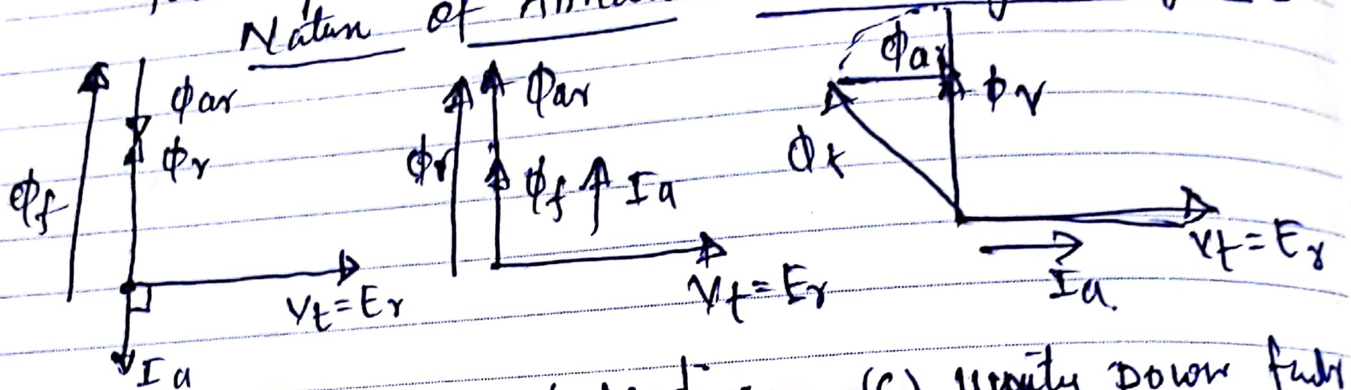
Alternators

Nature of Armature Reaction

* Depends upon the p.f at which m/c is operating
* Depends upon the operating mode generating/motoring
for explanation, Assume R_a & X_L equal to zero

Nature of Armature Reac^n in generating m/c



(a) zpf lagging → Armature Reaction is demagnetizing (ϕ_{ar} opposes ϕ_f)

(b) zpf leading → Magnetizing

(c) unity power factor → Cross magnetizing

from the above discussion more general Conclusion Regarding a Syn m/c in gen mode

1) When m/c supplies a lagging power factor cln Armature Reaction has Both De-magnetizing & Cross mag.
2) leading (Magnetizing & cross magnetizing)

Conclusion for motoring machine

1) When m/c supplies lagging factor cln, the Armature React^n both magnetizing & cross-magnetiz
2) leading (De-magnetizing & cross-magnetiz)

Notes

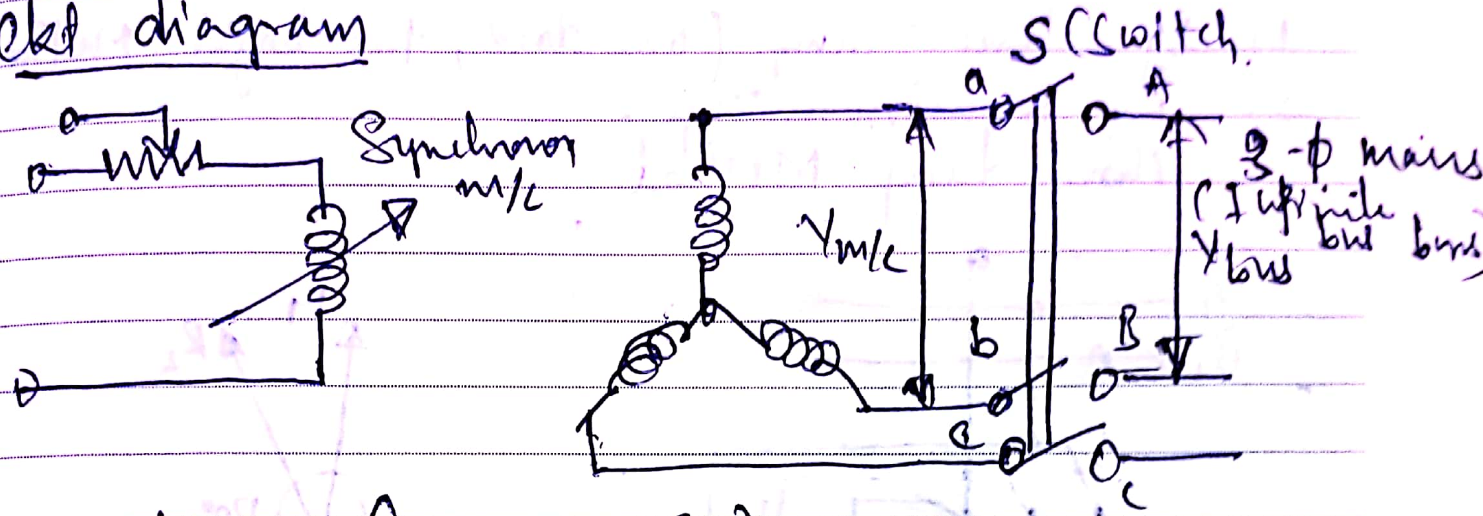
Synchronizing to Infinite bus Bars

Infinite bus Bar's

Mean's a 3 phase supply of constant vtg and frequency independent of the load (exchange) [fed into bus-bars or drawn from bus bars]

Connecting synchronous m/c to Infinite Bus Bars

Ckt diagram



Conditions (Synchronizing)

1) * Phase of Alternator vtg same as busbar

*2) m/c is run as generator with its terminals so Arranged that its phase Sequence is same as that of bus-bars

*3) M/c terminal vtg must be nearly equal to Bus Bar vtg

* 4) M/c frequency is nearly equal to bus bars freque

Condition (i) & (iv) indicated by Synchronizing ~~Lamps or Synchronoscope Phase Sequence Indicate~~

Condition (iii) indicated by voltmeter.

