SUPPRESSION OF VOLTAGE RISE AT THE GENERATOR TERMINALS BY THE APPLICATION OF AN H.V.D.C. LINK ON REMOTE LOAD INTERRUPTION

A DISSERTATION
submitted in partial fulfilment of the
requirements for the award of the Degree
of
MASTER OF ENGINEERING
in
ELECTRICAL ENGINEERING
(Power System Engineering)

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CERTIFICATE

CERTIFIED that the dissertation entitled, 'SUPPRESSION OF VOLTAGE RISE AT THE GENERATOR TERMINALS BY THE APPLICATION OF AN H.V.D.C. LINK ON REMOTE LOAD INTERRUPTION' which is being submitted by Shri Rajendra Kumar Jain in partial fulfilment for the award of Degree of Master of Engineering in 'Power System Engineering' of the University of Roorkee, Roorkee is a record of student's own work carried out by him under our supervision and guidance. The matter embodied in this dissertation has not been submitted for the award of any other degree or diploma.

This is further to certify that he has worked for a period of 7 months from February to August, 1976 for preparing dissertation for Master of Engineering degree at this university.

9/10

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SYNOPSIS

When a load is interrupted at a remote end of an a.c. transmission line, it is seen that voltage rises at the Generator terminals. The causes of voltage rise at the generator terminals on remote load interruption have been discussed. The literature available at this stage has been appended briefly. The rectifiers and inverters control has been discussed in brief. The inductive properties of H.V.D.C. link have been brought out. The effect of an H.V.D.C. link on suppression of voltage rise at the generator terminals on remote load interruption has been established. The percentage error has also been obtained between the results worked out by calculation and existing practical obtained one. The methods of suppression of voltage rise at the generator terminals on remote load interruption have been discussed. The author has also discussed the practical available test resultson the suppression of voltage rise at the generator terminals on remote load interruption with the application of H.V.D.C link.

CONTENTS

CHAPTER I

INTRODUCTION

When the receiving end of a long distance a.c. transmission line is opened because of the bus bar fault, Ferranti effect and speed increase of the generator result in an extraordinary rise of generator terminal voltage.

The dynamic over voltages which occur on opening the receiving end circuit breaker can be quite high on the generator terminals as the line charging M.V.A. is of the same order as the generator M.V.A. Thus, the system over voltages are quite high for several seconds after the load rejection, and over voltage at this time may determine system insulation requirements.

When over speed occurs as a result of full load rejection, the speed governor acts to close the gate linearly in nearly 5 seconds after 1 second time delay. So there is abnormal voltage rise at the generator terminals during 1 sec.

In order to prevent this abnormal voltage rise, a shunt reactor bank might be installed between the transmission line and ground. If a.c. system is coupled with a d.c. system the amount of the above mentioned shunt reactor may be reduced (possibly to zero).

CHAPTER II

BRIEF INTRODUCTION OF H.V.D.C. SYSTEMS

2.1 BASIC THEORY AND BRIEF DESCRIPTION OF THE OPERATION OF RECTIFIER AND INVERTER:

The main essential equipment, responsible to contribute a H.V.D.C. system are converters at both the ends of the d.c. line and their associated control arrangements, converter transformers and smoothing reactors. The smoothing reactors at the two ends are used to limit the rate of rise of current and to reduce the ripples in the d.c. output.

The universally accepted three phase bridge connection known as Graetz connection, which provides the best utilization of the transformer is used every where. The basic bridge configuration for the operation of rectifier and inverter are shown in Fig 2.1(A) and Fig.2.2(A) respectively. Fig 2.1(B) and Fig.2.2(B) shows the oscillograms of the output voltage for rectifier and inverter respectively.

In rectifier the valve conduction can be delayed or accelerated by controlling the grid operation. The relation of rectifier for delay angle α is given(6) by,

$$V_d = \frac{3\sqrt{2}}{\pi} E \cos \alpha \qquad (2.1)$$

Here V_d is d.c. output voltage and E is r.m.s value of a.c voltage between two phases.

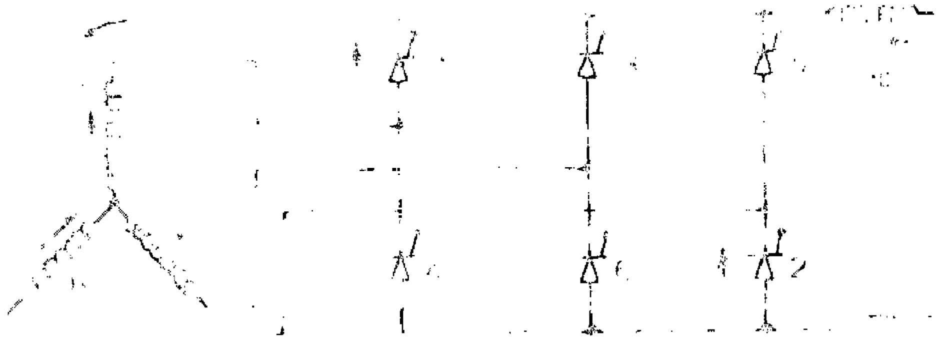


Fig.2.1(A) Valve arrangement.

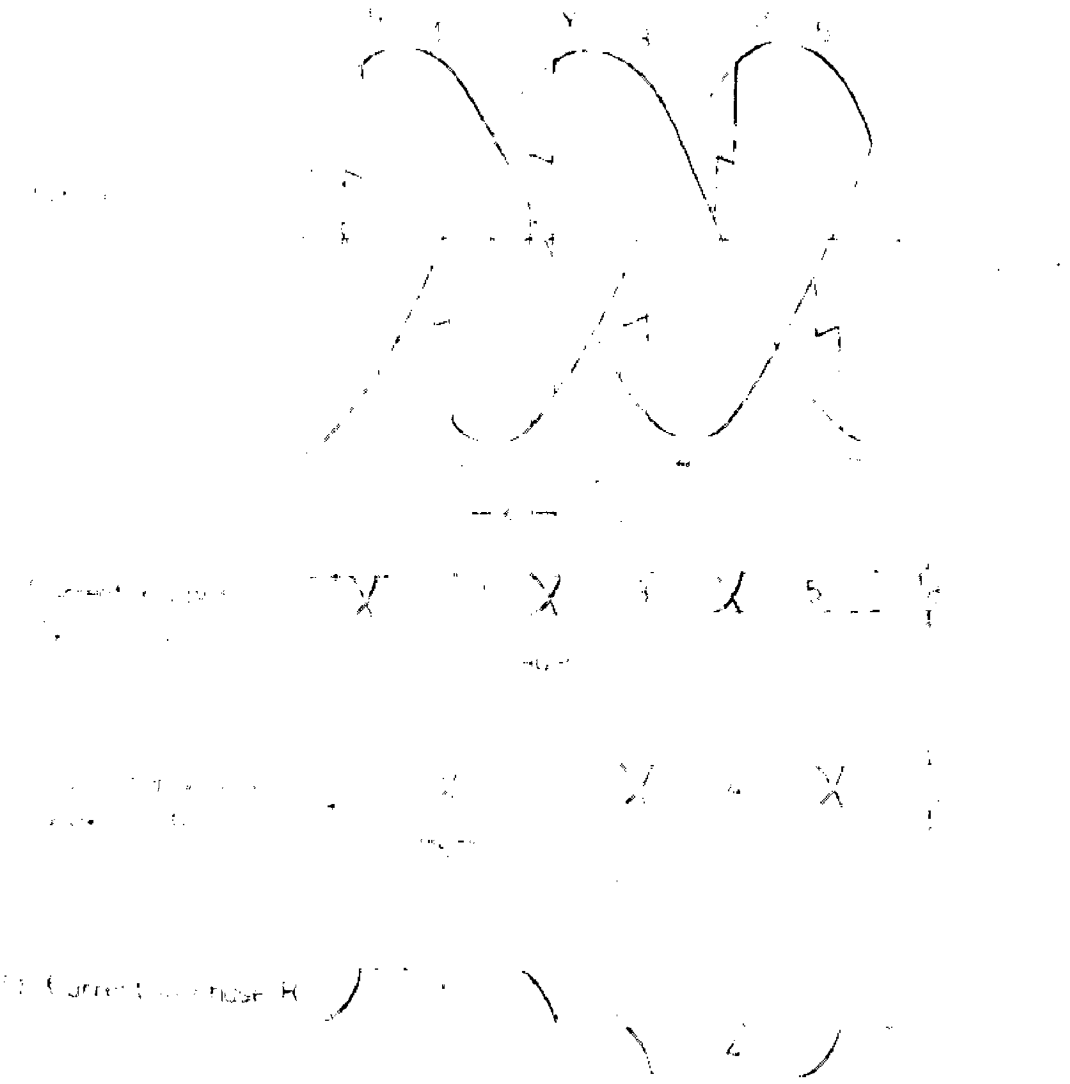


Fig.2.1(B) Operation as a rectifier.

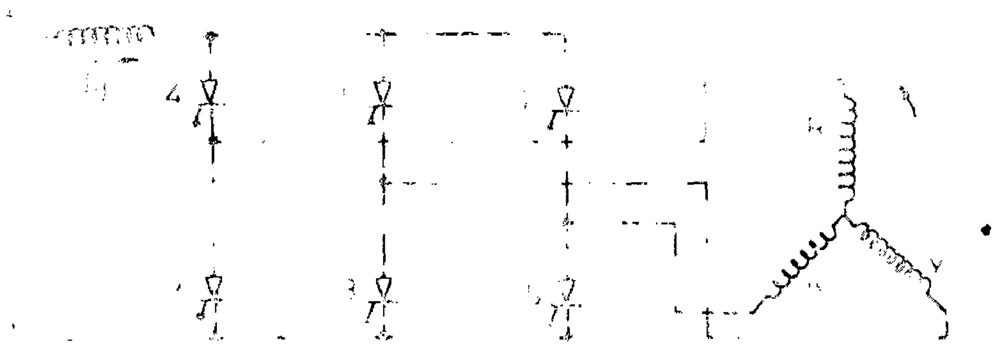


Fig.2.2(A) Inverter valve arrangement .

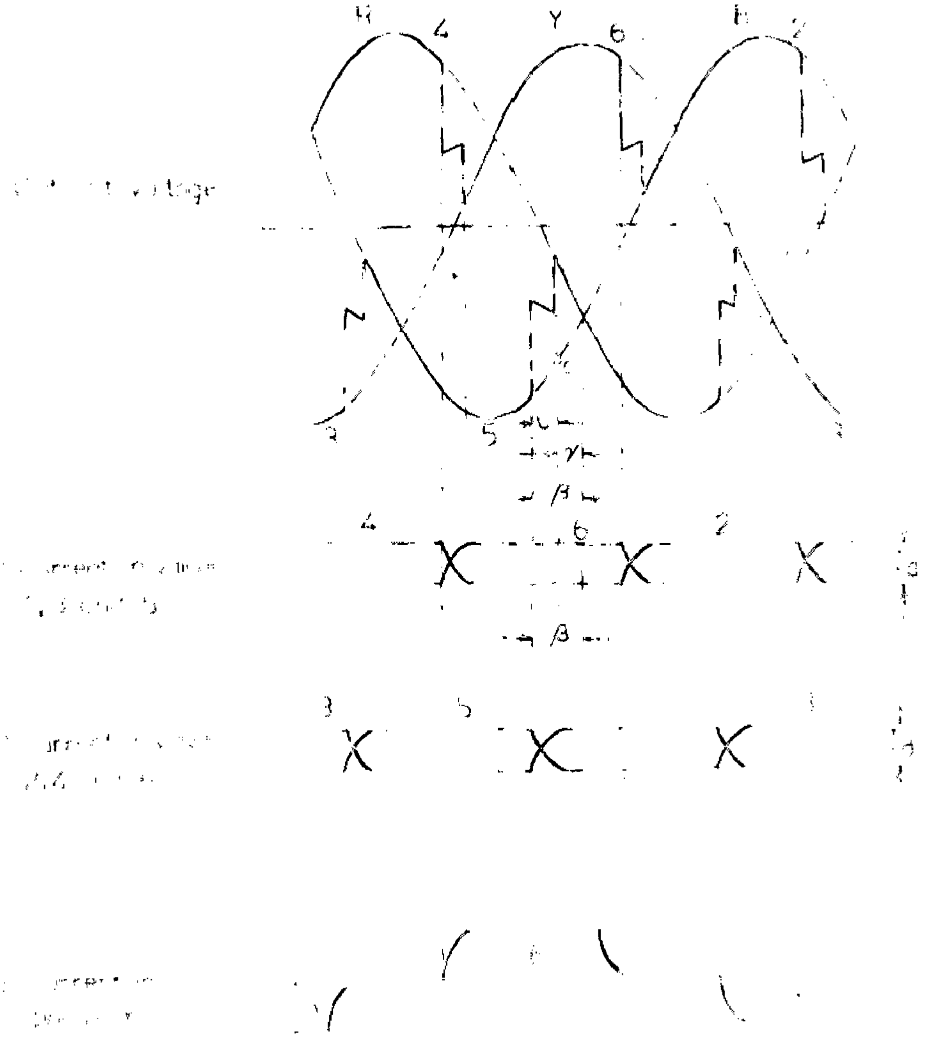


Fig.2.2(B) Operation of an inverter .

