reactance X, series compensating reactance Xc, and load impedance Z

The "corresponding standardized terminal voltage" V, versus power P plots, with "unity power factor load at 0, 50, and 75% series capacitive compensation", are shown in Figure (6)

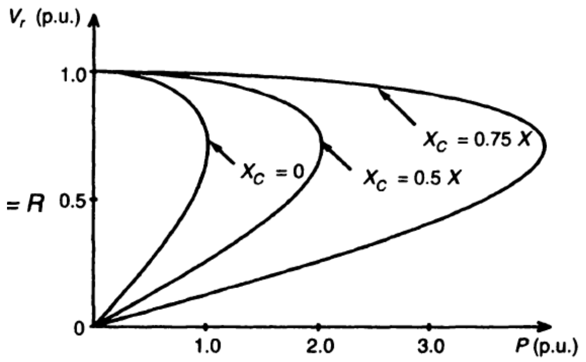

Figure 6: the corresponding standardized terminal voltage" V, versus power P plots, with unity power factor load at 0, 50, and 75% series capacitive compensation

The "nose point at each plot given for a particular compensation level represents the corresponding voltage instability"[6].
Series capacitive compensation does it by dropping" a portion of the line reactance and subsequently", in effect, giving a stiff "voltage source for the load.

For increasing the voltage stability limit of overhead transmission", series compensation is essentially more effective than shunt compensation "of the same MVA rating".

Improvement of the Transient Stability

The "powerful ability of series line compensation" to control "the transmitted power can be used much more effectively" to "increase the transient stability limit" and to "provide power oscillation" damping [7], [8].

4. Actual Results

The "series capacitor bank was installed and a picture of it shows on" Figure (7)

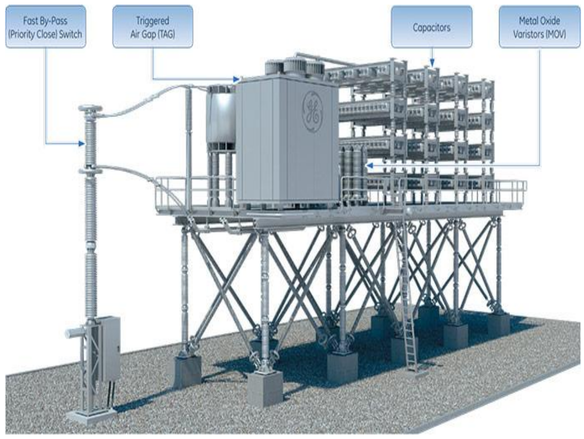

Figure 7: the series capacitor bank

This "system was activated under normal conditions getting considerable voltage level increase at some periods of load". So no oscillations were verified.

Line with Single Consumer

If the radial line feed only one consumer, which is situated at its end (Figure 8), the area issue for a capacitor is resolved. For this situation the best location for "series capacitor" is the line end, because of this location minimizes the exposure of the capacitor to stresses due to faults. [1]

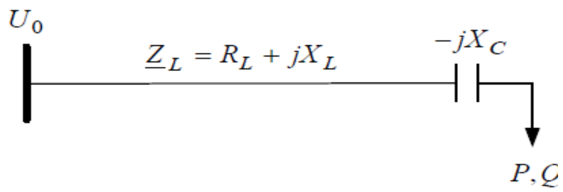

Figure 8: the radial line feed only one consumer

The ideal value of reactance, in conditions in which "active and reactive powers" P and Q, absorbed by the consumer.

Line with Several Consumption Nodes

If the radial line is tapped with lateral feeders or multiple load along the main feeder and Pi, Qi (i = 1, …, m) the absorbed powers in networks nodes is a variety the time interval T (Figure 9), for the determining of the series capacitor situation, the actual line is supplanted with a fictional equivalent line. This line feed a consumer which absorbs the

Active power $\sum_{i=1}^{m} = pi$

and

Reactive power $\sum_{i=1}^{m} = Qi$

Parameters of the fictional line: the resistance R and the reactance X can be calculated knowing the UF voltage value in the fictional node and the ratio R/X of the real line. [1]

