ISSN 2229-5518

Reactive Power Compensation Technique

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Abstract— Present power system scenario reveals that it has some limitations, leaving behind a scope of improvement in this area. Maintain ing a stable, cost-effective and secure operation of power system is therefore a very important and challenging issue. Power can be utilized economically by minimizing its reactive component.

At present thysistor-switched capacitors and thysistors-controlled reactors are as "active compensator". Apart from the cost consideration, these suffer constructional limitations and are not suitable for power handling. Moreover, the triggering circuits used for such capacitors and reactors are quite complicated. However the present work attempts to overcome the above drawbacks and provides an improved system effecting feedback and open loop control for compensation in power system which comprises of (i) step down transformer (T), (ii) bipolar junction transistor (BJT) or MOSFET, vacuum triode or any electric amplifier (Q_1), (iii) coupling capacitor(C_c) connected transformer (T), (iv) power frequency choke(L_c), (v) AC biasing indicator(L_1),AC biasing resistors(R_1) and (R_3) (vi) blocking capacitor(C_b), (vii)DC emitter feedback resistor(R_2),(viii) AC bypass capacitor and AC biasing capacitor(C_2) (ix) DC biasing Resistor (R_{b1}) and(R_{b2}),(x) regulated DC supply voltage(V_{cc}).

Index Terms— Reactive Power, load compensation, line compensation, induction generator

1 Introduction

In the present work, an attempt has been made to envisage various ways for use of reactive power by adjusting the power factor of the system both the line side and load sides by using closed loop control with help of amplifiers which include both vacuum tubes and solid state devices, with an emphasis on making the system cost-effective too.

The main type of compensation in power systems are load compensation and power compensation. In load compensation, power is adjusted with respect to an individual load and compensating device is connected across the load itself to achieve the main objectives of better voltage profile, power factor correction and load balancing.

In line compensation, on the other hand, the electrical characteristics of a power line are modified using devices In line compensation, on the other hand, the electrical characteristics of a power line are modified using devices to minimize the Ferranti effect usually happening with hydroelectric power stations, generally located far away from the load center, to avoid the under excited operation of the alternators, and thereby enhance power transfer capability of the system.

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2 THEORETICAL BACKGROUND

A. A new approach for compensation in power system

The present research work is a new approach which relates to an improved system for effecting feedback as open loop control in power system. More Particularly this approach pertains to a system and method which is simple yet cost effective suitable for both load and line compensation in power system using an open or closed loop control with amplifying devices.

B. The principle of operation

Basic reactance modulator used in frequency modulation transmitter for providing a voltage variable reactance behaves as a three terminal reactance which can be made inductive or capacitive using appropriate components in the gate biasing of an amplifier at the power frequency. The value of reactance depends on the trans conductance (g_m) of the devices, which is turn can be made to depend on the bias applied to the control terminal and its variables. Any amplifying device such as Bipolar Junction Transistors (BJT), field effect transistors (FET), Insulated Gate Bipolar Transistor (IGBT) or vacuum Triode Tubes (VTT) can be used as a voltage variable reactance.

Basic reactance modulator: if certain simple conditions are made, the impedance Z, as seen at the input terminals A-A (Drain and Source), is almost entirely reactive. Z can be controlled by a signal at the third terminal i.e. Gate. The circuit shown in Figure 1 is the basic circuit of a FET reactance modulator, which behaves as a three terminal reactance. It can be made inductive or capacitive by a simple component change. The value of this reactance is proportional to the trans conductance of the device which in turn can be made to depend on the gate bias and its variation.

In order to determine Z, a voltage 'v' is applied to the terminal A-A between which the impedance is to be measured and the resulting current 'i' is calculated. The voltage is then divided by this

ISSN 2229-5518

current, given the impedance seen when looking into the terminals.

To make Z pure reactance- capacitive here, the bias network

current i_b must be negligible compared to the drain current. That is to say, the impedance of the bias network must be large enough to be ignored.

$i_b = v/(R-jX_c)$

$v_g = Ri_b = Rv/(R-jX_c)$

now FET drain current,

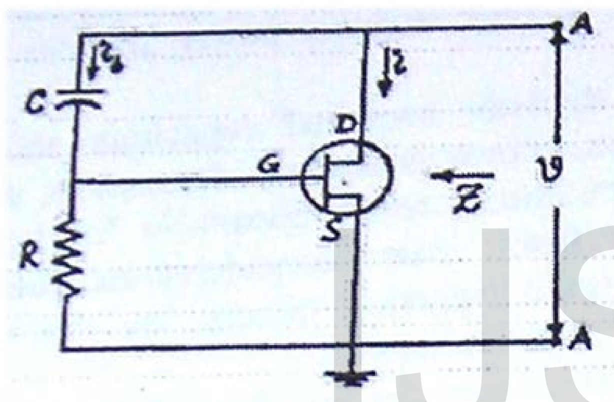

Fig.1. A FET reactance modulator

$i = g_m v_g$

$= g_m Rv/(R-jX_c)$

Therefore, $Z=r_0-jx_0/g_m$

Where, $r_0=i/g_m$

And $x_0 = X_c/g_m R$

$= 1/wC_0$

Where, C0 = g_mRC, which shows the capacitive effect

Also we can write if Xc>>R,

$$Z = -jXc/g_m R = 1/2\pi f g_m RC$$

Again, if we interchange the the a.c biasing components the circuit becomes (as shown in Fig. 2):