When one value stops conducting, the current does not immediately decline to zero, but it takes a finite time corresponding to an angle 'u' electrical degree, to come to zero, due to the reactance of a.c system. Similarly the current does not attain I_d(Direct Current) value immediately in the incoming valve when it is rendered conducting. As shown in Fig.2.1(B) and Fig.2.2(B), the period 'u' is known as over lap angle. There is also a reduction of direct voltage due to the overlap angle. Therefore net output voltage can be expressed in mathematical terms as follows:

$$V_d = \frac{3\sqrt{2}}{\pi} E \left[\frac{\text{Cos } \alpha + \text{Cos}(u+\alpha)}{2} \right] \tag{2.2}$$

$$I_d = \frac{E}{\sqrt{2}\omega L} \left[\text{Cos } \alpha - \text{Cos}(\alpha+u) \right] \tag{2.3}$$

Here L is the inductance of transformer winding. Equation 2.2 shows that by increasing α d.c. average voltage goes on decreasing, passes through zero, and when α equal or exceed 90^0, the average voltage becomes negative. Now if an external d-c voltage forces the current in the direction, in which the valve conducts against the negative voltage, the firing angle is known as 'angle of advance firing' and is given by,

$$\beta = 180^0 - \alpha$$

It is important to note that current is still flowing in the same direction forced as the rectifier voltage. During inverter operation it is important to note that commutation is to completed before the point 'C' in Fig 2.2(B). In fact commutation must be completed with certain extinction angle, γ_o, before voltage zero. The angle γ_o enable the valve to deionise, other-wise same valve will conduct again and take current from next valve. It is therefore, very important to give the inverter sufficient angle of advance $\beta = \gamma_o + u$. Therefore delay angle control is an essential feature for an inverter operation.

Since the inverter is merely a rectifier with delay angle α greater than 90^o, the same equation No.2.3 and 2.4 will hold good for inverter operation also. The inverter equation are expressed interm of advance firing angle β and extinction angle γ_o. The expression for direct voltage and current are,

$$V_d = \frac{3\sqrt{2}}{\pi} E \left[\frac{\mathrm{Cos}\ \beta + \mathrm{Cos}\ \gamma_o}{2} \right] \tag{2.5}$$

$$I_d = \frac{E}{\sqrt{2}wL} (\mathrm{Cos}\ \gamma_o - \mathrm{Cos}\ \beta) \tag{2.6}$$

2.2 CONTROL OF RECTIFIERS AND INVERTERS

The theory of the converter operation shows that direct voltage and current are function of α and u for rectifiers and β, u, and γ for inverters. By varying these quantities in a suitable way, the converters can be given any desired characteristic over its range of operation. The selection of the converter characteristics therefore should be such as to meet the requirement of regulation and protection.

The trend in d.c. transmission is that power transmission is controlled by the rectifiers and it is important to consider the operation of the valves strictly with in their current rating, since there is substantial risk of damage in case of current exceeds the rated value. This resulted in the incorporation of constant current control(C.C. Control) in the rectifier side. In case the current rises above the particular setting, the constant current control immediately increase the delay angle α, there by reduces the output voltage, consequently the current is brought to the set valve. In addition to the constant current control rectifier is provided with automatic tap changer. On the other hand safety of operation has to be kept in view, in case of inverter operation. To guard the safety, the inverters are provided with a control such that the firing angle is always in optimum value to enable the grid attaining its deionisation state and to have the reactive power consumption with in limit.

2.3 APPLICATION OF H.V.D.C. SYSTEM:

Since the major super thermal stations will be located near to the pitch heads, a problem of 'pumping out the bulk power' from the super thermal stations into the national grid is characteristic of the sixth plan power network configrations.

Hence one of the possible applications would be connecting the large super thermal station of more than 1000-1500 M.W. to a convenient point of the national grid. This does not preclude the rightful necessity of interconnection of the supper thermal station into a ring of trunk lines amongst the other large thermal stations in the coal belt areas. Alternatively, supper thermal station located on the periphery of the coal belt regions could be connected by an H.V.D.C. line to load centre through a point to point power transfer of bulk power. It is obvious this proposition may prove economical solution in comparison to E.H.V. A.C. only if longer distances are involved. An example of this could be interconnection of Chandrapur-Umrer super thermal stations to load centres near Bombay- Poona area. This link could be in parallel to 400 K.V. A.C. Koradi-Kalwa transmission and may serve as a stabilising measure for bulk power transmission in the area. Another example would be connection of the eastern periphery of the coalbelt to the Calcutta load centre.

The major hydro resources are located in the northern Himalayan region. Power from these hydrosites- with potential upto 1000 M.W. stations may be fed into the national grid by means of H.V.D.C. lines. Distance involved would be of the order of 200-350 kms in such cases.

Interconnection between Grids-National Level:

At present there is a plan to connect the regional power systems into National grid. The regional grids themselves would develop into major system in the next fifteen years and the pattern of formation of such systems may have to be reconsidered. It is common experience that the operation of such interconnected systems poses problems from the point of view.

(a) Stability of system
(b) Short circuit levels going too high
(c) Control of frequency
(d) Generator terminal voltage rise on remote load interruption.

Improvement of System Stability:

The transient stability of an a.c and d.c system is much better than that of an a.c system only and the transient stability can be improved with stability limits increased by effecting a control of the current. in the d.c system or by a damping method in which surplus power is dissipated through a high resistance connected in parallel with the a.c lines.

According to control methods, the power flow of d.c system can be controlled by which disturbance in a paralleling a.c system may be removed with out delay. If the d.c power is rapidly increased in case of the a.c system faults, the transient stability is improved.

Limiting of Short Circuit Levels:

The short circuit currents in any developing power system, increase fast with the addition to the directly connected generators and the number of system interconnections. The increase can be arrested either by choosing and superimposing a higher voltage net work or segregating the systems after particular limit such as 30 to 40 K.A. is reached. The spliting or segregation of regional grids could be achieved by means of short d.c. link serving as asynchronousties, which would in turn limit the short circuit currents. The R and D effort required for higher fault level with stand apparatus would still take a long time in India.

Asynchronous ties for Frequency Control:

The d.c asynchronous link between regional grids may serve to contain frequency fluctuations and disturbances to that particular system alone. These link would not allow a chain reaction of frequency collapse and avoid the snowballing effect of such an eventuality leading to major system desaster. Frequency control in Indian systems at present is not very satisfactory. Introduction of larger steam sets would impose further restrictions and frequency dips common at present may not be tolerated by the system.

Suppression of Generator Terminals Voltage Rise on Remote load Interruption:

When the receiving end of a long distance a.c. transmission line is opened because of any fault, the charging capacity of line results in a voltage rise at the generator terminals. In order to prevent this voltage rise, a shunt reactor bank might be installed between transmission line and ground. If a.c system is coupled with a d.c. system, the amount of this shunt reactor may be reduced to zero. This dissertation work investigates the suppressing effect of d.c system on the generator terminal voltage rise at the time of remote load interruption.

CHAPTER III

VOLTAGE RISE AT THE GENERATOR TERMINALS ON REMOTE LOAD INTERRUPTION

3.1 VOLTAGE RISE DUE TO FERRANTI EFFECT:

In a long transmission line, open circuited or very lightly loaded, the charging current flows due to the charging capacity of line. Because of this current flow, a rise of pressure occurs at the generator terminals with respect to internal voltage of the generator which is kept constant.

This pressure rise is due to the e.m.f. across the inductance of generator winding. Thus both capacitance and inductance are necessary to produce this effect.

In order to determine the magnitude(10) of pressure rise one half of capacitance will be assumed to be concentrated at the receiving end and one half at the generator terminal. In Fig.3.1 is shown, the receiving end voltage represented by OR, while OD drawn 90° ahead of OR, is charging current consumed by charging reactance of a.c line. When load is disconnected, OD is total current at generator terminal. The voltage consumed by the resistance of each conductor is RC drawn in phase with OD and voltage consumed by the reactance of each conductor is CS , draw 90° ahead of OD. Thus voltage at the generator terminal is OS. Voltage consumed by the reactance of the generator winding is drawn by SG in phase with CS. Thus the induced voltage of the generator is OG, which is smaller than the generator terminal voltage E_t i.e. OS in diagram.

The voltage rise at the generator terminal on remote load interruption may be shown mathematically also.

Consider a long line of which, z is the series impedance of element of line per unit length and y is the shunt admitance per unit length. Then voltage expression for long line are(11)

$$V_S = V_R \text{ Cosh } \lambda l + I_R Z_C \text{ Sinh} \lambda l \tag{3.1}$$

$$I_S = I_R \text{ Cosh } \lambda l + \frac{V_R}{Z_C} \text{ Sinh } \lambda l \tag{3.2}$$

Here V_S is sending end voltage, which is also generator terminal voltage. I_S is the sending end current, I_R and V_R are the receiving end current and voltage respectively.

Here $Z_C = \sqrt{z/y}$, called charecteristic impedance of line

$\lambda = \sqrt{yz}$, called propogation constant

For unloaded line.

$$I_R = 0$$

$$V_S = V_R \text{ Cosh } \lambda l \tag{3.4}$$

$$I_S = \frac{V_R}{Z_C} \text{ Sinh } \lambda l \qquad (3.5)$$

or $$I_S = \frac{V_S}{Z_C} \tanh \lambda l \qquad (3.6)$$

Here as load on the line is zero, current supplied to line is nothing but only the charging current of line.

So we may put $I_S = I_C$ and $V_S = E_t$

Then equation (3.6) become

$$I_C = \frac{E_t \tanh \lambda l}{Z_C} \qquad (3.7)$$

This current splits up into two component, one in phase, and one in quardature with respect to terminal voltage E_t.

The quardature component of $I_C = jI_{C_q} = I_m\left[\frac{E_t \tanh \lambda l}{Z_C}\right]$

(3.8)

I_m instead for imaginary in equation 3.8.

Voltage rise due to this quardature component of charging current at the generator terminals is,

$$\Delta E = -j\, X_g . I_m\left[\frac{E_t \tanh \lambda l}{Z_C}\right] \qquad (3.9)$$

In order to reduce this voltage at load interruption a shunt reactor is necessary which draws lagging current and compensates the leading quardature component of I_C.