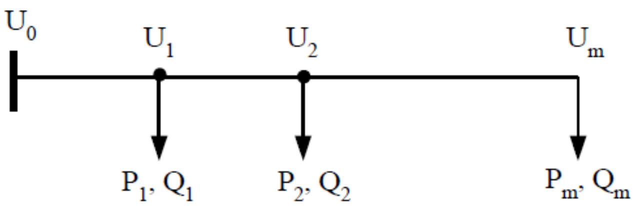

Figure 9: the radial line is tapped with lateral feeders

$$U_F = U_0 - \frac{\sum_{i=1}^{m} P_i.R + \sum_{i=1}^{m} Q_i.X}{U_n},$$

$$R/X = ct.$$

$$R/X = ct.$$

The fictional voltage UF is determined from the condition that the arithmetic average of the squares of voltage deviations for nodes Ui(i = 1,..., m) "of the actual network to be equal to the average of the squares of voltage deviations" in fictional node, relation

$$\frac{1}{m}\sum_{i=1}^{m}\frac{1}{T}\int_0^T [\frac{U_i(t)-U_n}{U_n}]^2 dt = \frac{1}{T}\int_0^T [\frac{U_F(t)-U_n}{U_n}]^2 dt$$

The ideal value of the reactance XC is calculated with the relation

$$X_c = X + \frac{\overline{P.Q}}{\overline{Q^2}}.R - \frac{U_n.(U_0-U_n)}{\overline{Q^2}}.\overline{Q}$$

where: $\overline{Q}$is the average value of the reactive power of the interval T;

$\overline{Q2}$ - the mean square of the "reactive power",

$$\overline{Q^2} = (\overline{Q})^2 + \sigma_Q^2$$

$\boldsymbol{\sigma_Q^2}$– "the scattering toward the average value of the reactive power"

$\overline{P.Q}$ - the average value of the product of active and reactive powers, calculated with

$$\overline{P.Q} = \overline{P}.\overline{Q} + \sigma_P.\sigma_Q.r_{PQ}$$

$\boldsymbol{r_{PQ}}$- the ratio of correlation between irregular variables P and Q. If P and Q present comparable varieties rPQ□ 1.

In this manner, for every node ”i” is calculated the sensitivity $s_i^x$of the "sum of the squares of the voltage deviations" from network nodes in relation to the reactance Xi of the line section i at the end of which is the consumer i.

$$S_i^X = \frac{\Delta[\sum_{i=1}^{m}\Delta U_i^2]}{\Delta X_i}$$

5. Case Study

a-We consider a ring overhead line of distribution, of 33 kV, which feeds 5 lateral feeders. The lengths of sections and absorbed powers in a regime of maximum load by sidelong feeders are indicated in Figure (10). Conductors of AL-OL have the cross section of 70 mm2. Total length line 40 km work simulation by (program calculation set mode of the systems electric).

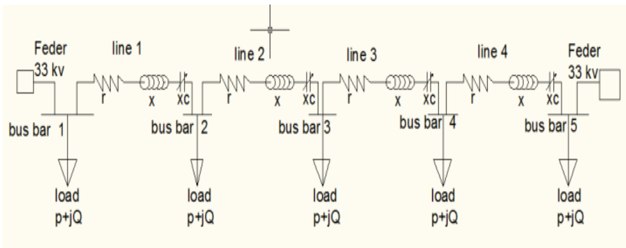

Figure 10: overhead line feeds 5 lateral feeders

Table 1: Without series capacitor xc

Bus	U kv	Load P+jQ	line	r	x	xc
1	33	10 +j8	1 - 2	0.9	3.6	
2	31.13	10 +j8	2 - 3	0.9	3.6	
3	30.5	10 +j8	3 - 4	0.9	3.6	
4	31.13	10 +j8	4 – 5	0.9	3.6	
5	33	10 +j8				

Table 2: With series capacitor xc on lines 1-2 and 4-5

Bus	U kv	Load P+jQ	line	r	x	xc
1	33	10 +j8	1 - 2	0.9	3.6	1.6
2	31.8	10 +j8	2 - 3	0.9	3.6	
3	31.2	10 +j8	3 - 4	0.9	3.6	
4	31.8	10 +j8	4 – 5	0.9	3.6	1.6
5	33	10 +j8				

Table –3: With series capacitor xc on lines 2-3 and 3-4

Bus	U kv	Load P+jQ	line	R Ω	X Ω	XcΩ
1	33	10 +j8	1 - 2	0.9	3.6	
2	31.13	10 +j8	2 - 3	0.9	3.6	1.6
3	30.7	10 +j8	3 - 4	0.9	3.6	1.6
4	31.13	10 +j8	4 – 5	0.9	3.6	
5	33	10 +j8				