Condition (ii) indicated by phase sequence Indicator

3 WED

After above conditions are satisfied the instant of switching on (Synchronising) must be determined such that two voltages are almost co-phasal (acceptable phase difference is of order 5°). This instant is determined by two method i.e condition (i) & (ii)

1) By three lamp (one dark, two bright) method
2) By synchroscope.

Three lamp method

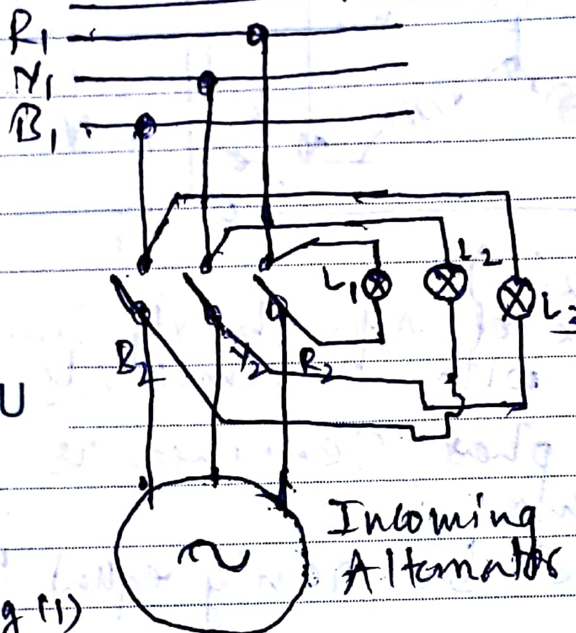


fig (1)

4 THU

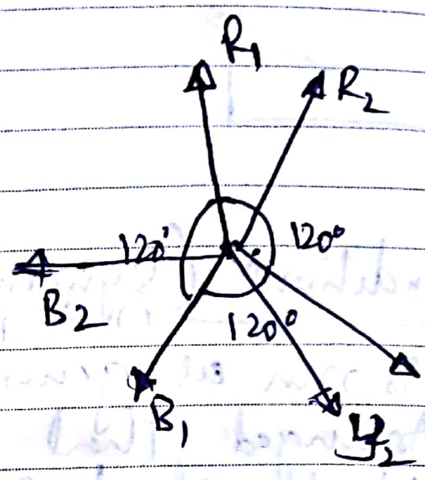


fig (2)

* Three lamps L_1 & L_2 & L_3 are connected as shown in fig
* lamp L_1 is straight connected betⁿ corresponding phases (R_1 & R_2) & other two are cross connected betⁿ two phases
* When the frequency and phase of voltage of incoming alternator is same that of busbars, L_1 will be dark, while L_2 & L_3 ~~are~~ will be equally bright

* At this instant synchronisation is perfect & switch is closed & (2) connected ||el to bus-bar.

FEBRUARY 2010

In fig (2)

5 FRI

* phasors R_1, Y_1 & B_1 represents Busbars voltage & phasors R_2, Y_2 & B_2 vtg's of incoming Alternator
* At the instant when R_1 is in phase with R_2, vtg across lamp L_1 is zero & vtg across L_2 & L_3 are equal
∴ L_1 is dark & L_2 & L_3 are equally bright.

(ii) Synchronoscope

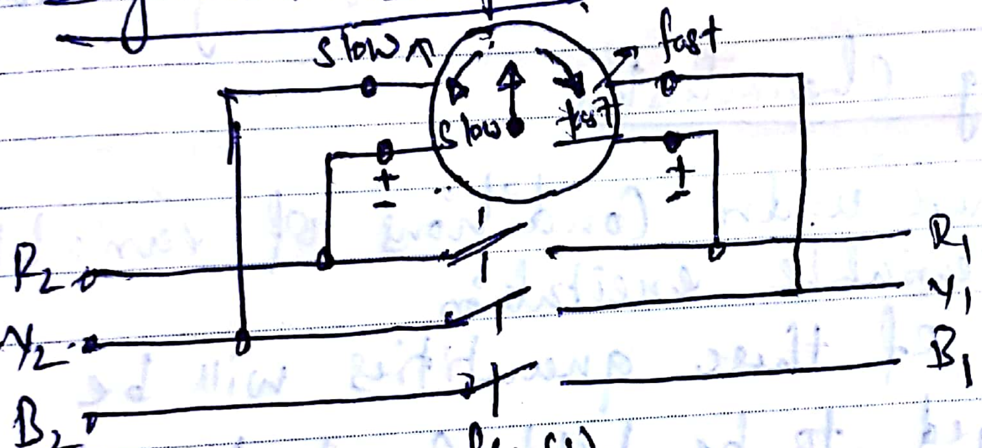


fig (1).

