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RESEARCH ARTICLE

EFFECT OF REACTIVE POWER FLOW ON TRANSMISSION EFFICIENCY AND POWER FACTOR

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ABSTRACT

The compensation of VAR involves the management of reactive power for the improvement of electric power system performance. Power quality problems such as fast voltage profile maintenance at all power transmission levels and improvement of power factor, transmission efficiency and system stability can be solved by adequate reactive power control. This paper establishes the effect of reactive power flow on the transmission efficiency and power factor. Series and shunt VAR compensation methods were used to modify the natural electrical characteristics of power system. Series compensation was used to modify the reactance parameters of the transmission system while shunt compensation was used to change the equivalent load impedance.

Series-capacitive arrangement reduced the total reactive power loss by a large margin as compared to shunt-capacitive arrangement. Shunt-capacitive arrangement improved the system power factor by a large margin as compared to series-capacitive arrangement. Load power factor always remain constant with and without any compensation. A maximum reactive output power of 20.93KVAr gave a transmission efficiency of 88.7% and a power factor of 0.966.

The result of the work showed that shunt-capacitive arrangement reduced the total active power loss while series-capacitive arrangement had no effect on it. In both compensation methods, the line reactive power was effectively controlled thus improving the performance of the overall power system.

INTRODUCTION

The reactive power service is required for transmission of active power, control of voltage, normal and secure operation of a power system. As a result of this, the reactive power support service is identified as one of the key services in the competitive electricity market structures (Van 2011). The actual amount of power being used, or dissipated, in a circuit is called true or real power. Reactive loads such as inductors and capacitors dissipate zero power, yet they drop voltage and draw current giving the deceptive impression that they actually dissipated power (Hao 2003).

The reactive power oscillates between the source and the reactor or capacitor at a frequency equal to twice the rated value. Power dissipated by a load is referred to as true power where as power merely absorbed and returned in load due to its reactive properties is referred to as reactive power. However in nature, most of the loads are inductive loads absorbing reactive power and resulting in low lagging power factor (Majumder 2013, Dai *et al* 2003). The low power factor due to reactive power flow in line conductors necessitates large-sized conductor to transmit same power when compared to the conductor operating at high power factor.

The voltage variation is due to imbalance in the generation and consumption of reactive power in the system (Gustafson and Baylor 2008). If the generated reactive power is more than the consumed one, then the voltage levels go up and vice versa. However, if the two are equal, then the voltage profile becomes flat and it happens only when the load is equal to natural load. Unfortunately, the reactive power in a system keeps on varying and if the reactive power generation is simultaneously controlled, a more or less flat voltage profile could be maintained (Chattopadhyaya *et al* 1995, Kankar 2001). As most of the loads operate at low lagging power factor, they require significant amount of lagging reactive power during peak load condition. However, if this significant amount of lagging reactive power is supplied by the generator from the sending end, all equipment starting from the sending-end may

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be over loaded thereby causing low receiving end voltage. During off peak conditions, the line generates net VARs which must be absorbed to obtain voltage stability. Shunt compensation involves the use of shunt capacitors during peak load conditions to generate lagging VARs at the receiving end and shunt reactors during off peak conditions to absorb line generated VARs to avoid voltage instability (Bhattacharya and Zhong 2001, Rajesh *et al* 1998). Consider Figure 1 showing the equivalent circuit of an a.c generator supplying power to a practical inductive load and its phasor diagram.

It is desirable both economically and technically to operate the electric power systems at near unity power factor (u.p.f). Usually, power factor correction means to generate reactive power as close as possible to the load which it requires rather than generating it at a distance and transmit it to the load, as it results in not only in a large sized conductor but also increased losses thereby reducing transmission efficiency.

Effects of low power factor on transmission lines.

Low power factor has some effects on transmission lines as listed below (Choi *et al* 1998, Kahn and Baldick 1994, Marsteller 2008):

1. The transformers at power stations and sub-stations draw the magnetizing current which causes the total current of the line to be lagging the line voltage.
2. The industrial heating furnaces , particularly induction heating will have very low lagging power factor consuming system.
3. Arc lamps, fluorescent lamps, mercury vapour lamps etc operate at lagging power factor.
4. Transmission and distribution lines and feeders will have more inductive effects, hence more power flow through the systems will be at low power factor.
5. Effect on generators: The generated KVA and KW capacities will have low power factor. The power supplied by the exciters is increased, copper losses in the generator winding are increased and so, the efficiency of the generator is decreased.
6. Effect on transformers: The transformers which are connected to transmission lines and distribution feeders will have the effect of decrease in Kw capacity with the decrease in power factor as well as an increase in line voltage.
7. Effect on switchgear and bus-bar :The cross-sectional area of bus-bars and the contact bars account for the same amount of power to be delivered at low power factors.
8. Effect on prime-movers: The generator will develop more reactive (KVAr) or wattage power with low power factor, but certain amount of energy is needed to develop this power which is being supplied by the prime mover.