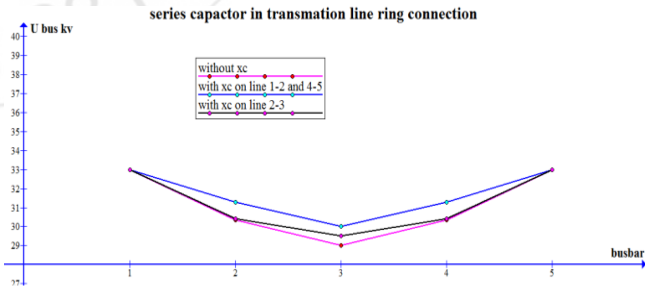

Figure 11: Voltage bus bares without and with series capacitor ring connection

b- We consider a rural overhead line of distribution, of 33 kV, which feeds 3 lateral feeders. radial connection total length line 20 km

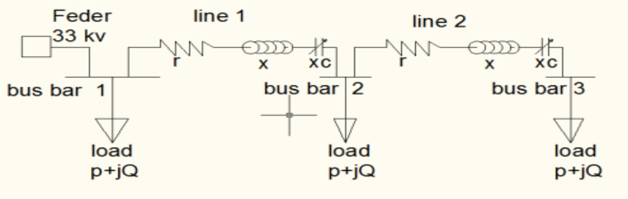

Figure 12: rural overhead line feeds 3 lateral feeders

Table 4: Without series capacitor xc

Bus	U kv	Load P+jQ	line	r	x	xc
1	33	10 +j8	1 - 2	0.9	3.6	
2	30.36	10 +j8	2 - 3	0.9	3.6	
3	29	10 +j8				

Table 5: With series capacitor xc on lines 2-3

Bus	U kv	Load P+jQ	line	r	x	xc
1	33	10 +j8	1 - 2	0.9	3.6	
2	30.4	10 +j8	2 - 3	0.9	3.6	1.6
3	29.5	10 +j8				

Table 6: With series capacitor xc on lines 1-2

Bus	U kv	Load P+jQ	line	r	x	xc
1	33	10 +j8	1 - 2	0.9	3.6	1.6
2	31.3	10 +j8	2 - 3	0.9	3.6	
3	30	10 +j8				

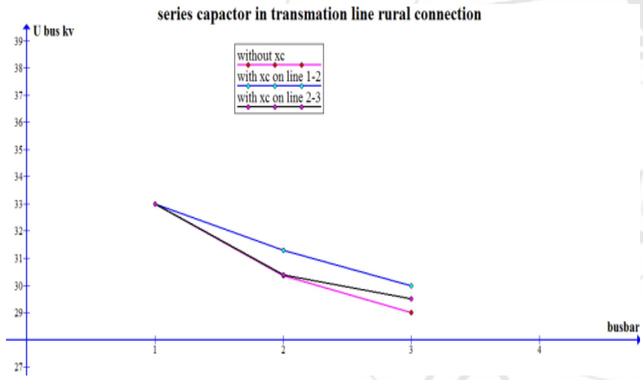

Figure 13: Voltage bus bares without and with series capacitor rural connection

6. Conclusions

In this paper, the method to "determine the optimal placement of the fixed series capacitor in distribution networks" and its reactance value has been described. And the method uses the peculiarity, which is a quality pointer of the voltage, being directly proportional to the damage caused by voltage variations in recipient nodes. The results acquired in the case study show that the location of the series capacitor and its reactance value established by the method presented in this paper leads to an improved profile of the voltage" along the line.

References

[1] Ilona, B., and Flavius Dan S. (2009), "Optimal Placement of Fixed Series Capacitor in Distribution Networks." Proceedings of the 9th WSEAS/IASME International Conference on Electric Power Systems, High Voltages, Electric Machines, 65-70

[2] Nelson J., Hermes O., and Carlos F., (2007), "AES SUL'S Experiences Using Series Compensation On Distribution System.", 19th International Conference on Electricity Distribution Vienna, 21-24 May 2007

[3] Wamkeue R., Kandil N. East J., and Boisclair Y., (2003), "Series Compensation for a Hydro-Quebec Long Distribution Line." RE&PQJ, Vol. 1, No.1, 66-72

[4] Narain G. H., Laszlo G., (2000), "Understanding FACTS Concepts and Technology of Flexible AC Transmission Systems." Book (By the Institute of Electrical and Electronic Engineers, (IEEE) Inc.3 Park Avenue, 17th Floor, New York).

[5] Miller, J., Brunet-Watson, M., and Leighfield, J.(2014) "Review of Series Compensation for Transmission Lines." PSC North America.

[6] ABB, (2010). "Series Compensation – Boosting transmission capacity". A02- 0135E, 2010-12

[7] Sobhi, A., (2015), "Basic information for overhead transmission lines." 1-33

[8] IEC 60143 "Series Capacitors for Power Systems"., Parts 1, 2, and 4