6 SAT

Defn
Synchronoscope is an instrument that indicates by means of a revolving pointer the phase difference and frequency difference betw vtges of incoming Alternator & busbars

working
* It is essentially a small motor, the field being supplied from the busbars through a potential transformer & rotor from incoming Altern & pointer attached to rotor
* When incoming Alternator running fast

(i.e f is higher than busbar), the rotor
7 SUN and hence pointer moves in clockwise direction.

* When alternator running slow (f is less) the pointer moves in anticlockwise direction
* When frequency of incoming alternator is equal to that of bus bars, no torque acts upon the rotor & pointer points vertically upwards (12'o clock). It indicates synchronisation

Operating Characteristics

1) * Explained here under conditions of variable load & variable excitation
2) * one of these quantities will be
8 MON Assumed to be held constant at a time while other will be allowed to vary over a wide range.
3) * $R_a = 0$.

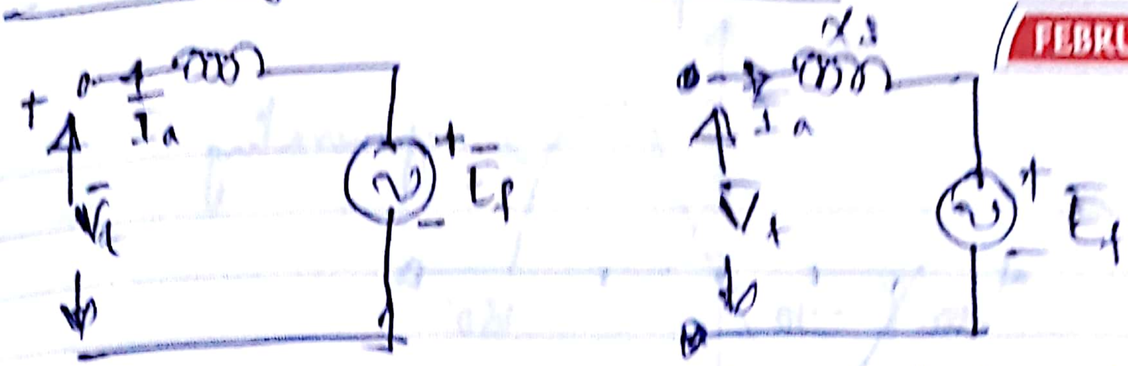
Generating machine

$P_e(out) = P_m(in)$ (net) [deducting iron loss & windage & friction]

Motoring machine

$P_e(in) = P_m(out)$ [deducting iron loss & w&f]

Power angle Characteristics

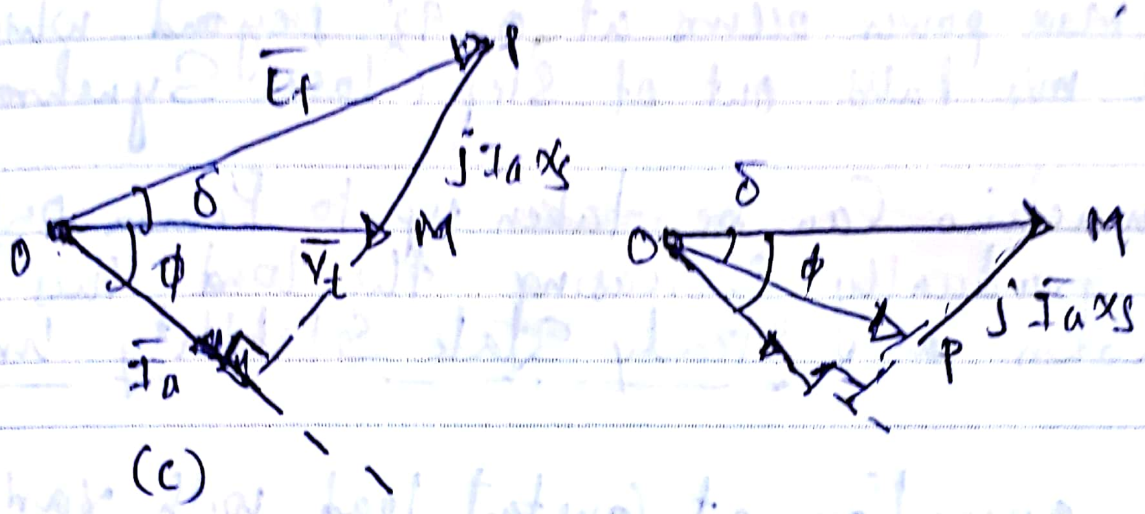


(a) generating mode

$$\bar{E}_f = \bar{V}_t + j\bar{I}_a x_s$$

(b) motoring mode

$$\bar{E}_f = \bar{V}_t - j\bar{I}_a x_s$$



(c)

from Δ^{le} OMP.