For the neutralisation of the effect of this charging current, the lagging current drawn by shunt reactor should be equal to $I_1 = - j\, I_{Cq}$

$$\text{Thus } I_1 = - I_m \left[\frac{-E_t \tanh \lambda l}{Z_C} \right] \qquad (3.10)$$

$$\text{Required Shunt reactor} = j\, X_S = \frac{E_t}{-I_m \left[\frac{E_t \tanh \lambda l}{Z_C} \right]}$$

$$= \frac{-1}{I_m \left[\frac{\tanh \lambda l}{Z_C} \right]} \qquad (3.11)$$

3.2 VOLTAGE RISE DUE TO SPEED INCREASE OF THE GENERATOR

When load in interrupted, the accelerating power P_a increases. This increase of accelerating power, increases the torgue angle δ and speed w of the generator, that can be shown by swing equation$^{(2)}$

From swing equation

$$M \frac{d^2\delta}{dt^2} = P_a \qquad (3.12)$$

Integrating this equation with respect to t,

$$\frac{d\delta}{dt} = w = \frac{1}{M} \int P_a dt + K_1$$

$$= \frac{P_a t}{M} + K_1$$

When $t = 0$, $w = w_o$ = rated speed.

So $$w = \frac{P_a t}{M} + w_o$$

Thus increase in speed $= (w-w_o) = \dfrac{P_a t}{M}$ (3.13)

Here M is the inertia constant which is not strictly constant because speed w varies some what during the swings which follows the disturbance. In practical cases, however, the change in speed w before synchronism is lost is so small in comparison to the normal speed w_o, that very little error is introduced by the assumption that M is constant. Hence, it is customary in solving the swing equation regard M as constant and equal to $I\omega_o$, the value of angular moment at the normal speed. This value of M is known as the inertia constant of machine.

Now change or rise in voltage is directly proportional to rise in speed. If ΔE is rise in voltage due to rise of speed then,

$$\Delta E = \frac{(w - w_o)}{w_o} E_o \qquad (3.14)$$

$$= \frac{P_a . t}{M . w_o} E_o \qquad (3.15)$$

Here E_o is generated voltage at rated speed of the generator.

VOLTAGE RISE DUE TO RESONANCE

If in a circuit consisting a condenser (of capacitance C farad) in series with an inductance and resistance (of value L henories and R Ohms respectively), there impressed an alternating voltage of E volts, then current in that circuit is given(10) by,

$$I = \frac{E}{\sqrt{R^2+(wL - \frac{1}{wc})^2}}$$

Here $w = 2\pi f = 2\pi \cdot$ frequency

The conductive reactance $1/wC$ thus to neutralise the inductive reactance wL. Complete neutralisation is obtained when $1/wc = wL$, and condition is called electrical resonance. The current then becomes equal to E/R and is in phase with the impressed voltage, hence, so far as current is concerned, the circuit is equivalent to a simple resistance only.

From another point of view however as regard to the voltage distribution in the circuit the resonating circuit is by no means equivalent to simple circuit of resistance R. For while in the latter the potential difference between only two points can never exceed the value of impressed voltage, in the resonating circuit, potential difference occur which may be large multiples of the impressed voltage.

In commercial transmission circuit the capacitance is usually so small that resonance can not occur at the fundamental supply frequency, but if the generator e.m.f. wave is distorted, trouble may be experienced due to resonance of one of the higher harmonics. This is owing to the fact that with a constant inductance, the value of the capacitance required to produce resonance varies inversely as the square of frequency.

Fig.3.1 vector diagram for voltage rise due to ferranti effect .

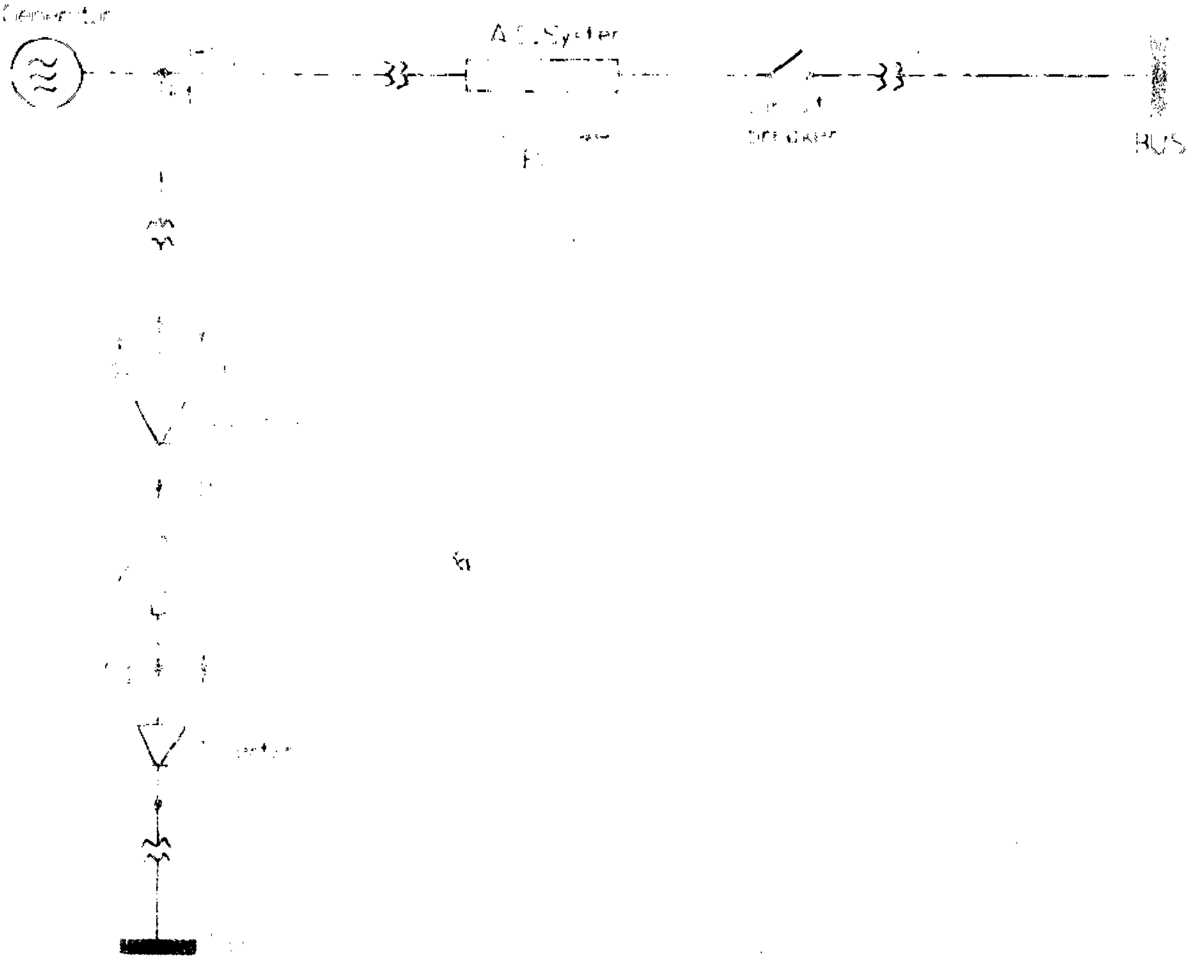


Fig.4.1 . A.c. and d.c. system .

CHAPTER-IV

GENERATOR TERMINAL VOLTAGE RISE SUPPRESSING PROPERTIES OF AN A.C. SHUNT REACTOR AND A D.C. LINK.

4.1 EFFECT OF A.C. SHUNT REACTOR:

When inductive shunt reactor is connected across an a.c. line, it takes lagging current from the a.c system, which is usefull for suppression of voltage rise at the generator terminal on remote load interruption.

Let X_C is total charging reactance of a.c. line and X_S is shunt reactor used to suppress the generator terminal voltage rise. When load is interrupted, the charging current I_C will flow through the generator winding and due to this there must be a voltage rise at the generator terminal. But as shunt reactor is also present so lagging current I_1, drawn by the shunt reactor will also flow in the generator winding and this current will reduce the voltage at the generator terminal as given below. If E_{t2} is the generator terminal voltage after load interruption, E_o is induced voltage of generator, and X_g is generator winding reactance then,

$$I_C = \frac{E_{t2}}{-jX_C} \qquad (4.1)$$

$$I_1 = \frac{E_{t2}}{+jX_S} \qquad (4.2)$$

Taking the effects of these reactive component of currents, the generator terminal voltage E_{t_2} on remote load interruption may be found out mathematically as follows:

$$
\begin{aligned}
|E_o| &= |E_{t_2}| + \left|(I_c + I_1).jX_g\right| \\
&= |E_{t_2}| + \left|\left(\frac{E_{t_2}}{-jX_c}\right) + \frac{E_{t_2}}{jX_s}\right) jX_g\right| \\
&= |E_{t_2}| \left[1 - \frac{X_g}{X_c}\left(1 - \frac{X_c}{X_s}\right)\right] \qquad (4.3)
\end{aligned}
$$

Here $\frac{X_c}{X_s} = \frac{\text{Reactive power required by shunt reactor}}{\text{Reactive power supplied by changing capacity of a.c. line.}}$

From equation 4.3 we get

$$
\frac{|E_{t_2}|}{|E_o|} = \frac{1}{1 - \frac{X_g}{X_c}\left(1 - \frac{X_c}{X_s}\right)} \qquad (4.4)
$$

Above relation shows that for a fixed charging capacity of an a.c line, as the amount of reactive power required by shunt reactor increases the voltage rise at the generator terminals decreases.

4.2 EFFECT OF D.C. LINK:

When an a.c system is coupled with d.c system as shown in fig.4.1, the rectifier takes lagging current from a.c system or it require reactive power. Similarly the inverter is said either to take lagging current or to deliver leading current to the a.c system. Thus inverter operation also require reactive power. The shunt reactors and converters both draw lagging current from the a.c system, so both are analogous to each other in suppressing properties of voltage rise at the generator terminals on remote load interruption. Let X'_d is a.c side equivalent of X_d and represents the lagging component of equivalent admittance of d.c system. On remote load interruption when d.c system is coupled with a.c system, a reactive component of current I_{d1}, drawn by d.c system will also flow in the generator winding. The reactive component of current will neutrilize the effect of changing current.

Taking the effect of this reactive component of current drawn by d.c system and neglecting the effect of the active component of current drawn by d.c system on voltage rise at the generator terminals, equation (4.4) becomes,

$$\frac{|E_{t_2}|}{|E_{t_0}|} = \frac{1}{1 - \frac{X_g}{X_c}\left(1 - \frac{X_c}{X'_d}\right)} \qquad (4.5)$$

Here $\frac{X_c}{X'_d} = \frac{\text{Reactive power required by d.c system}}{\text{Reactive power supplied by charging reactance of a.c. line.}}$

If $|E_{t_1}|$ is voltage at generator terminal when generator is at rated load, and at this time generator terminal voltage is less than induced voltage $|E_o|$ due to lagging current of load.

Taking

$$\frac{|E_q|}{|E_{t_1}|} = 1.05$$

$$X_c = 3.65 \text{ p.u at generator base}$$

$$X_g = 0.5 \text{ p.u}$$

Substituting values in equation 4.5

$$\frac{|E_{t_2}|}{|E_{t_1}|} = \frac{1.05}{1 - \frac{0.5}{3.65}\left(1 - \frac{X_c}{X_d'}\right)}$$

Table 1 shows the voltage at the generator terminal after load interruption in times of voltage before load interruption versus X_c/X_d', which is the ratio of reactive power requirement in d.c system to the reactive power supplied by the charging capacity of a.c. line.

Table 1

S.No.	X_c/X_d'	$\lvert E_{t_2}\rvert/\lvert E_{t_1}\rvert$	S.No.	X_c/X_d'	$\lvert E_{t_2}\rvert/\lvert E_{t_1}\rvert$
1	0	1.22	6.	1.0	1.050
2	0.2	1.180	7	1.2	1.030
3	0.4	1.145	8	1.4	1.010
4	0.6	1.115	9	1.6	0.980
5	0.8	1.085			

The plot in Fig. 4.2 shows that, as the reactive power requirement of d.c. system increases, the generator terminals voltage rise on remote load interruption reduces. Fig 6.4 shows practical available results of system considered in Chapter six. This also shows the voltage rise at the generator terminal on remote load interruption versus percentage of reactive power in D.C. system and shunt reactor to a.c line charging capacity. The plots of Fig.4.2 and Fig 6.4 are coinciding with each other. The error between two is under acceptable limits. Fig 4.3 shows the percentage error between two versus percentage of reactive power in d.c system to a.c line charging capacity.