MATERIALS AND METHOD

Development of a model for power transmission system

Consider two grids connected by a transmission line assumed to be lossless and represented by the reactance X_L. $V_1 < \delta_1$ and $V_2 < \delta_2$ represent the voltage phasors of the two power grid buses with angle $\delta = \delta_1 - \delta_2$ between the two. The corresponding phasor diagram is shown in Figure 1 below.

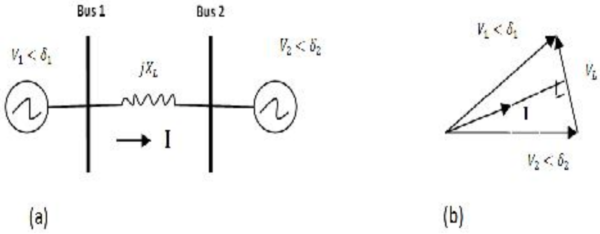

Figure 1 A simplified model for power transmission system.

In the transmission line, the magnitude of the current is given by:

$$I = \frac{V_L}{X_L} = \frac{|V_1 < \delta_1 - V_2 < \delta_2|}{X_L} \quad (1)$$

The active and reactive components of the current flow at bus 1 are given by

$$I_{d1} = \frac{V_2 \sin\delta}{X_L}, I_{q1} = \frac{V_1 - V_2\cos\delta}{X_L} \quad (2)$$

The active power and reactive power at bus 1 are given by

$$P_1 = \frac{V_1 V_2 \sin\delta}{X_L}, \qquad Q_1 = \frac{V_1(V_1 - V_2\cos\delta)}{X_L} \quad (3)$$

The active and reactive components of the current flow at bus 2 are also given by

$$I_{q1} = \frac{V_1 \sin\delta}{X_L}, \qquad I_{q2} = \frac{V_2 - V_1\cos\delta}{X_L} \quad (4)$$

The active and reactive power at bus 2 are given by

$$P_2 = \frac{V_1 V_2 \sin\delta}{X_L}, \qquad Q_2 = \frac{V_2(V_2 - V_1\cos\delta)}{X_L} \quad (5)$$

where,
$I =$ Current
V_L = Line Voltage
X_L -=Line Reactance
δ - Phase Angle
P_1, P_2 – Active Power at bus 1 and 2
Q_1, Q_2 – Reactive Power at bus 1and 2
From equations (1) to (5), it means that the active and reactive power/current flow can be regulated by controlling the voltages, phase angles and the line impedance of the transmission system. The power flow will reach the maximum value when the phase angle is 90 degrees.

The compensation of transmission systems can be divided into two main groups namely the shunt and series compensation.

Shunt reactive compensation are used in transmission system to regulate the voltage magnitude, improve the voltage quality and enhance system stability. Shunt-connected resistors are used to reduce the line over-voltage by controlling the reactive power, while shunt-connected capacitors are used to maintain the voltage levels by compensating the reactive power to transmission lines.

Consider a simplified model of a transmission system with shunt compensation as shown in Figure 2. The two buses have the same voltage magnitude V and phase angle δ. Ii is assumed that the transmission line is lossless and having a reactance X_L. A controlled capacitor C is shunt-connected at the midpoint of the transmission line. The voltage magnitude at the connection point is maintained at V.

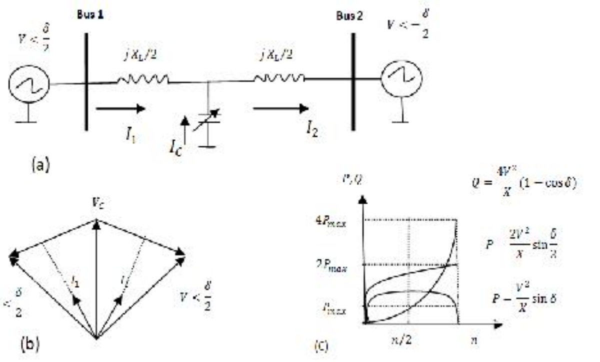

Figure 2 Transmission system with shunt compensation (a) Simplified model (b) Phasor diagram (c) Power angle curve.