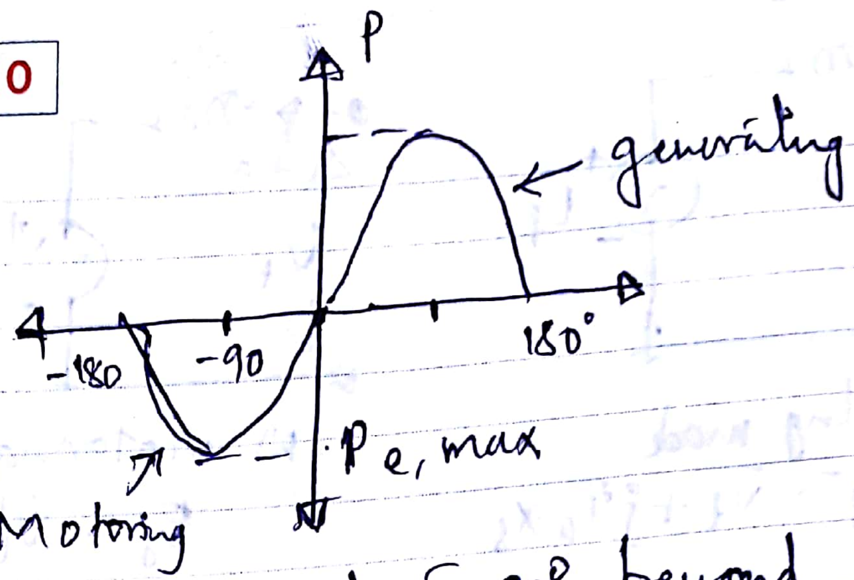
$$\frac{E_f}{\sin(90 \pm \phi)} = \frac{I_a x_s}{\sin\delta} \Rightarrow I_a\cos\phi = \frac{I_a x_s}{\sin\delta} = \frac{E_f}{x_s}\sin\delta$$

Multiplying both sides V_t.

$$V_t I_a \cos\phi = \frac{V_t E_f}{x_s}\sin\delta$$

$$\boxed{P_e = \frac{V_t E_f}{x_s}\sin\delta} \quad (1)$$

11 THU



The max power occurs at $\delta = 90^0$ beyond which the m/c falls out of step (loses Synchronism)

The machine can be taken up to P_{emax} only by gradually increasing the load. This is known as Steady State Stability limit

12 FRI

operation at constant load with variable Excitation

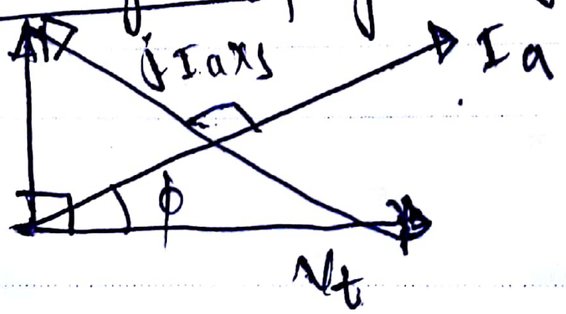
At constant load

$$E_f \sin\delta = \frac{P_e X_s}{V_t} = \text{const}$$

Also ; $V_t I_a \cos\phi = P_e = \text{Const}$.

or $I_a \cos\phi = \frac{P_e}{V_t} = \text{Const}$

Phasor Dgm of generating m/c at steady state stability



2010	Sun	Mon	Tue	Wed	Thu	Fri	Sat
	31					1	2

Problem on Two Reaction theory (Ashfaq Hussain)

FEBRUARY 2010

Ex. 3.19 :-

A 1500 KVA star connected, 2200 V, 3 phase, Salient-pole Synchronous generator has Reactances $X_d = 1.95 \Omega$ & $X_q = 1.40 \Omega$ per phase. All losses may be Neglected. Find the excitation voltage for operation at rated KVA & p.f. of 0.85 lagging.

13 SAT

Ex :- 3.21 June/July 2011

A 400 V, 50 Hz, delta connected alternator has a direct axis Reactance of 0.07 Ω per phase. The Armature resistance is negligible. The Alternator is supplying 1000 A at 0.8 lagging pf

a) find the excitation emf neglecting saliency & assume $X_s = X_d$

b) find excitation emf taking into account saliency

Dec 2010 08

14 SUN

A 3 phase, Y connected Synchronous generator supplies a current of 10A having phase angle of 20° lagging at 400 V (phase voltage). Find (i) load angle (ii) Components I_d & I_q of Armature Cu (iii) Vtg Regulation given $X_d = 10 \Omega$ & $X_q = 6.5 \Omega$. Neglect R_a

$$\Rightarrow \quad \tan\delta = \frac{X_q I_a \cos\phi}{V + X_q I_a \sin\phi}$$

$\cos\phi = \cos 20 = 0.94$

$\sin\phi = 0.342$

08 marks

$\tan\delta = 0.1447 \Rightarrow \delta = 8.23°$.

FEBRUARY 2010

15 MON (ii) $\psi = \delta + \phi = 28.23°$

$I_d = I_a \sin\psi = 4.73A$

$I_q = I_a \cos\psi = 8.81 A$

iii) $E_f = V\cos\delta + X_d I_d = 443$ V/s

Vtg Regn $= \frac{E_0 - V}{V} \times 100 = \frac{443 - 400}{400} \times 100 = 10.75\%$

02/11/11.