4.3 TO INCREASE THE REACTIVE POWER REQUIREMENT OF D.C. SYSTEM:

As discussed in section 4.2 that for the suppression of voltage rise at the generator terminals, the reactive power requirement of d.c system should be increased. The reactive power requirement of rectifier increases with the increase of delay angle α. This can be shown mathematically as follows.

The power factor for rectifier,

$$\cos \theta = \frac{1}{2} (\cos \alpha + \cos (\alpha + u)) \qquad (4.6)$$

Reactive power requirement of rectifier that is,

$$Q = V_{d_0} I_d \sin \left[\cos^{-1} \frac{(\cos \alpha + \cos(\alpha + u))}{2} \right] \qquad (4.7)$$

When $\alpha = 0$

$$I_d = \frac{\sqrt{2}\,E}{2\pi f L}(1 - \text{Cos}\,u_o) \qquad (4.8)$$

Here u_o is commutation angle and V_{do} is d.c output voltage when there is no delay in firing i.e. $\alpha = 0$

When α is finite

$$I_d = \frac{\sqrt{2}\,E}{2\pi f L}(\text{Cos}\,\alpha - \text{Cos}(u+\alpha)) \qquad (4.9)$$

When current in d.c line is kept constant, from equation (4.8) and (4.9) we get

$$\text{Cos}\,\alpha - \text{Cos}(\alpha+u) = 1 - \text{Cos}\,u_o$$

$$\text{Cos}(\alpha+u) = \text{Cos}\,\alpha + \text{Cos}\,u_o - 1 \qquad (4.10)$$

Substituting the value of $\text{Cos}(\alpha+u)$ from equation (4.10) in eqn.(4.7), one can get

$$Q = V_{do}\,I_d\,\text{Sin}\left[\text{Cos}^{-1}\left(\text{Cos}\,\alpha + \frac{(\text{Cos}\,u_o - 1)}{2}\right)\right]$$

Taking $V_{do}I_d = 0.2$ p.u on generator base

$u_o = 15$ Electrical degree

$$Q = 0.2\,\text{Sin}\left[\text{Cos}^{-1}(\text{Cos}\,\alpha - 0.0174)\right] \qquad (4.11)$$

Table 2 shows the variation of reactive power requirement of rectifier versus delay angle α. The plot shown in Fig.4.4 shows that as delay angle α increase the reactive power requirement also increase upto rectifier operation.

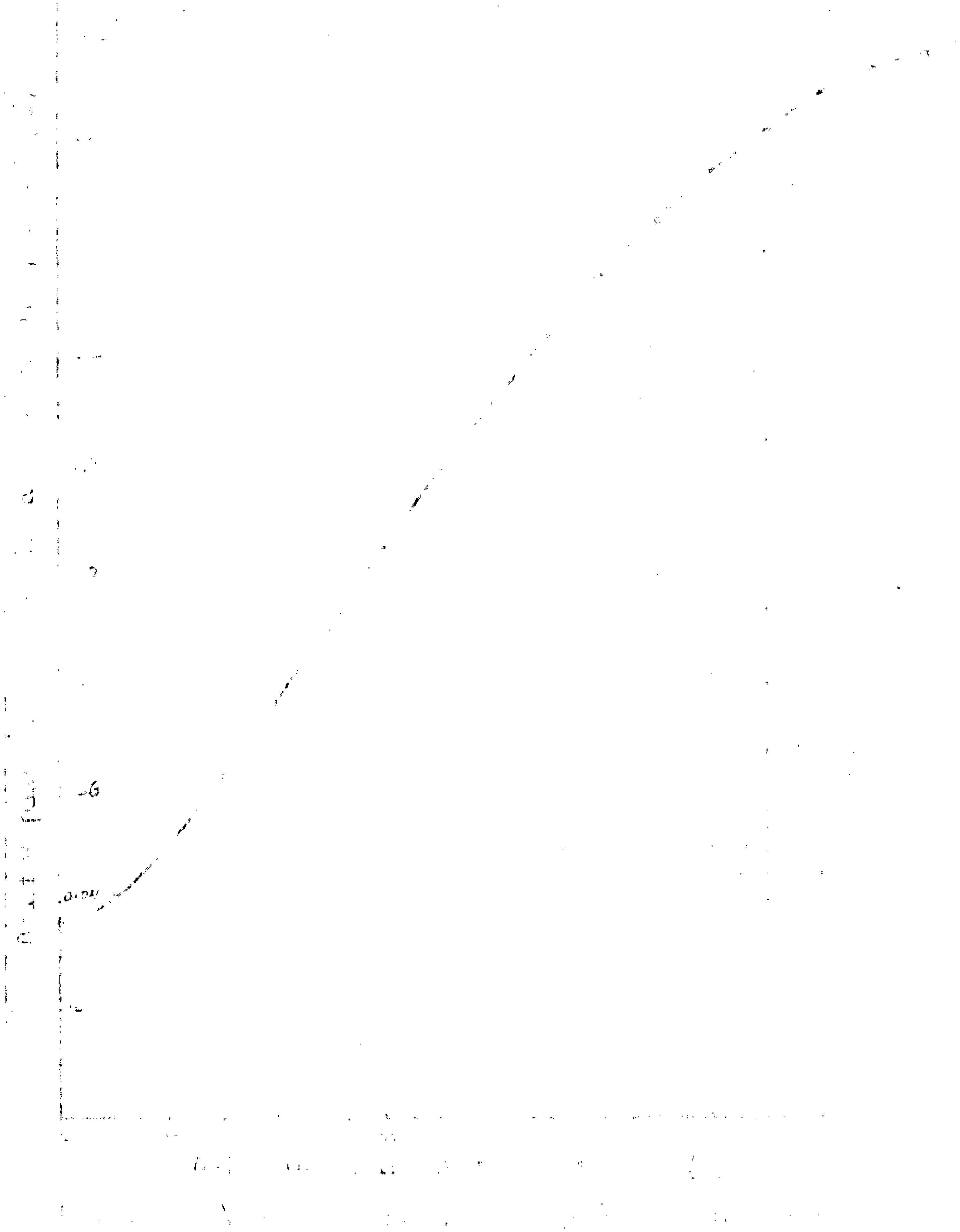


Table 2

S.No.	α in Elect°	Q in p.u.	S.NO.	α in Elect°	Q in p.u.
1	0	0.036790	10	45	0.144751
2	5	0.040616	11	50	0.156010
3	10	0.050358	12	55	0.166164
4	15	0.063130	13	60	0.175290
5	20	0.077182	14	65	0.182804
6	25	0.091336	15	70	0.189086
7	30	0.105688	16	75	0.194060
8	35	0.119432	17	80	0.196962
9	40	0.132524	18	85	0.199510

CHAPTER V

METHODS OF SUPPRESSION OF THE GENERATOR TERMINALS VOLTAGE RISE USING D.C. LINK

When a.c. system is coupled with a d.c system as shown in Fig. 4.1, the voltage rise at the generator terminals on remote load interruption can be reduced by power flow control of the d.c. system. For preventation of this generator terminal voltage rise, the d.c system may be controlled to absorb as much generator power out put as possible(1). When only the a.c system exists, the Ferranti effect and the generator terminal voltage rise are prevented by installation of reactance X_S to cancel the charging capacity of a.c line X_C. As shown in Fig.5.1 the d.c system can be viewed from the generator as a shunt load with an equivalent admittance Y_R. Thus the equivalent admittance Y_R can play the same role as this X_S. In constrast to the X_S which is constant reactance, the Y_R can be varied arbitrarily by power flow control of the d-c. system and thus utilise the advantage for the suppression of the generator terminal voltage rise. Fig.5.2 shows the model made up of an a.c and d.c transmission system. As discussed in Chapter IV that by increasing reactive power requirement of d.c system, the voltage rise at the generator terminals can be suppressed.

With no ignition delay, the rectangular pulse of alternating line current are concentrated on the half sine

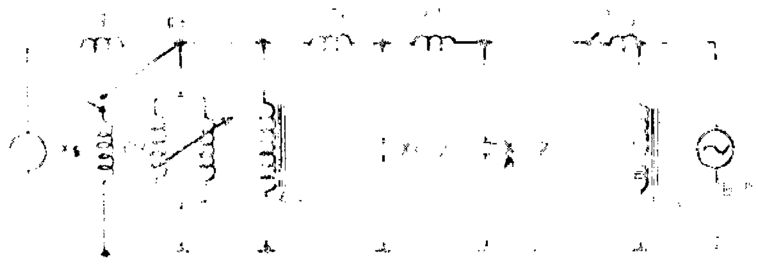


Fig.5.1 Equivalent circuit of fig.4.1 .

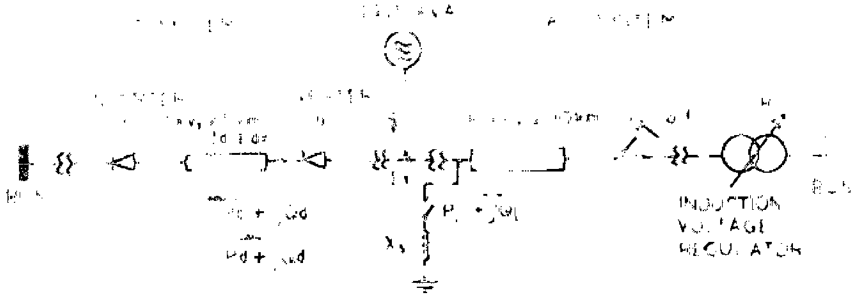


Fig.5.2 A.c. and d.c. artificial transmission system .

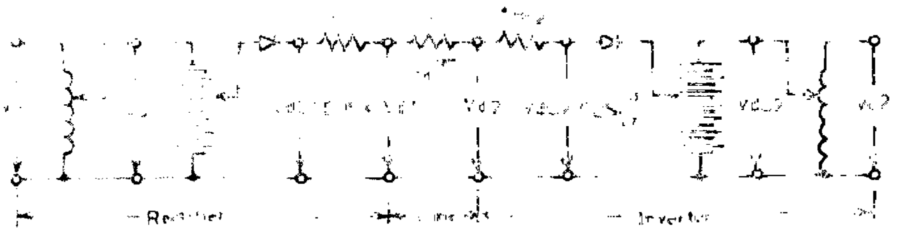


Fig.5.5 Equivalent circuit of d.c. transmission road for average currents and voltage

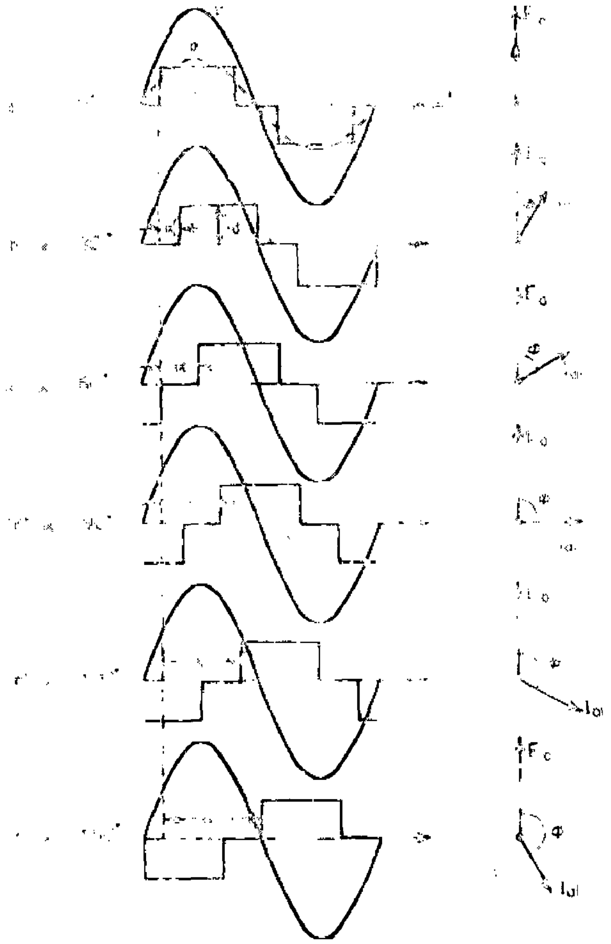


Fig.5.3 _ Relation between ignition delay and phase displacement.