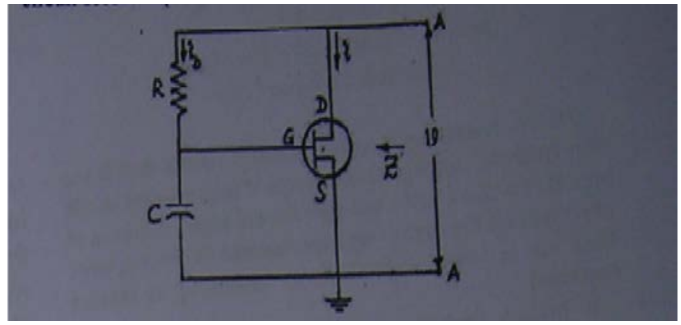

Fig.2. A FET reactance after inter charging A.C. biasing components

Now, $Z = r_0 + jwL_0$ (4)

Where, $r_0 = 1/g_m$ (5)

And $L_0 = RC/g_m$ (6)

This shows the inductive effect.

Instead of using C in the a.c biasing circuit if we use L then the circuit will show the inductive effect. Again by interchanging, the gate biasing components i.e., R and L, shows the capacitive effect.

It can be summarized as:

TABLE I. FOR LOAD SIDE COMPENSATION

Component (a.c biasing)	Zgd	Zgs	Condition	Reactance
RC	C	R	Xc>>R	$C_{eq} = g_m RC$
RL	R	L	R>>XL	$C_{eq} = g_m L/R$

TABLE II. For Line Side Compensation

Component (a.c biasing)	Zgd	Zgs	Condition	Reactance
RC	R	C	R>>XC	$L_{eq} = RC/g_m$
RL	L	R	XL>>R	$L_{eq} = L/g_m R$

Now, for load side compensation,

$C_{eq} = g_m RC$

Taking loge on both sides, we have,

$\ln C_{eq} = \ln g_m + \ln R + \ln C$ (8)

$\partial C_{eq}/C_{eq} = \partial g_m/g_m + \partial R/R + \partial C/C$ (9)

Again, $C_{eq} = g_m L/R$ (10)

$\ln C_{eq} = \ln g_m + \ln L/L – \ln R$ (11)

$\partial C_{eq}/C_{eq} = \partial g_m/g_m + \partial L/L - \partial R/R$ (12)

Also for line side compensation,

$L_{eq} = RC/g_m$ (13)

ISSN 2229-5518

$\ln L_{eq} = \ln R + \ln C - \ln g_m$ (14)

$\partial L_{eq}/L_{eq} = \partial R/R + \partial C/C - \partial g_m/g_m$ (15)

And, $L_{eq} = L/g_m R$ (16)

$\ln L_{eq} = \ln L - \ln g_m - \ln R$ (17)

$\partial L_{eq}/L_{eq} = \partial L/L - \partial g_m/g_m - \partial R/R$ (18)

From the above equations, it is found that without disturbing the bias voltage, in general we can employ the system more efficiently by adjusting the values of R and L as per requirement of the system.

This voltage variable reactance technique used in FM transmitter is now being employed in the proposed compensation device.

Application of the system of the present research work for power system compensation, i.e., use of voltage variable reactance has been illustrated in fig. 5 showing line and load side compensations respectively, form which in may be noted BJT has been used. In Fig.3 the device in each acts as a voltage variable inductor with the condition

$XL = wL >> R$ (19)

Here L = L1 and R + R1, shown Fig.3

Where $w=2\pi f$, f being the system frequency in Hz. The variable inductance is given by

$L_{eq} + L/g_m R$ (20)

Where, g_m = trans or mutual conductance in siemen of the amplifying device used (here BJT, reference Fig.3)

And $L_{eq} = RC/g_m$ (21)

Where, $R >> 1/wC$ (22)

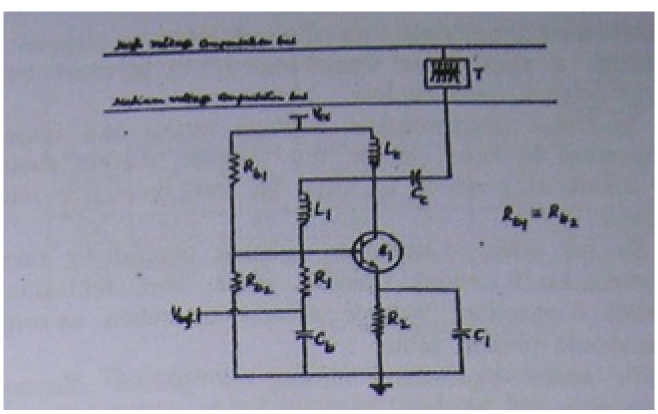

Fig.3. the voltage variable inductor

The dc bias voltage +Vcc can be derived from a combination of voltage regulator and a three phase rectifier bridge. The bias voltage V_{ref} applied to the base of the BJT can be obtained from a three phase power factor type device employing the principle of rotating magnetic field. The variation of V_{ref} can be used to vary the trans conductance g_m and hence the value of L_{eq} in equations (20) and (21) or the value of C_{eq} in equations (25) and (26) can be applied within limits for power factor corrections in each case.