02, 06, 10, 11, 13, 18, 21, 24, 25, 29, 33, 44, (51), 56, 58, 61

parallel operation of Alternators

Interconnection of power system — grid

16 TUE

Reason's of parallel operation

* Several alternators can supply a bigger load than a single alternator
* During periods of light loads, one or more Alternators may be shut down, & those Remaining operate at near full load, and thus more efficiently.
* When one machine is taken out of the service for its scheduled maintenance and inspection, the Remaining machines

maintain the continuity & supply

* If there is a breakdown of a generator, there is no interruption of the power supply

* In order to meet the increasing future demand of load more machines can be added without disturbing the original installation
* Operating cost & cost of energy generated are reduced when several generators operate in parallel

Conditions Necessary for paralleling Alternators

The process of connecting one machine in parallel with another machine or with an infinite bus busbar system is known as Synchronizing

Before incoming m/c connecting to running m/c conditions to be satisfied.

* Phase Sequence of Busbar Voltage & Incoming Machine Voltage must be same
* The busbar voltages & incoming machine terminal voltage machine must be in phase

19 FRI

* The terminal voltage of incoming machine should be equal to that of alternator with which it is to be run in parallel or with busbar voltage

* The frequency of generated vltg of incoming M/c must be equal to frequency of vltg of live busbars

prime mover characteristic

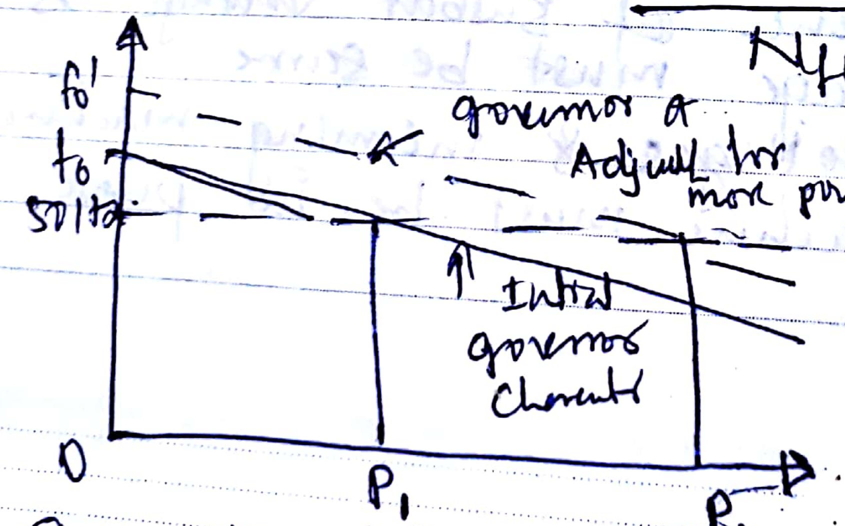
In general, for Alternators to operate successfully in parallel, load - speed characteristic of the prime movers should be drooping

20 SAT

that is speed of the prime mover should decrease slightly with increasing loads.

Speed droop also called governor

$$\text{Speed droop} = \frac{N_{nl} - N_{fL}}{N_{fL}} \times 100\%$$



Shift of speed (frequency) load characteristics

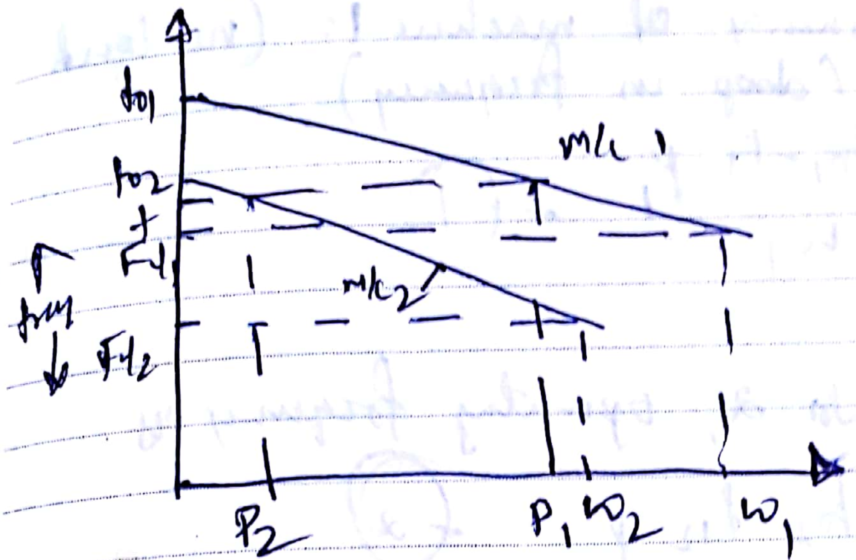
Notes

January 2010	Sun	Mon	Tue	Wed	Thu	Fri	Sat
	31					1	2
	3	4	5	6	7	8	9
	10	11	12	13	14	15	16
	17	18	19	20	21	22	23
	24	25	26	27	28	29	30