The active powers at bus 1 and 2 are equal.

$$P_1 = P_2 = 2\frac{V^2}{X_L}\sin\frac{\delta}{2} \qquad (6)$$

The injected reactive power by the capacitor to regulate the voltage at the mid-point of transmission line is given by

$$Q_c = 4\frac{V^2}{X_L}(1-\cos\frac{\delta}{2}) \qquad (7)$$

where,
Q_C – Reactive power of the capacitor
X_C – Reactance of the capacitor

From the power angle curve, it can be deduced that the transmitted power can be significantly increased and the peak point shifts from 90 degrees to 180 degrees. The operation margin and the system stability are increased by the shunt compensation. The reactive power compensation at the end of the radial line is effective to enhance voltage stability.

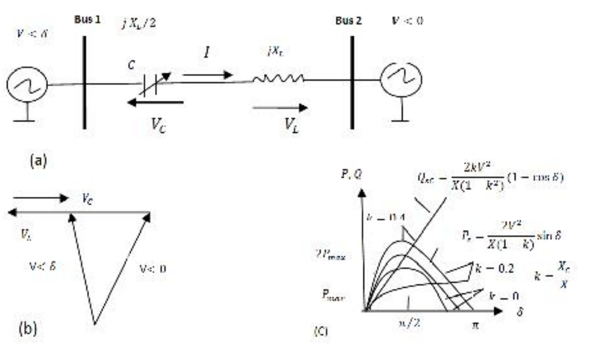

Figure 3 Transmission system with series compensation (a) Simplified model (b) Phasos diagram

Series compensation controls the overall series line impedance of the transmission line. Equations (1) to (5) show that the A.C power transmission is limited by the series reactive impedance of the transmission line.

Consider a simplified model of a transmission system with series compensation as shown in Figure 3. The two buses have the same voltage magnitude V and phase angle δ. The transmission line with reactance X_L is assumed lossless. The phasor diagram is also shown.

The capacitance C as a function of line reactance is given by

$$X_C = kX_L \qquad (8)$$

The total series inductance of the transmission line is

$$X = X_L - X_C = (1-k)X_L \qquad (9)$$

The active power transmitted is

$$P = \frac{V^2}{(1-k)X_L}\sin\delta \qquad (10)$$

The reactive power supplied by the capacitor is

$$Q_c = 2\frac{V^2}{X_L}\frac{k}{(1-k)^2}(1-\cos\delta) \qquad (11)$$

where,
X_C - Capacitance expressed as a function of line reactance
X_L - Reactance of the transmission line
Static VAR Compensator (SVC).

Static VAR Compensator is a shunt-connected static VAR generator or absorber whose output is adjusted to exchange capacitive or inductive current in order to maintain or control specific parameters of the electrical power system.

It is based on thyristors without gate turn-off capability. The operating principles and characteristics of thyristors realize SVC variable reactive impedance . SVC can be : Thyristor –controlled and Thyristor –Switched Reactor(TCR and TSR) or Thyristor –Switched capacitor(TSC).
Figure 4 below shows the diagram of SVC.

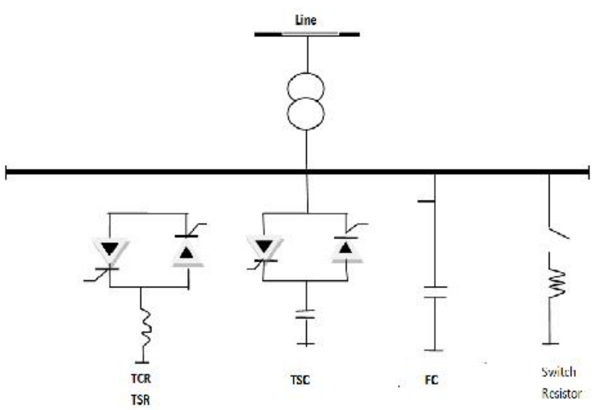

Figure 4 Static VAR Compensator..

TCR and TSR are made up of a shunt –connected reactor controlled by two parallel reverse –connected thyristors . TCR is controlled with proper firing angle input to operate in a continuous manner whle TSR is controlled without firing angle control resulting in a step change in reactance.

TSC shares similar composition and same operational mode as TSR, but the reactor is replaced by a capacitor. The reactance can only be either fully connected or fully disconnected zero as a result of the capacitor characteristics.

Simulation

A computer simulation of the two power grid systems represented by a reactance *X* and connected by a lossless transmission line is then carried out using MATLAB with voltage drop along the transmission line and output reactive power as input parameters for the computation of the reactance *X*.