In case of voltage variable reactance using static amplifying devices like BJT,FET,IGBT or vacuum triodes, there is no need of use of supplementary devices due mainly to their extremely fast response.

C. Equivalent circuit of the proposed compensation device

Generally for reactive power compensation in the load side, capacitive effect is required for the power factor improvement. Similarly for the same reason in case of line side to reduce Ferranti effect, inductive effective is required.

As we know from the expression of Z that

$$Z = 1/g_m - jXC/g_m R = 1/g_m - j/g_m RC$$
$$= 1/g_m - j/2\pi f g_m RC \quad (23)$$

From this expression the equivalent circuit of the compensating device for each phase can be drawn as:

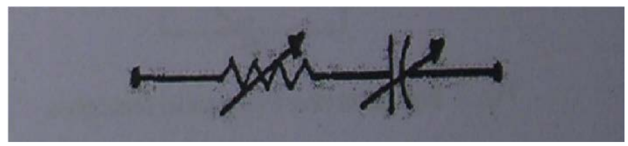

Fig.4: Equivalent Equation

This is the basic equivalent circuit of the compensating device. The specific component wise equivalent circuit can be drawn by taking g_m value in consideration. For BJT as a basic component we generally use it in this purpose in CE mode, for FET in CS mode and for IGBT in CE mode and for vacuum triode we use common cathode circuit here.

In series compensation, impedance drop should be as small as possible, current rating should be equal to the load current, otherwise the current must be stepped down through a step down transformer (C.T), g_m must be high and reactance must be low.

In shunt compensation, voltage rating and impedance drop must be equal to the line voltage, current should be as small as possible, g_m must be low, reactance must be high.

So for series connection, current should be taken as reference i.e., it should remain same for shunt or parallel connection, voltage should be taken as reference i.e., it should remain same.

For series equivalent circuit, the phasor diagram of each phase will be as:

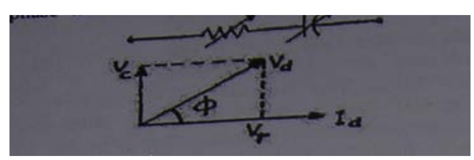

Fig.5. Equivalent circuit and Phasor diagram

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Where $\Phi = \tan^{-1} Vc/Vr$ and Vc = capacitor voltage and V_d = device voltage, Vr = resistor voltage, Id = device current. The three phase connection of this compensating device will be as shown in Fig.6

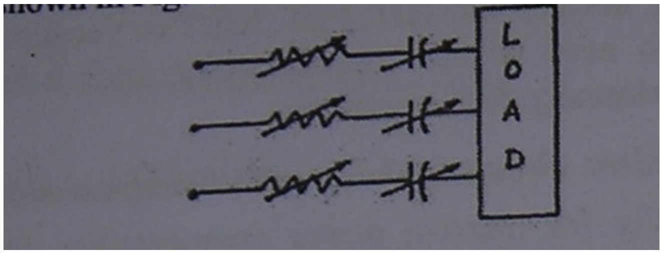

Fig.6. Equivalent circuit and phasor diagram

Equivalent circuit for shunt connection can be drawn from:

$$Y=\frac{1}{Z}=\frac{1}{\frac{1}{g_m}-\frac{jX_c}{g_m R}}=\frac{\frac{1}{g_m}+\frac{jX_c}{g_m R}}{\frac{1}{g_m^2}+\frac{X_c^2}{g_m^2 R^2}}=\frac{\frac{1}{g_m}}{\frac{1}{g_m^2}+\frac{X_c^2}{g_m^2 R^2}}+j\frac{\frac{X_c}{g_m R}}{\frac{1}{g_m^2}+\frac{X_c^2}{g_m^2 R^2}}$$

Therefore, the equivalent circuit is as shown in Fig.7

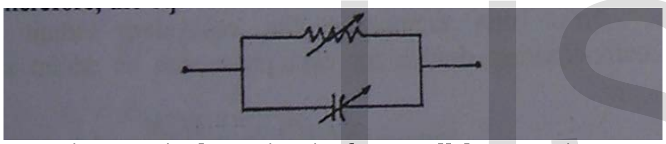

Fig.7 Equivalent Circuits for parallel connection

3 Conclusion

In future the proposed system can be used for enhancement of Generation, capacity better protection system, advantages of use of asynchronous generator, in non-conventional energy sources potential for better utilization of fuel in transport services.

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