Expressions for powers shared by two Alternators

FEBRUARY 2010

21 SUN



Let w_1 = full load power rating of m/c 1

w_2 = full load power rating of m/c 2

P_1 = power shared by m/c 1, P_2 = Power shared by 2

P = total power supplied by two m/cs

22 MON

f_{01} = no-load frequency of m/c 1

f_{02} = no-load frequency of m/c 2

F_{l_1} = full load frequency of 1 f_{l_2} = FL freq. of m/c 2

f = Common operating frequency when two m/cs are running in parallel

Machine 1

Drop in frequency from no-full load $= f_{01} - f_{l_1}$

Drop in freq per unit rating $= \frac{f_{01} - f_{l_1}}{w_1}$

Drop in freq for load of $P_1 = \frac{f_{01} - f_{l_1}}{w_1} P_1$

Sun | Mon | Tue | Wed | Thu | Fri | Sat   Notes

23 TUE

Operating frequency of machine 1 = (no-load frequency) − (drop in frequency) *

$$f = f_{01} - \frac{f_{01} - f_1}{W_1} P_1 \quad \text{—} (1)$$

Machine 2

Illy for alternator 2, operating frequency is

$$f = f_{02} - \frac{f_{02} - f_{12}}{W_2} P_2 \quad \text{—} (2)$$

from (1) & (2)

$$f = f_{01} - \frac{f_{01} - f_{l1}}{W_1} P_1 = f_{02} - \frac{f_{02} - f_{l2}}{W_2} P_2 \quad \text{—} (3)$$

24 WED

Also $P_1 + P_2 = P$ — (4)

eqn (3) & (4) are used to determine P_1, P_2 & f

Ashfaq husain

Ex:- 3.23:-

Two 1000 KVA 3-phase alternators are operating in parallel and supply a load of 1500 KVA at 0.8 lagging power factor. If one machine is operating at 0.4 lagging power factor & supplying 800 KVA, find o/p of other m/c and power factor at which it is operating

* Two 500 KVA alternators operate in parallel to supply the following loads

(i) 250 KW at 0.9 pf lag.
(ii) 300 KW at 0.75 pf lag.
(iii) 150 KW at 0.8 pf lag

One m/c supplies 100 kw at 0.8 p.f lagging. Calculate pf of other m/c. (June/July 11).

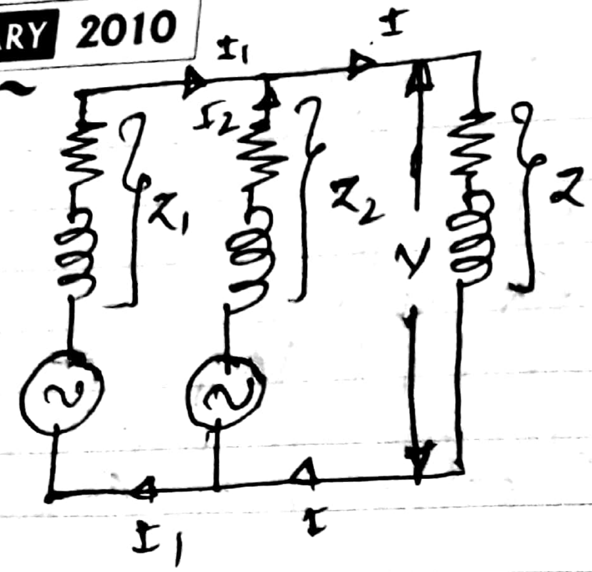
03/11

01, 05, 06, 10, (13), 18, 24, 25, 39, 41, 44, 48, 52, 54, 58, 6.

* Two Identical 2000 KVA alternators operate in parallel. The governor of first machine is such that the frequency drops uniformly from 50 Hz on no load to 48 Hz on full load. The corresponding uniform speed drop

of second machine is 50 Hz to 47.5 Hz.
(a) How will two machines share a load a load of 3000 kw? b) What is maximum load at upf that can be delivered without overloading either machine.

Sharing of Load Currents by two Alternators in Parallel



Consider two alternators with Identical speed/load Characteristics in parallel.

Let E_1, E_2 = Induced emf's per phase

Z_1, Z_2 = Synchronous Impedances per phase

Z = load Impedance per phase

I_1, I_2 = Crns supplied by two m/c

V = Common terminal Voltage per phase

$$V = E_1 - I_1 Z_1 = E_2 - I_2 Z_2$$

$$I_1 = \frac{E_1 - V}{Z_1}, \quad I_2 = \frac{E_2 - V}{Z_2}$$

$$I = I_1 + I_2$$

$$V = (I_1 + I_2) Z = I Z$$

Circulating crn on no load

$$I_C = \frac{E_1 - E_2}{Z_1 + Z_2}$$

* Two single phase alternators are connected in parallel and supply crn to a load

Notes

at a terminal voltage of $1000\angle 0°$ volts. Alternator A has an induced emf of $13000\angle 22.6°$ volts & a reactance of 2Ω; alternator B has an emf of $12500\angle 36.9°$ volts & reactance of 3Ω. find c/n supplied by each alternator

$$I_A = \frac{13000\angle 22.6° - 10000\angle 0°}{2\angle 90°} = 2700\angle -21.8° A$$

$I_B = 2500\angle 0° A$

* Dec 09/Jan 10 Two single phase alternators operating in parallel have induced Emf on open circuit of $230\angle 0°$ V & $230\angle 10°$ V & the respective reactances are $j2\Omega$ & $j3\Omega$. Calculate

(1) Terminal vtg (2) Currents

(3) power delivered by each of alternators to load of Impedance 6Ω (Resistive). (10 m)