Simulation Parameters

System Quantities	Standards
Supply Voltage	230V/ph
Line Impedance	L..=0.005mH, R..=0.001 ohm
Line Reactance	0.67 ohm.
Main load	Active power = 1 Mw, Reactive power = 100 VAR
Frequency	50 Hz

RESULTS AND DISCUSSION

The input and output reactive powers fluctuated throughout as illustrated in Figure 1. When the input reactive power was 16.35KVAr, the output reactive power was 8.43KVAr. The input reactive power increased to 18.96KVAr with a corresponding decrease in the output reactive power to 7.58KVAr. The values of the input reactive power decreased appreciably to 10.73KVAr with a corresponding value of 2.36KVAr in the output reactive power. The fluctuation continued throughout for both the output and the input reactive powers.

The relationship between the output reactive power and the transmission efficiency is illustrated in Figure 2. The transmission efficiency at an output reactive power of 8.43KVAr was 51.5% . At a transmission efficiency of 21.9%, the output reactive power was 2.36KVAr. This fluctuation is noticed throughout the values of the transmission efficiency and the output reactive power. The transmission efficiency became maximum at 96.4% which corresponds to a reactive power output of 14.87KVAr while the least transmission efficiency of 21.9% gave rise to an output reactive power of 2.36KVAr as evident from Figure 2.

Figure 3 illustrates how the output reactive power varied with the power factor. The power factor fluctuated as well as the output reactive power factor. The minimum output reactive power of 1.29KVAr was recorded corresponding to power factor of 0.952 even though this power factor was not the least in this range. The minimum power factor recorded was 0.746 which corresponds to an output reactive power of 15.93KVAr which was not actually the least in this range. The maximum value obtained for the output reactive power was 20.93KVAr corresponding to a power factor of 0.948 even though this value was not the largest. The maximum power factor was 0.984 corresponding to an output reactive power of 12.63KVAr which was also not actually the largest value of power factor in this case.

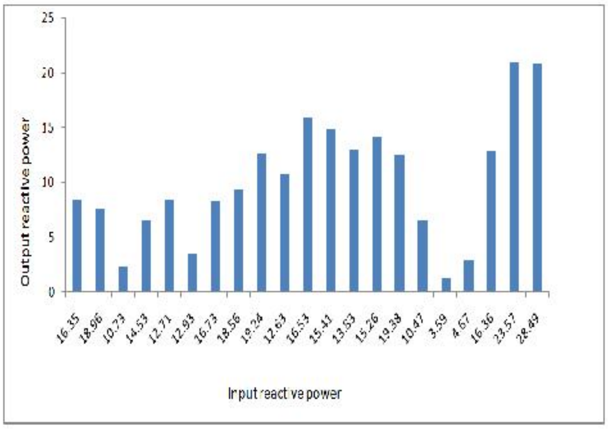

Figure 1 Output reactive power Versus Input reactive power

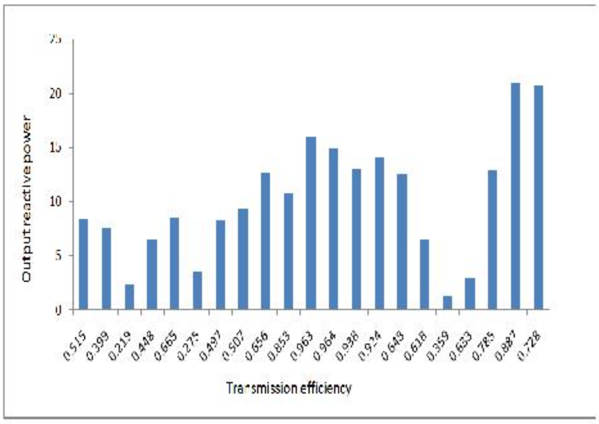

Figure 2 Output reactive power Versus Transmission efficiency

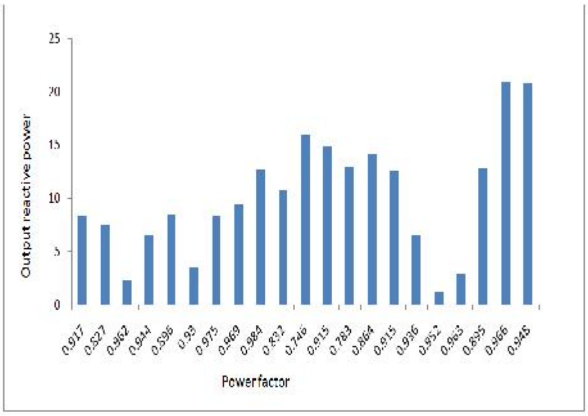

Figure 3 Output reactive power Versus Power factor

Figure 4 illustrates the relationship between the square of the voltage drop and the output reactive power. The voltage drop was 4.2volts at an output reactive power of 8.43KVAr. A high level of fluctuations was noticed in the voltage drop along the transmission line. The same trend of fluctuations was observed in the values of the output reactive powers of the transmission lines. The voltage dropped to a minimum value of

0.7 volts thus corresponding to an output reactive power of 1.29KVAr. A maximum voltage drop of 10.5volts was recorded when the output reactive power was 20.93KVAr. Thus, the voltage drop depends on the output reactive power. If reactive power flows over the transmission line, there will be a voltage drop.