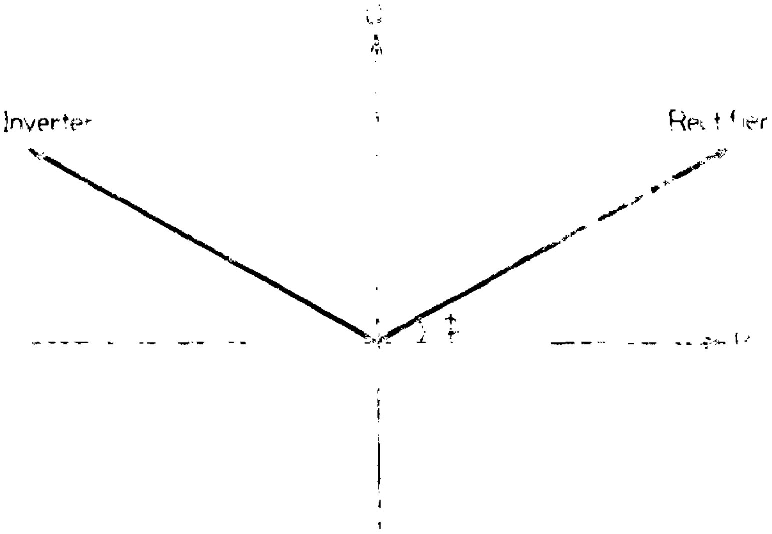


Fig.5.4 Power vector diagram.

waves of line to neutral voltage as shown in Fig 5.3(a) and the fundamental sine wave of current is in phase with that voltage wave. Ignition delay α shifts the current wave and its fundamental component by angle $\phi = \alpha$, as shown in Fig 5.3(b),(c),(d),(e) and (f). Thus the convertor-rectifier or invertor both draws reactive power 'Q' from the a.c system. This can be shown from vector diagram in Fig.5.4. There are two methods the use of which can suppress the voltage rise at the generator terminals on remote load interruption.

5.1 CONSTANT D.C. CONTROL METHOD:

When power flow of the d.c in the d.c system is in normal direction as shown in Fig. 4.1, a rise in generator terminals voltage cause an increase of d.c current I_d. Now the measured current in the rectifier is greater than the set current I_{ds}. The equivalent circuit of d.c system is shown in Fig.5.5. Here V_{do_1} is rectifier output in ideal condition when α and u both are zero. From equivalent circuit(3

$$V_{d_1} = V_{do_1} \cos \alpha - \delta V \qquad (5.1)$$

Here,

V_{d_1} = d.c. output voltage of rectifier in presence of grid control and appreciable winding reactance of transformer.

V_{do_1} = d.c. output voltage of rectifier when transformer winding reactance is zero and no grid control.

δV = voltage drop due to commutation.

During the commutation process the two phases of a.c transformer becomes short circuited and due to the flow of short circuit current 'i_s' there is a drop in output voltage. Neglecting the resistance of the transformer windings and arc drop, which is very small as compared to leakage inductance L of each phase of transformer winding, we get,

$$2L \frac{d\,i_s}{dt} = \sqrt{2}\, E \,\mathrm{Sin}\, wt \qquad (5.2)$$

Integrating both sides of equation 5.2

$$i_s = \frac{-\sqrt{2}E}{2wL}\,\mathrm{Cos}\, wt + K_2 \qquad (5.3)$$

When $wt = \alpha$, $i_s = 0$

$$\text{So} \quad K_2 = \frac{\sqrt{2}\, E}{2L}\;\frac{\mathrm{Cos}\,\alpha}{w}$$

$$K_2 = \frac{\sqrt{2}\, E}{2wL}\;\mathrm{Cos}\,\alpha \qquad (5.4)$$

Substituting the value of K_2 in equation (5.3)

$$i_s = \frac{\sqrt{2}}{2LW} E(\mathrm{Cos}\,\alpha - \mathrm{Cos}\, wt)$$

When $w.t = u + \alpha$, $i_s = I_d$.

$$\text{So} \quad I_d = \frac{\sqrt{2}\, E}{2wL}\left[\mathrm{Cos}\,\alpha - \mathrm{Cos}(\alpha+u)\right] \qquad (5.5)$$

From Fig 2.1(B) we can find out δV, from which

$$\delta V = \frac{3}{\pi}\cdot\frac{1}{2}\int_{\alpha}^{\alpha+u} \sqrt{2}\, E \,\mathrm{Sin}\, wt\; dwt.$$

$$\delta V = \frac{3\sqrt{2}}{2\pi} E \left[\text{Cos}\ \alpha - \text{Cos}(\alpha + u) \right] \tag{5.6}$$

$$V_{do_1} = \frac{3}{\pi} \int_{-\pi/6}^{\pi/6} \sqrt{2}\ E\ \text{Cos}\ wt\ dwt$$

$$= \frac{3\sqrt{2}}{\pi}\ E \tag{5.7}$$

From Equation (5.1), (5.6) and (5.7), one can get

$$V_{d_1} = \frac{V_{do_1}}{2} \left[\text{Cos}\ \alpha + \text{Cos}\ (\alpha + u) \right] \tag{5.8}$$

Factor $\frac{\text{Cos}\ \alpha + \text{Cos}(\alpha + u)}{2}$ is called power factor of rectifier. Now from equation (5.5) and (5.6)

$$\delta V = \frac{3wL}{\pi} .\ I_d \tag{5.9}$$

Thus voltage drop is proportional to I_d and the effect of commutation appears as a resistance of d.c side equal to $3wL/\pi$ which results in a voltage drop of $\frac{3wL}{\pi} .\ I_d$ in d.c side output voltage. As $3wL/\pi$ is constant, so may be replaced by R_{C_1}, the commutation resistance. So puting $\delta V = R_{C_1} I_d$ in Equation (5.1) we get

$$V_{d_1} = V_{do_1} \text{Cos}\ \alpha - R_{C_1} I_d \tag{5.10}$$

Similarly for the case of invertor side in the equivalent circuit, shown in Fig.5.5 we get

$$V_{d_2} = V_{do_2}\ \text{Cos}\ \beta + I_d R_{C_2}$$

Here V_{d_2} = d.c. side voltage of inverter in presence of grid control and appreciable winding reactance of transformer.

V_{do_2} = d.c side voltage of inverter when no grid control and winding reactance of transformer is zero

R_{C_2} = Commutation resistance of inverter

If R_1 is the d.c resistance of d.c link then

$$V_{d_1} = V_{d_2} + R_1 I_d \tag{5.11}$$

or $V_{do_1}\cos\alpha - R_{C_1}I_d = V_{do_2}\cos\beta + I_d R_{C_2} + R_1 I_d$

$$I_d = \frac{V_{do_1}\cos\alpha - V_{do_2}\cos\beta}{R_{C_1} + R_{C_2} + R_1} \tag{5.12}$$

The variation of current in d.c. system will follow the above relation given in equation (5.12). Now as discussed before, when generator terminals voltage rises, it will increase the output voltage of rectifier and current I_d will increase accordingly. Now for constant current control the value of Cos α must decrease to maintain I_d constant. For this, delay angle α must be increased in order to decrease cos α and thus there will be a decrease in the internal voltage of rectifier V_{do_1} Cos α.

Thus it is clear that for maintaining current I_d constant at the time of terminal voltage rise, the delay angle α has to be increased. As control angle α increases, the reactive power requirement of d.c system increases because of necessity of keeping I_d constant. So constant d.c. control method is effective for the suppression of the generator terminals voltage rise by increasing the reactive power requirement of d.c. system. Constant d.c. control method involves the following:

(a) Measurement of current I_d.

(b) Comparison of I_d with the set valve I_{ds} and amplification of the difference error $(I_d - I_{ds})$, called error.

(c) Application of the output signal of the amplifier to a phase shift circuit that alters the ignition angle α of the valve.

(a) Measurement of Current:

A direct current, in a circuit isolated from the main circuit can be obtained, which is proportional to but less than the direct current in the main circuit, by means of a d.c. transformer. This device consists of two saturable reactors-(transductors), each having two windings, an a.c. supply usually fed through a small step-down transformer, and a rectifier employing several small diodes(3).

The reactor core have a sharp saturation point and a very low M.M.F. F_m for saturation (Fig.5.6). One winding (the primary one) carries the direct current I_d to be measured. If this current is great , the primary winding is not really a winding but merely a staight bar or cable passing through the center of the window of the core- an arrangement commonly used also in a.c. current transformers for high

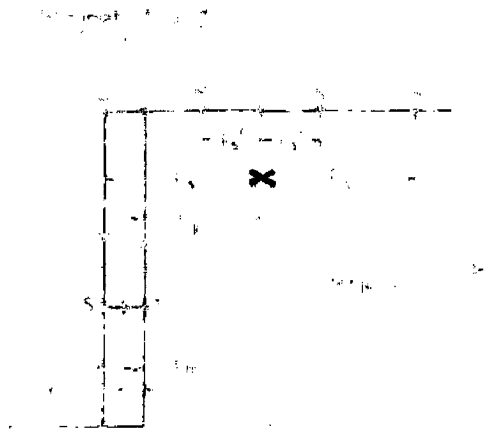


Fig. 5.6 Magnetization curve of high permeability core for d.c. current transformer.

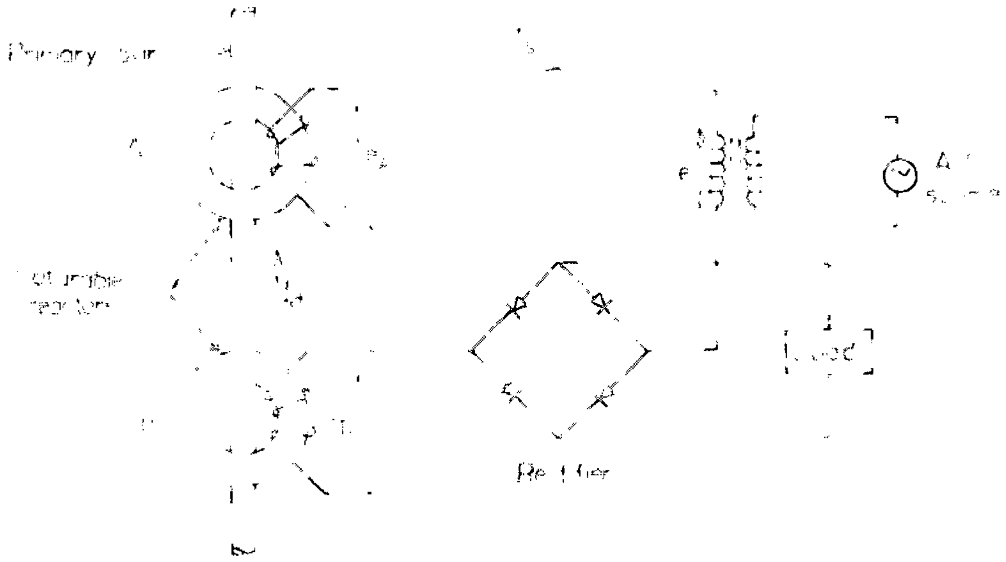


Fig. 5.7 Circuit diagram of conventional series type of d.c. current transformer

primary currents. Such a primary is considered to have one turn. The secondary winding has many turns, and the current ratio is inversely as the turns ratio. The secondary winding are excited by alternating current.