$P_1 = \sqrt{3} V I_1 \cos\phi_1$

$$I_A = \frac{E_A - E_A + I_A Z_A}{Z_A} =$$

$$I_1 = \frac{E_1 Z - E_2 Z + E_1 Z_2}{Z(Z_1 + Z_2) + Z_1 Z_2}$$

3 WED

$$I_1 = \frac{(\bar{E}_1 - \bar{E}_2)\bar{Z} + \bar{Z}_2 \bar{E}_1}{\bar{Z}(\bar{Z}_1 + \bar{Z}_2) + \bar{Z}_1 \bar{Z}_2} = 14.90 \angle -17.71$$

$$I_2 = \frac{(\bar{E}_2 - \bar{E}_1)\bar{Z} + \bar{E}_2 \bar{Z}_1}{\bar{Z}(\bar{Z}_1 + \bar{Z}_2) + \bar{Z}_1 \bar{Z}_2} = 20.36 \angle -7.238$$

$I = 210.6 \angle -11.65^\circ$ wb

$P_1 = V I_1 \cos\phi_1 = 2989.22$ watt

$P_2 = 4253.72$

from ① & ②

$\bar{V} = \bar{E}_1 - \bar{I}_1 \bar{Z}_1$

$\bar{E}_1 = \bar{V} + \bar{I}_1 \bar{Z}_1 = \bar{I}\bar{Z} + \bar{I}_1 \bar{Z}_1$

$= (I_1 + I_2)\bar{Z} + \bar{I}_1 \bar{Z}_1$

$= I_1(\bar{Z} + \bar{Z}_1) + \bar{I}_2 \bar{Z}$ — ①

$= I_2(Z + Z_2) + I_1 Z$ — ②

4 THU

* $S_A + S_B = S_{L_1} + S_{L_2} + S_{L_3}$

$\frac{250}{0.9} = 277.77$ $\frac{300}{0.75} = 400$ $\frac{150}{0.8} = 187.5$

$125 \angle -36.86 + S_B = 277.77 \angle -25.84 + 400 \angle -41.40 + 187.5 \angle -36.86$

$= 859.26 \angle -35.43$

$S_B = 734.20 \angle -35.18$

$\cos(35.18)$.

$E_1 - E_2 = I_1 Z_1 + I_2 Z_2$

$I_A = \frac{E_A - V}{Z_A}$ put $V = E_A - 1$

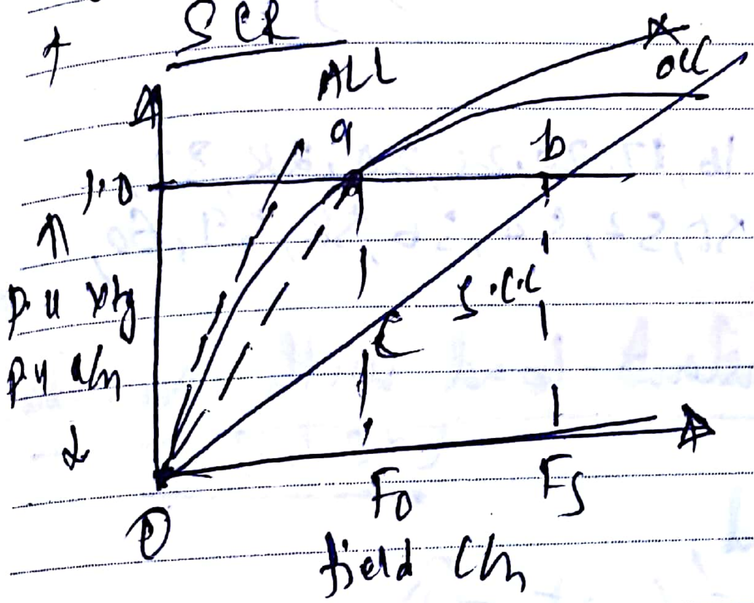
04 !!!

02, 06, 10, 11, 13, 24, 40, 46, 52, 54, 58,

June/July 2011

* Show that Short Circuit Ratio of Synchronous generator is Reciprocal of Synchronous Reactance

* SCR



Short Circuit Ratio of a Synchronous machine is defined as ratio of field Ch Required to produce Rated voltage on open Circuit to field Ch required to Circulate rated Current at Short circuit.

According to Condition

$$SCR = \frac{OF_o}{OF_s} = \frac{CF_o}{bF_s} = \frac{CF_o}{aF_o} = \frac{1}{aF_o/CF_o}$$

$$= \frac{1}{\text{per unit vtg on open Ckt / corresponding per unit Ch on short ckt}}$$

Notes

Sun	Mon	Tue	Wed	Thu	Fri	Sat
				1	2	3

8 MON

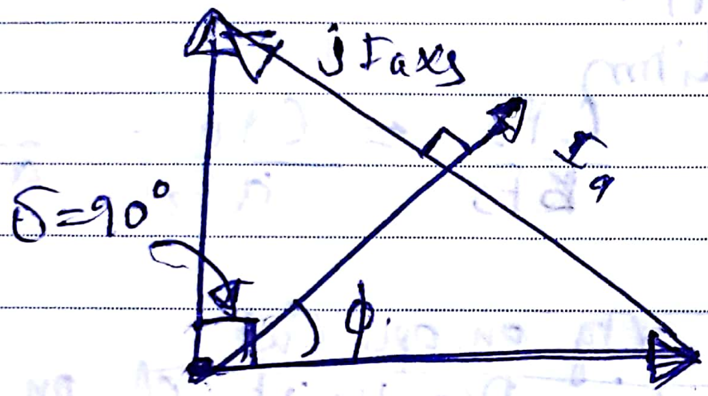
operation at constant load with variable excitation

