VOLTAGE CONTROL USING SYNCHRONOUS CONDENSER

Motivation:

Owing to the inevitable resistance & reactance of all conducting systems (whether overhead lines or underground cables), there will be a drop of volts along the system when current is flowing and further this drop will vary with the current and the power factor. In short transmission lines, it is possible to design an economical system in which the voltage drop does not exceed values which are outside the capacities of he automatic voltage regulators which control the generator terminal voltage.

With very long transmission lines, the line capacitance becomes significant, this having the effect not only of adding its own component to the total line drop, but also of causing wide variations of power factor with changes of load. This, combined with the fact that the total line drop with such a system cannot be kept at the low percentage value as in short lines, necessitates that the control of the load end voltage shall be effected by an entirely different method.

Several methods are used to achieve the voltage control and one such method is to connect an idle running synchronous motor, called a synchronous condenser across the line at the receiving end. A detailed study of the synchronous condenser performance and its Var compensation capability is necessary for deciding the compensation to be provided in a power system for an efficient & smooth voltage control.

Objective:

1. To determine the change in voltage, voltage regulation, line power factor and transmission efficiency for varying loads with & without Var compensation.
2. To determine the Var to be supplied by a synchronous condenser for maintaining zero regulation for a given transmission line for varying loads.

Theory

A synchronous condenser is a synchronous motor operating at no load. It is a property of such a motor that it takes lagging kVA, when the field current is below a certain value, and a leading kVA when the field current is above this value. The efficiency of this machine is very high. The real power it takes will be small, just its losses. For simplicity, let us consider a line having resistance R and inductive reactance X, and work in terms of voltage to neutral Ep, which may be assumed to be the same at the two ends of the line.

Let I_1 = load current a t a p.f of Cos ϕ

And I_m = synchronous condense r current

It is convenient to split I_1 into its in phase and quadrature components i.e.

Ia $= I_1$ Cos ϕ, the in -phase component

Ib $= I_1$ Sin ϕ, the quadrature component

The three currents Ia, Ib and $_{Im}$ produce resistance & reactance drops per phase of Ia R, Ia X; I_bR, I_bX; I_mR, I_mX, the resistance drops being in phase with and the reactive drops being in quadrature leading with the corresponding currents. The

phasor diagram is shown in FIG.1. Note that since I_m and I_b are in direct opposition and that $I_{m\ must}$ be greater than I_b, the four drops due to these two currents simplify to

$(I_m - I_{b)}$ R in phase with I_m

and $(I_m - I_b)X$ I quadrature leading I_m
. Since the lengths OA and OF are to be equal, we have from FIG.1
$OF^2 = (OA + AB - DF)^2 + (BC + CD)^2$

Therefore, $Ep^2 = [Ep + Ia R - (Im - Ib) X]^2 + [IaX + (Im - Ib) R]^2$

This is an equation with only one unknown, viz. Im, and the solution therefore gives the necessary wattless leading current to be taken by the synchronous condenser. Finally, wattless kVA capacity of the condenser

$= 3Ep\ Im/1000 = \sqrt{3}.\ E\ Im\ /1000$

where E is the L-L voltage.
Generally the load delivered by a transmission line is not constant and it is thus possible to prepare a family of curves from which one can tell the VAR required for any load at any power factor normally expected to be supplied using a given transmission line.

Pre-experimental quiz

1. Why does an a.c transmission line require Var input?
2. A synchronous motor can be operated at a desired power factor by varying the excitation of the motor
a. True
b. false
3. A synchronous capacitor is nothing but a synchronous motor running on no load with overexcitation
a. True
b. False

Equipment

3-phase variac, transmission line model, wattmeters, voltmeters, ammeters, RLC load units

Procedure:

1. Connect as per the connection diagram shown in FIG.2 and maintain the sending end voltage constant at 400 V
2. Vary the loads at the receiving end and measure Vr, I $_{line}$, I $_{load}$, Wload and Ws.
3. Synchronise the machine connected at the receiving end of the transmission line to the mains and let it run as a synchronous motor.
4. Starting at zero, increase the excitation current till the line current becomes a minimum.

5. Adjust the excitation gradually and make the receiving end voltage equal to the sending end voltage (say 400 V0. Note the Var taken by the synchronous condenser (including the sign) at various steps in the process.
6. Keep the receiving end voltage at this value (say 400 V). Switch on a load of about 1A at u.p.f.
7. Adjust the excitation of the synchronous condenser and the variac to make both the sending and receiving end voltages 400 V and note the Var taken by the condenser. Also record I $_{line}$, I $_{load}$, I sync.condenser, Wload and Ws.
8. Repeat steps 5 & 6 for different values of load at u.p.f
9. Repeat steps 3 to 6 for inductive as well as capacitive loads.
10. If suitable combinations of inductances & capacitances are available , repeat steps 3 to 7 for different load power factors.