In common form of d.c. current transformer the two secondary windings are connected in series opposition and are in series with the a.c. source and a full wave rectifier.(Fig.5.7). The primary current I_d exerts a M.M.F. $F_p = N_p I_d$ that, in the absence of a secondary current, drives the cases of both reactors far into saturation, producing flux Ø and M.M.F. F represented by point P in Fig.5.6. The secondary current I_S has a M.M.F. $F_S = N_S I_S$. that is added to F_p in reactor A and substracted from it in reactor B. Thus the total M.M.F_s are

$$F_A = F_P + F_S = N_p I_d + N_S I_S$$

$$F_B = F_P - F_S = N_p I_d - N_S I_S$$

The points on the magnetisation curve representing these condition, are always equidistant horizontally from P, as, for example, are M and N. Points M and N are for a very small secondary current, and both reactor core are still saturated. A larger secondary current, drives these points farther apart (Point Q or S and R), causing reactor B to become unsaturated.

The flux Ø in each reactor core is ordinate of the respective point on the magnetisation curve. If both reactors are saturated, the fluxes in both cores are almost equal. If one is saturated and the other unsaturated (point R and S), the fluxes are unequal.

The relation between these fluxes and the applied alternating voltage e will now be developed. If the resistance of the secondary circuit, including secondary winding of transformer and reactors, rectifier, and load, is negligible, the applied voltage is consumed in the inductive drop almost all of which is in the two reactors.

$$e = N_S \frac{d\phi}{dt} = N_S\left(\frac{d\phi_A}{dt} - \frac{d\phi_B}{dt} \right)$$

The negative sign arises from the opposite connection of the two secondary windings. The time integral of this voltage is

$$\int e dt = N_S\phi = N_S(\phi_A - \phi_B)$$

It is the difference of secondary flux linkage of two reactors. If the integration begins when $I_S = 0$ and if both reactors are alike, as assumed, the constants of integration for both cores are equal and disappear in the difference. Suppose that the voltage of a.c source is sinusoidal.

$$e = E_m \mathrm{Cos}\ wt$$

Then the flux linkage of the secondary circuit is like wise sinusoidal and lags 90° behind the voltage

(Fig 5.8(a)) because

$$\psi_S = N_S\phi = \int e \, dt = \frac{E_m}{w}\,\mathrm{Sin}\, wt$$

At every instant the net flux linkage of two reactors must conform to the value on this sine curve. The crest value E_m of the applied voltage must be chosen so that the crest value of the flux linkage E_m/w is some what less than the height of the hysteresis loop, making it impossible for the two reactors to be saturated in opposite directions. With no primary current, both are nusaturated through out the cycle. With primary current having M.M.F greater than F_m, one reactor or the other is unsaturated during most of the cycle (points R and S). Only for short time intervals near the zeros of the flux-linkage wave(near crests or volleys of the voltage wave) are both reactors saturated (point M and N). Hence during most of the cycle the M.M.F. F_m of the secondary current I_S is very nearly equal to the F_p of the primary current I_d, differing by ± F_m, depending on whether $|\phi|$ is increasing or decreasing. While $|\phi|$ is increasing the operating point of one reactor is moving downward on the left hand branch of the magnetisation curve and $F_S = F_p + F_m$, while $|\phi|$ is decreasing, the operating point is moving upward on the right-hand branch of the curve and $F_S = F_p - F_m$. If F_m is very small, this difference is unimportant, and, in any event, the average of these two quantities is the desired value F_p.

The wave shape of the secondary current I_S is shown in Figure 5.8(b). This current is rectified to form the output current i_s shown in Fig.5.8(c). The output current faithfully follows the magnitude of primary or input current except two minor features.

1. Narrow notches in small time interval when both reactors are unsaturated.
2. Differences of $+I_m$ occuring before and $-I_m$ after a step at crest value of $|\psi_s|$ (zeros of e), I_m being the magnetizing current corresponding to F_m.

The notches are the chief source of error, for I_m is very small if suitable material is used in the cores. The notches are undesirable in applications in which the output signal must operate fast-acting devices.

The notches can be obviated by the use of two or three devices like that described supplied with alternating voltage from different phases of a polyphase source and with their output terminals paralleled. The final output current is at every instant equal to that of the unit having the greatest current.

(b) Comparison of I_d with the set value I_{ds} and amplification of difference error:

Block diagram is shown in Fig.5.9. The actual value of I_d is compared with set value of current I_{ds}. The difference of two is amplified only when I_d is greater than I_{ds}, and amplified output is used as V_{cc} in proposed scheme of Fig.5.11.

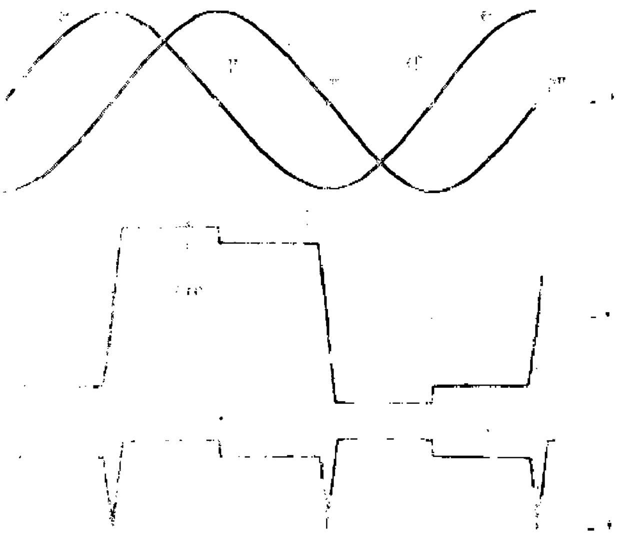
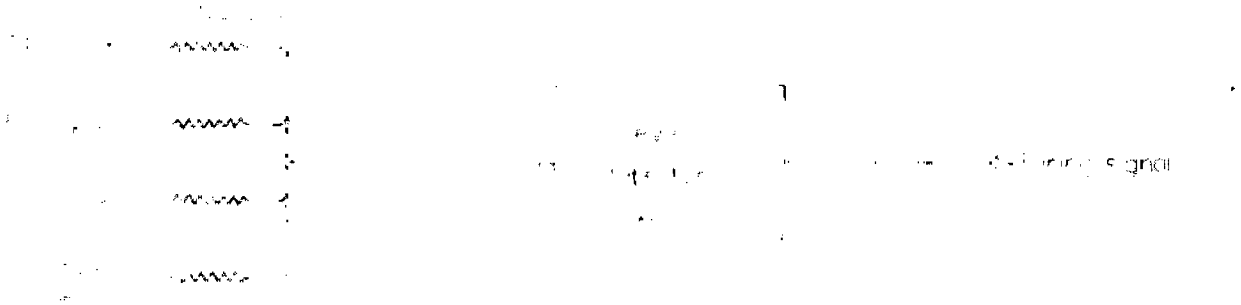


Fig. 5.8 [illegible] transformer of Fig. 5.7



[illegible]

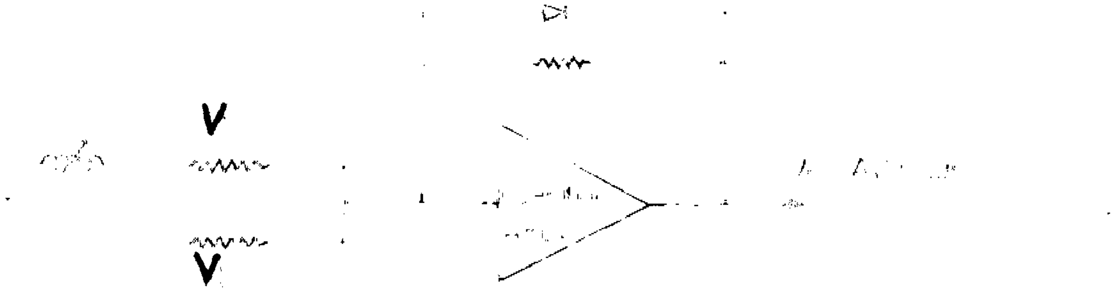
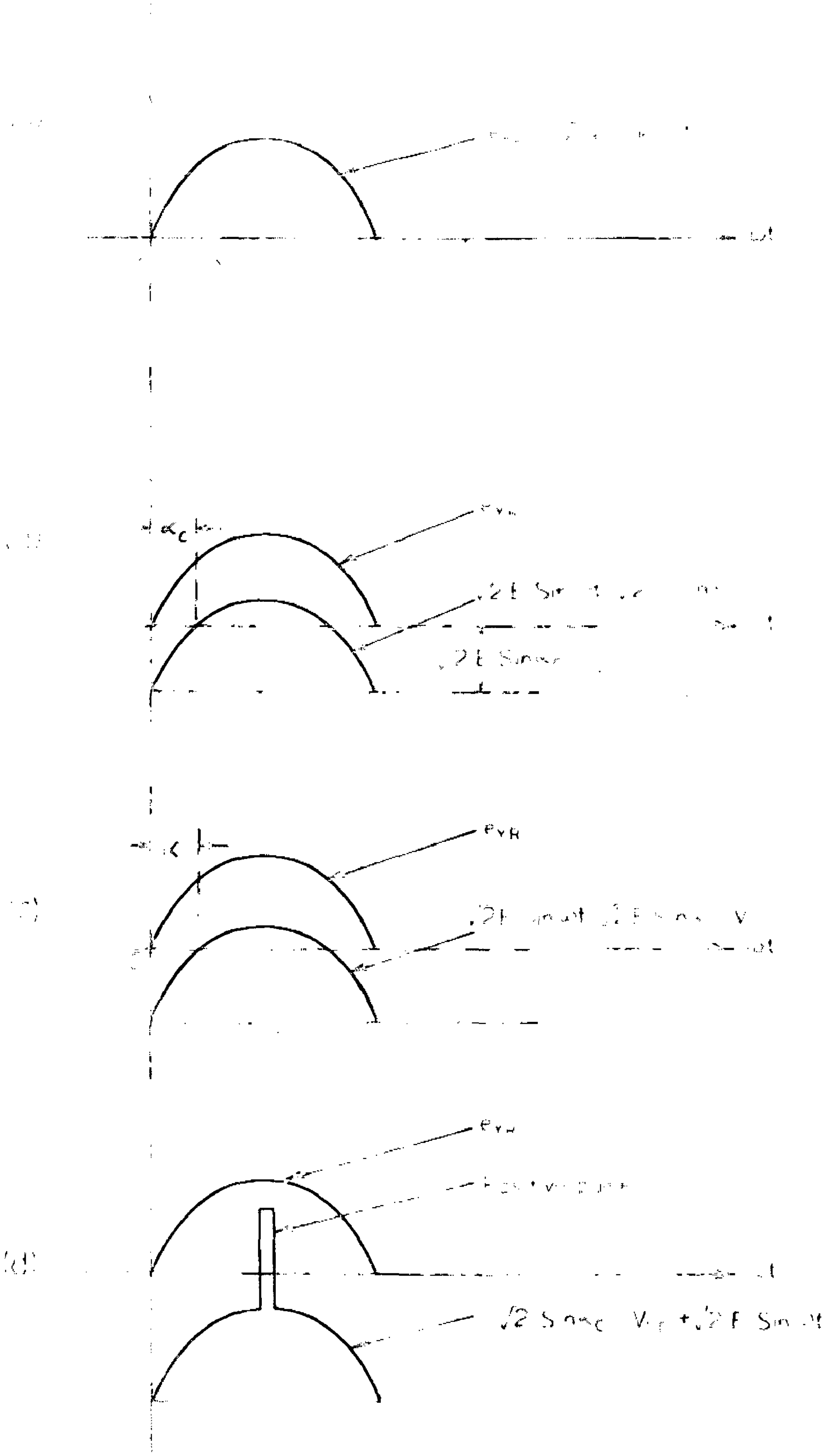


Fig. 5.9 [illegible]


ωt
α_c
e_{YR}
√2 E Sin ωt
ωt
α_c
e_{YR}
ωt
(d)
e_{YR}
ωt
√2 Sin α_c V_F + √2 E Sin ωt

[illegible] 5.10 [illegible]

When I_{dS} is greater than I_d, the amplifier output is clamped to zero by diode $D^{(6)}$.