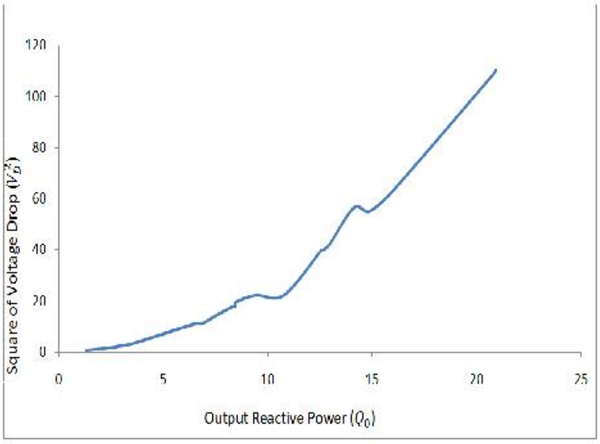

Figure 4 Square of Voltage Drop Versus Output Reactive Power

CONCLUSION

The effect of reactive power flow on transmission efficiency and power factor has been presented. Shunt-capacitive arrangement reduced the total active power loss while series-capacitive arrangement had no effect on it. Series-capacitive arrangement reduced the total reactive power loss by a large margin as compared to shunt-capacitive arrangement. Shunt-capacitive arrangement improved the system power factor by a large margin as compared to series-capacitive arrangement. Load power factor always remain constant with and without any compensation. A maximum reactive output power of 20.93KVAr gave a transmission efficiency of 88.7% and a power factor of 0.966.Shunt-capacitive arrangement reduced the total active power loss while series-capacitive arrangement had no effect on it. The line reactive power was effectively controlled in both compensation methods, thus improving the performance of the overall power system.

References

Bhattacharya K and Zhong J (2001):"Reactive power as an ancillary service", IEEE Transactions on power systems". Vol.1, No 6, Pp 294-300

Chattopadhyaya D, Bhattacharya K and Parikh J.(1995):"Optimal reactive power planning characteristics spot pricing": An integrated approach" IEEE Transactions on power systems", Vol.10. No 4, Pp 2014-2015.

Choi J.Y, Rim S and Park J(1998):"Optimal real time pricing of real and reactive powers," IEEE Transactions on power systems, Vol.13, No 4, Pp1226-1231.

Dai Y, Liu X.D, Ni Y.X, Wen F.S, Han Z.H, Shen C.M, Wu FF(2003):"A cost allocation method for reactive power service based on power flow tracing"; Electrical power system research.Vol.6, No.4, Pp59-65

Gustafson M.W and Baylor J.S(2008):"Transmission loss evaluation for electric systems", IEEE Transactions on Power Systems, Volume 3, No. 3, Pp 1026-1032.

Hao S (2003): "A reactive power management proposal for transition operators", IEEE Transactions on power system, Vol. 18, No 4,Pp 1374-1381.

Kahn E and Baldick R.(1994):"Reactive power is a cheap constraint", The Energy Journal, Vol.15, No 4, Pp 191-201.

Kankar B and Jin Z (2001):" Reactive power as an ancilliary service", IEEE Transactions on power systems, Vol. 16, Issue 2, Pp 294-300.

Majumder R (2013):"Reactive power compensation in single-operation of micrograds "IEEE Transactions on Industrial Electronics, Vol.60, No.4, Pp1403-1416.

Marsteller G.F. (2008): "Analytical notes on the economics of power factor" Current. Journal of the Institution of Electrical Engineers, Vol.6, No.6, Pp 975-983.

Rajesh R, Fernando A, Arrthur M, Robert C and Susan J(1998):"Determination of location and amount of series compensation to increase power transfer capability", IEEE Tranactions on Power systems, Vol. 13, No. 2, Pp 294-300.

Van C.T (2011):"A method to compute reactive power margin with respect to voltage collapse", IEEE Transactions on power systems, Vol. 6, No. 1, Pp 145-156.

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