Precautions:

1. Take care to see that the synchronous motor runs stably i.e. there are no voltage & current oscillations, especially with capacitive loads.
2. Increase the load in small increments preferably 1-2 % of system capacity.

Data Sheet:

NO Var COMPENSATION

S.No.	Vs	Vr	I $_{line}$	I $_{load}$	Wload	Ws
S.No.	Vs	Vr	I $_{line}$	I $_{load}$	Wload	Ws

WITH Var COMPENSATION

S.No.	Vs	Vr	I $_{line}$	I $_{load}$	Wload	Ws	Var

Data Processing & analysis;

1. For each type of load, draw the curves VAR versus power taking care of the sign
2. For any given load condition, draw its voltage-reactive power output characteristics of he synchronous condenser.
3. Compare the experimental results with the theoretical results for a known load and p.f

Post-experimental quiz:

1. With a 100 MVA generator operating at 85 % p.f lagging, how much Mvar is produced?

2. To what MW load should the above machine be limited so that its MVA rating will not be exceeded?
3. Can the synchronous condenser deliver the rated output both on leading & lagging power factors?
4. Can the synchronous condenser be operated at zero p.f?
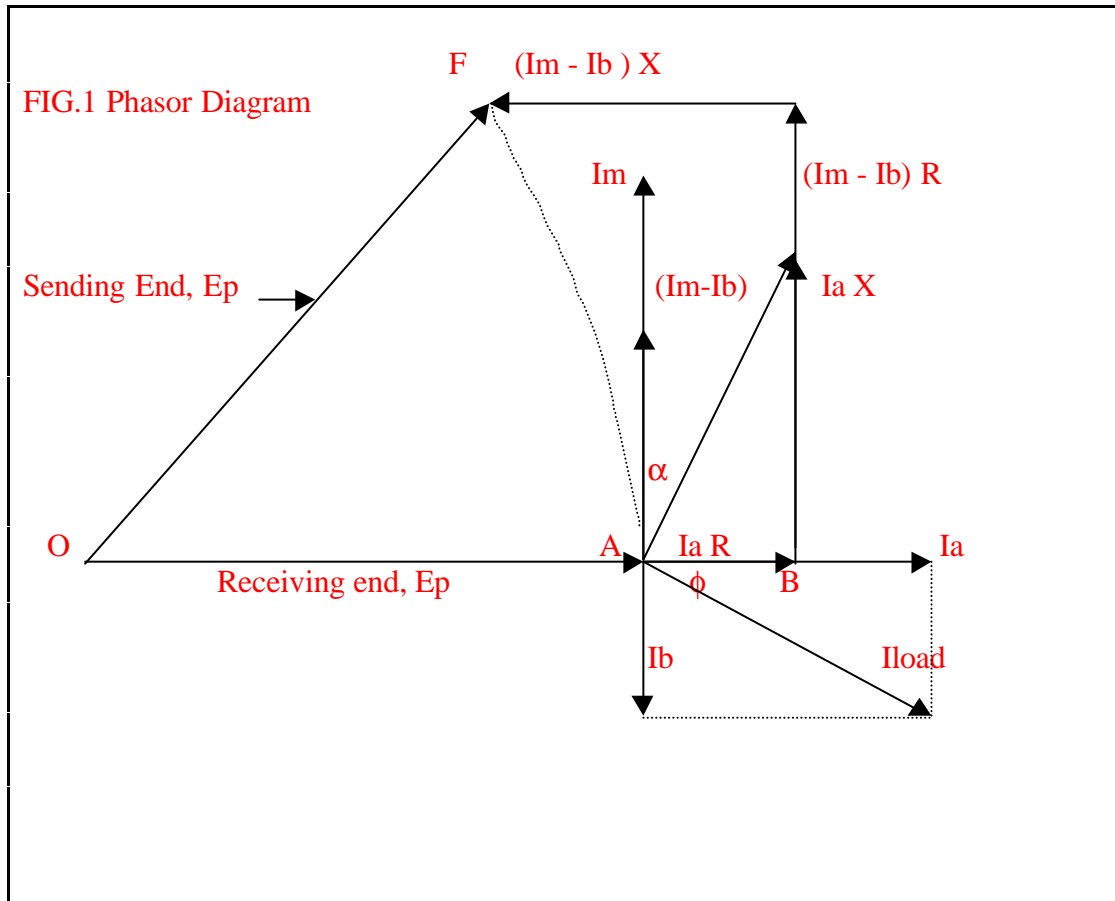5. What are the other methods of voltage control employed in power systems?

FIG.1 Phasor Diagram

FIG.2 on the next page

FIG.2

3-phase
400V
50Hz
supply

I_{line}

A

v

v

A

I_{sc}

Var measurement

Field

+
20V
DC
Supply
-

3-phase Variac
3-phase wattmeters
Transmission Line model

Synchronous Condenser

A I_{load}

3-phase wattmeters

R,L,C load units