(c) Application of the output signal of the amplifier to a phase shift circuit that alters the ignition angle 'α' of the valve:

The criteria for safe rectifier operation is that delay angle or ignition angle must be large enough so that this is greater than α_C (minimum value of α required), to ensure the reliable firing of the valve. The commutating voltage for valve 3 in Fig 2.1(a) is the voltage between phase R and Y and shown separately in Fig.5.10(a). The control circuit is so designed that α should be atleast α_C. The equation of commutating voltage of valve 3, taking 0 as reference point, is $\sqrt{2}E$ Sin wt. To get the point at which firing should start with angle of delay α_C, the following equation should be satisfied,

$$\sqrt{2}\,E\ \mathrm{Sin}\ wt - \sqrt{2}\,E\ \mathrm{Sin}\ \alpha_C = 0$$

The instant at which the equation is satisfied is the required firing point. When rectifier is on constant current control, a further signal- V_{CC} is also added to this and now the simulated equations,

$$\sqrt{2}\,E\ \mathrm{Sin}\ wt - \sqrt{2}\,E\ \mathrm{Sin}\ \alpha_C - V_{CC} = 0$$

V_{CC} is obtained from comparision circuit shown in Fig.5.9 and equal to $A(I_d - I_{dS})$, where A is amplification factor

When V_{CC} is zero i.e. measure value is equal to set value, the delay angle or ignition angle is α_C. The effect of adding-V_{CC} is shown in Figure 5.10(c). The greater the magnitude of signal greater will be the angle of delay and if V_{CC} is large enough, α will increased to 90^o. There is an obvious risk to making +V_{CC} too large so that summation signal never go to positive. This is taken care of by adding a positive impulse of a short duration to summing junction. The amplitude of this pulse is large enough to ensure that summation signal goes positive at least for the duration of this pulse.

Practical Arrangement:

A block diagram of the practical arrangement is shown in Fig 5.11. The commutating voltage $\sqrt{2}$ E Sin wt, signal$\sqrt{2}$ Sin α_C, the current control signal-V_{CC} and a positive pulse are fed into the summing junction and the summation signal is fed into the level detector A, which detects the instant when the summation signal passes through zero, while going positive. The trigger from the level detector is used as the starting point of valve pulse. The signal V_{CC} is obtained for constant current control from block diagram shown in Fig.5.9.

5.2 CONTROL METHOD TO REVERSE THE POWER FLOW-DIRECTION IN D.C. SYSTEM:

In this method the direction of power flow of d.c. system is changed at the time of remote load interruption, that is, normal direction(right to left) in Fig.5.2. Initially direction of d.c. power flow is opposite, that is left to right in Fig 5.2. In case of d.c. power flow from right to left $P_G = P_L + P_d$ and $Q_G = Q_L + Q_d$. Here P_G and Q_G are active and reactive power supplied by the generator P_L and Q_L are active and reactive power required by line and P_d and Q_d are active and reactive power required by d.c. system respectively. When d.c power flow from left to right $P_G = P_L - P_d$ and $Q_G = Q_L + Q_d$. So when generator is at full load it supplies active power equal to $P_L - P_d$ and reactive power $Q_L + Q_d$. Now on remote load interruption, P_L becomes zero and $- P_d$ changes to $+P_d$ by 'off' signal of circuit breaker. So generator output is taken by d.c. system only. As a part of input power of generator is taken by d.c. system then accelerating power of generator decreases and so rate of speed increase of generator decrease and because of this the voltage rise at the generator terminal will decrease. The reactive power supplied by the charging capacity of line is again taken by d.c system reactive power requirement. When the power flow of d.c. system is in opposite direction(refer Fig.6.6) converter I acts as rectifier with no current control, while converter II as inverter with constant current control. At the time of load interruption the direction of power flow of the d.c system is reversed by the 'off' signal of the circuit breaker, that is normal direction. In present position converter II acts as a rectifier with constant control while converter I as an inverter with no current control.

CHAPTER VI

DISCUSSION ON AVAILABLE PRACTICAL TEST RESULTS

Figure 5.2 illustrates the experimental model made up of an a.c and d.c artificial transmission system(1). The results, that would be discussed here, are obtained from the above experimental model. The generator is rated 220Volt and 22.5 K.V.A. The impedance of the X_C, the charging capacity of line, in tested system is 3.68p.u on generator base.

The direction of d.c power flow in the tested system, from right to left(<——) is called normal direction of power flow and from left to right(——>) is called opposite direction of flow.

6.1 WHEN POWER FLOW OF d.c SYSTEM IN THE NORMAL DIRECTION

Fig. 6.1 shows the oscillogram of the generator terminal voltage rise on remote load interruption in the a.c system when d.c link in Fig 5.2 is sending power in positive or normal direction. At the time of load interruption voltage rises due to Ferranti effect. After load interruption the acceleration power also increases and the speed of the generator rises. Because this speed increase, the induced voltage of the generator starts increasing and speed increase of the generator increases the terminals voltage as shown in Fig. 6.1.

There are some factors that controls the voltage rise at the generator terminals. They are the reactive power

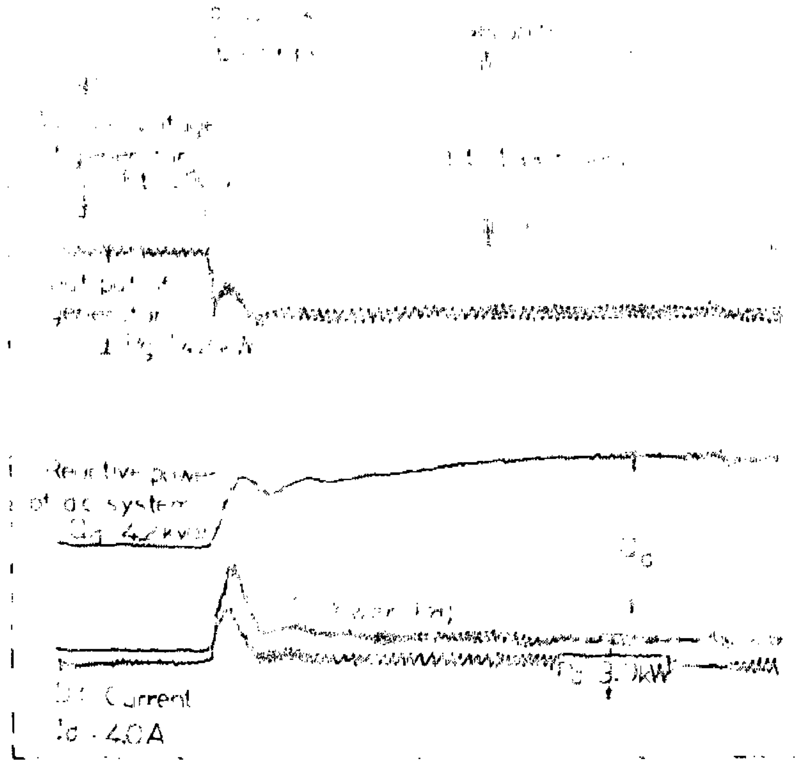


Fig. 6.1 Generator terminal voltage rise at remote load interruption in a.c. d.c. system; the normal direction of d.c power, generator without AVR a.c line without shunt reactors .

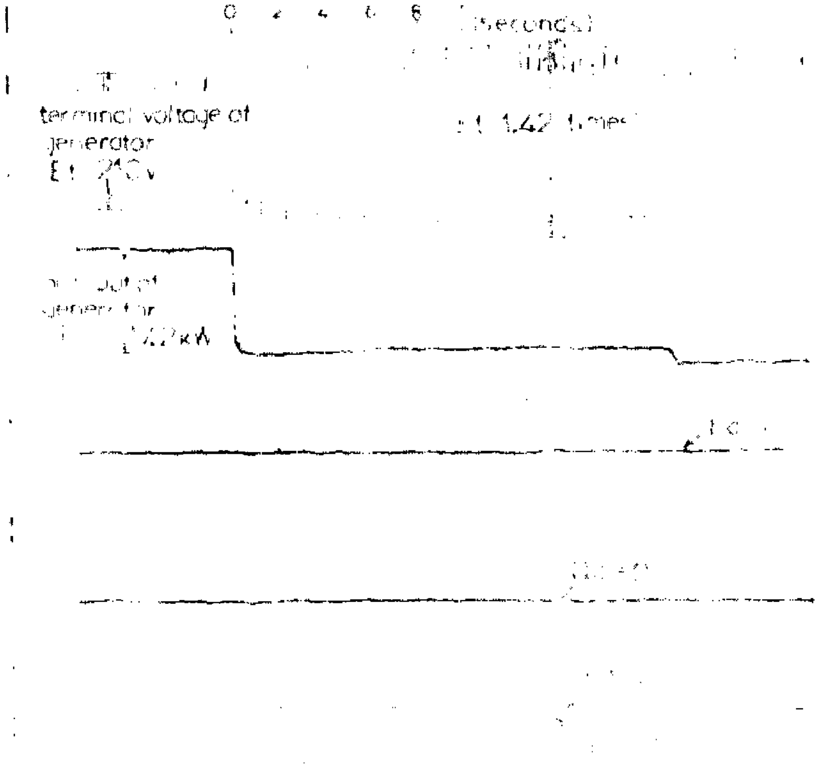


Fig. 6.2 Generator terminal voltage rise at remote load interruption [illegible] generator without AVR a.c. line with shunt reactor X_C/X_0 = 78.8 %

requirement of d.c. system and shunt reactors. As soon as voltage at the generator terminals starts rising, the current in d.c. link increases and so active and reactive power requirements of d.c. system rise at the same moment. As current in d.c. system increases, this increases the control angle α of the rectifier according to constant current control. Due to increase of control angle α the reactive power requirement of d.c. system increases further more and active power requirement reduces. The reactive power requirement characteristic of d.c. system is like a shunt reactor and this reduces the effect of voltage rise due to Ferranti effect.

Figure 6.2 shows the oscillograms for the case where d.c system is absent but shunt reactor is installed in a.c system. The generator is without A.V.R. and capacity of shunt reactor is 73.8 percent of charging capacity of a.c line. The generator terminal voltage rise is 1.14 times on remote load interruption. This voltage further increases due to speed increase of the generator. The shunt reactor connected here draws lagging current which neutralize the charging effect of X_c. In this case net voltage rise after one second is 1.42 times. Here no d.c. line is connected so Q_d and P_d are zero.

Fig. 6.3 shows the characteristic of the generator terminal voltage rise on remote load interruption with and without d.c system. The generator is not equipped with an

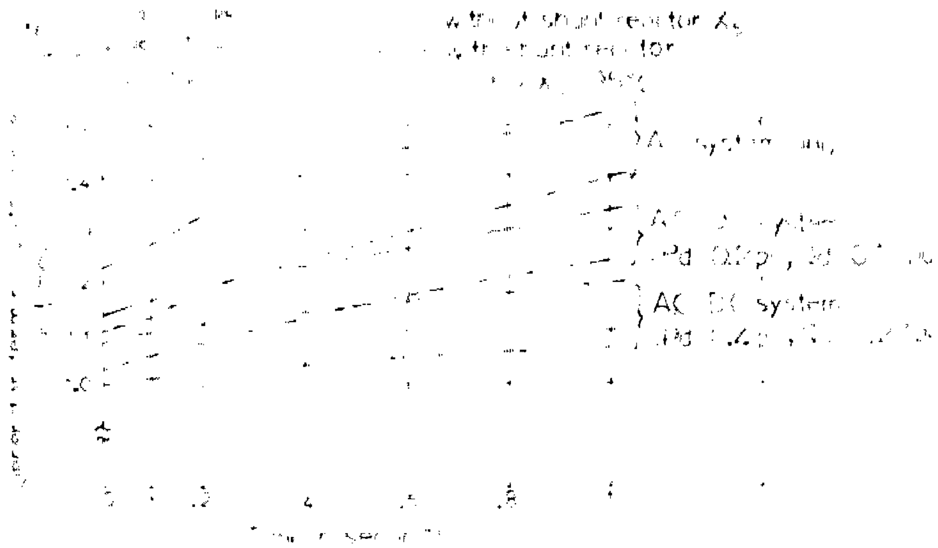


Fig. 6.3 Generator terminal voltage rise characteristics after remote load interruption; generator without AVR.

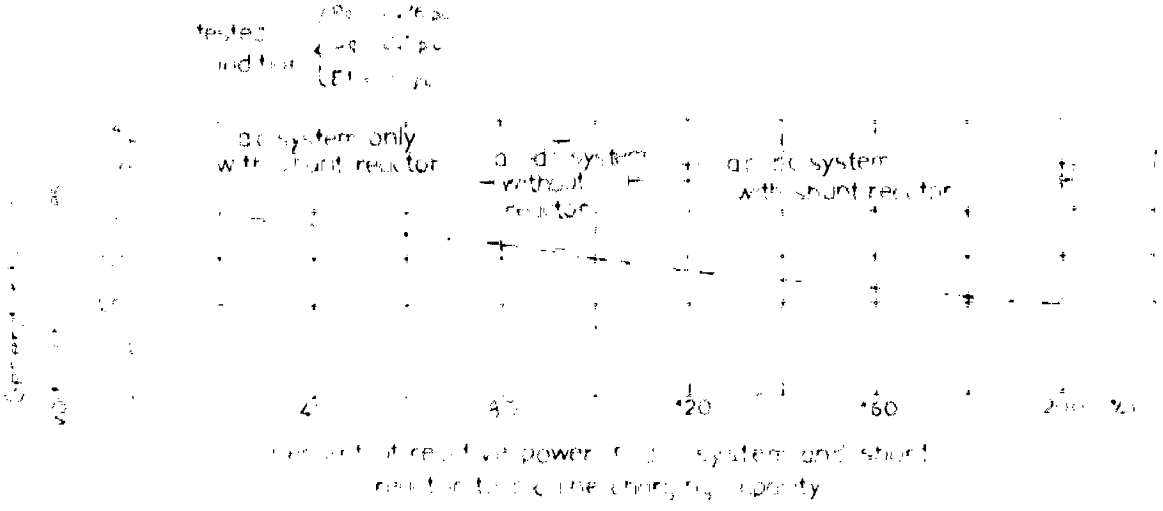


Fig. 6.4 Generator terminal voltage rise for various reactive powers of a.c. [illegible] generator without AVR.

A.V.R. The solid lines represent the case without shunt reactor, whereas the dotted lines, the case with shunt reactor. When there is no shunt reactor, no d.c. system is used then voltage rise at the moment of load interruption is 1.2 times that is due to Ferranti effect only. After that, because of accelerating power speed of generator increases and then voltage at the generator terminals also increases. This increase in voltage continues upto the point when governor comes in the operation. When shunt reactor is used in a.c system, this draws a lagging current and neutralise the leading current drawn by charging capacity of the a.c. line. Thus the voltage at generator terminal at the moment of load interruption is only 1.1 times when a.c. system is coupled with shunt reactor. The voltage rise due to speed increase remain same as before, because shunt reactor can not help in reducing the accelerating power of the generator.

When d.c system is also coupled with a.c system, the d.c system draws reactive as well active power from the a.c system. A part of reactive power supplied by a.c. line charging capacity is taken by d.c. system and so current drawn from the generator (leading current) on remote load interruption is less in comparision to without d.c. system. Thus the voltage rise at the moment of load interruption is less as comparison to without d.c. system. As d.c. system also draws active power, so accelerating power of the generator decreases. The rate of rise of voltage at the generator terminals due to speed increase, decreases as shown in figure 6.3.

Figure 6.4 shows the effect of reactive power requirement of d.c. system and shunt reactor on the suppression of the generator terminal voltage rise. In this Figure, the internal induced voltage is kept constant, i.e. the generator is not equipped with A.V.R. The reactive power requirement of d.c. system representing the abscissa of Figure 6.4 is chosen to X_C/X'_d, where X'_d is the a.c equivalent of X_d and represents the lagging component of equivalent admitance of the d.c. system before the load interruption. When both the d.c. system and shunt reactors are present, the abscissa represents approximately the value $(\frac{X_C}{X_S} + \frac{X_C}{X'_d})$ where X_C is line charging capacity of line. It is clear from figure 6.4 that the d.c system has the same effect of suppressing the generator terminals voltage rise as shunt reactor. The Fig. shows that with an increased value of reactive power requirement of d.c. system, the generator terminals voltage rise can be suppressed.

6.2 WHEN POWER FLOW OF d.c. SYSTEM IN THE OPPOSITE DIRECTION

Fig. 6.5 shows the oscillograms of the generator terminals voltage rise at the time of remote load interruption in the a.c system while the d.c. system in Fig.6.6 is sending power in the opposite (left to right) direction. The generator is equipped with an A.V.R. and no shunt reactor is installed on the a.c line. In this method d.c system is such that after the load interruption, the power flow of d.c. system is reversed

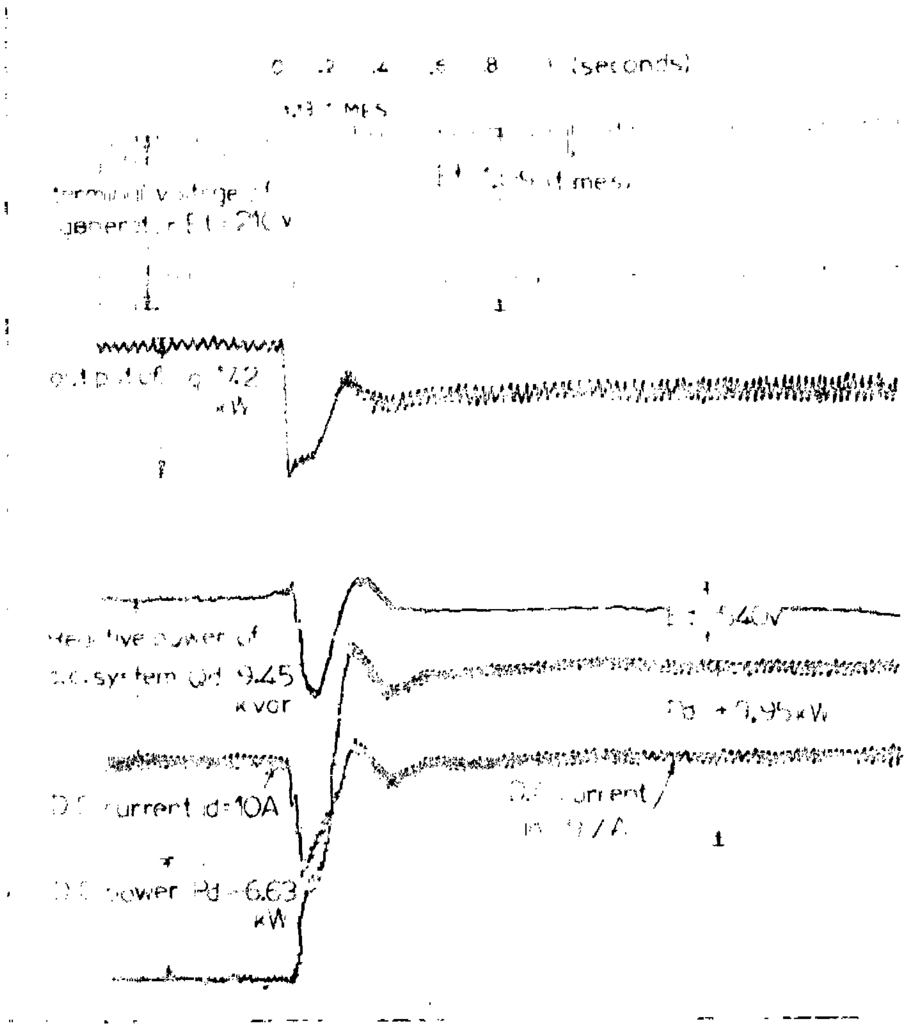


Fig. 6.5. Generator terminal voltage rise with reversal of d.c. power flow after remote load interruption; generator with AVR, no shunt reactor.

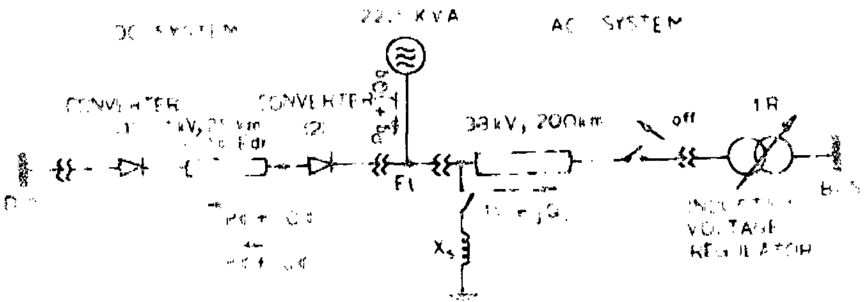


Fig. 6.6. A.c. and d.c. artificial transmission system.

i.e. left to right in Fig.6.6. The d.c. system is on constant current control maintained by the inverter before the power flow reversal and the rectifier after power flow reversal. In Figure 6.5, the generator terminal voltage rise at the time of load interruption is 1.13 times. This voltage rise is a result of, Ferranti effect which increases the generator terminal voltage and reactive power requirement of converter which suppress the voltage rise. When no d.c system is used the voltage rise at generator terminal is 1.2 times as shown in Fig.6.3. In this case, dealed in Fig.6.5, the d.c. system reactive power requirement is 9.45 K.V.A.R. which is 0.42p.u at generator base. This reactive power requirement of d.c. system reduces the voltage of the generator terminal upto 1.13 times. Since at the moment of load interruption the direction of d.c. power flow is reversed by the 'off' signal of the circuit breaker, so after load interruption d.c. system takes power from the generator. Thus accelerating power of generator is reduced and there by voltage rise due to speed increase of the generator is decreased. Here automatic voltage regulator is used which controls the voltage rise by controling the excitation of machine. As excitation of the generator decreases the induced voltage also decreases. So by using automatic voltage regulator and by reversing the direction of d.c. power flow, the generator terminals voltage rise can be reduced to appropriate level. Curve in Fig 6.5 shows that at the moment of load interruption the output of the generator is reduced to zero and it increases to P_d in

0.2 second and it remains zero upto 0.12 second. This time is required in the reversal of power flow direction. During this interval the effect of the d.c system can not be anticipated, but after this, the effect of power reversal control of d.c. system is quite remarkable. After 0.4 sec., the d.c system reduces the voltage rise to 1.09 times in contrast with 1.15 times without d.c system.

CHAPTER VII

CONCLUSION

As d.c. system can be regarded as a shunt load when viewed from the generator, it has a suppressing effect on the generator terminal voltage rise like the shunt reactor. This effect increases with the capacity of d.c system. Since the reactive power requirement of the d.c system increases with the generator terminals voltage rise, so the d.c. system is more effective than the constant reactor for the suppression of voltage rise.

The direction of the d.c. power flow should be reversed for the suppression of the general terminals voltage rise at the time of remote load interruption in the a.c system. During the power flow reversal, the d.c power passed through zero and corresponding drop of the reactive power requirement of d.c. reduces the suppressing effect. However the power flow of d.c system is reversed after about 0.1 second and then d.c. system become effective.

The amount of shunt reactor on the a.c system can be reduced if the a.c system is scheduled to the interconnection with a d.c. system. Also if the d.c. system is operated almost at its rated load with the reactive power supply from the a.c. system, the shunt reactor can be omitted.

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