At constant load,

$$E_f \sin\delta = \frac{P_e X_s}{V_t} = \text{Const} \quad (1)$$

Also $V_t I_a \cos\phi = P_e = \text{Const}$.

or $I_a \cos\phi = \frac{P_e}{V_t} = \text{Const} \quad (2)$



Phasor diagram of generating m/c at steady state stability

es

February 2010	Sun	Mon	Tue	Wed	Thu	Fr
		1	2	3	4	5
	7	8	9	10	11	1
	14	15	16	17	18	1
	21	22	23	24	25	2
	28					

∴* At Constant load, excitation Emf E_f is varied (by varying field cu I_f), The power angle δ varies such that $E_f \sin\delta$ remains Constant.

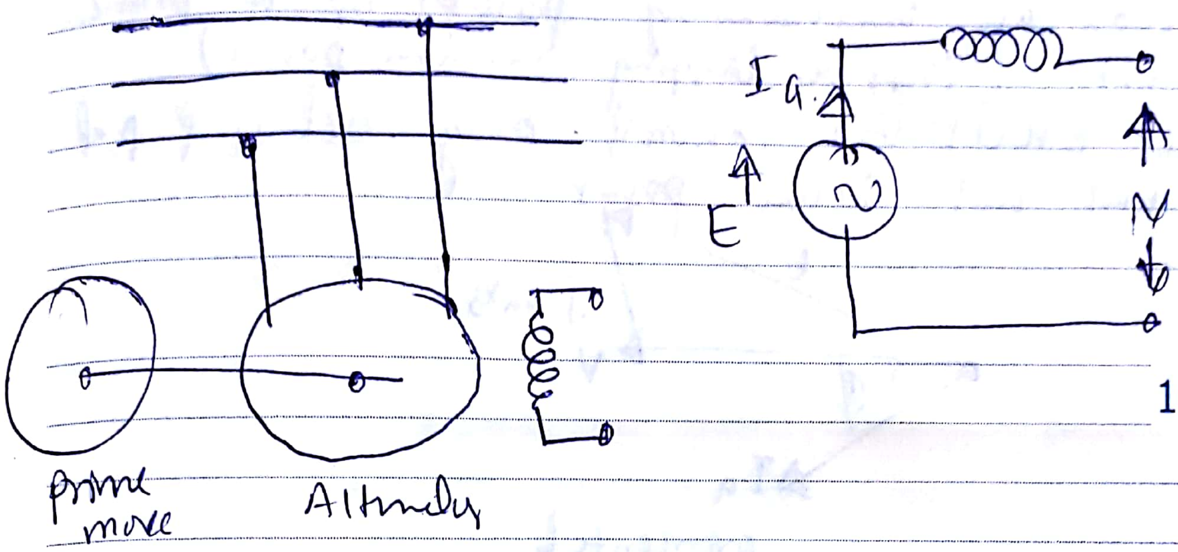
* Behaviour of m/c is depicted by phasor Diag

MARCH 2010

9 TUE

Alternator on Infinite Busbars

Effect of change of Excitation & mechanical I/p



10 WED

* Consider a Star Connected Alternator Connected to Infinite bus bars.
* Busbar terminal Vtg is constant & no frequency change loss occurs regardless changes made in power input or field excitation of Alternator

Behaviour of alternators to infinite busbars

1) Change made in operating cond^n not change vtg &fr
2) KW depends on PM not KVAR
3) Change in excitation Control KVAR not KW.

April 2010	Sun	Mon	Tue	Wed	Thu	Fri	Sat
					1	2	3
	4	5	6	7	8	9	10
	11	12	13	14	15	16	17
	18	19	20	21	22	23	24
	25	26	27	28	29	30	

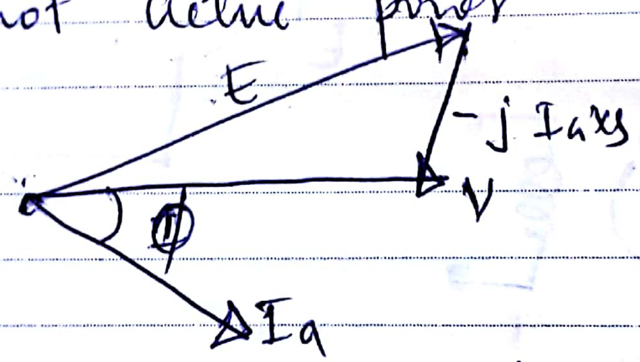
Notes

Effect of change of field excitation

11 THU

* Suppose the Alternator connected to infinite busbar, i.e operating at upf. It is normally excited
* Excitation increases over excited at which Alternator supplies lagging current at lagging pf without any change in active power & active component of current becoz of unchanging power i/p to prime mover. (supplies lagging reactive power)

Note excitation controls only active & pf but not active power



12 FRI

overexcited

* excitation decreased below normal excitation (under excited)

Conclusion:- An overexcited alternator operates at lagging power factor & supplies lagging Reactive power to Infinite bus bar.

on other hand, an underexcited alternator operates at leading power factor & supplying leading reactive power to infinite busbars

MARCH 2010

* Reverse is for motoring mode

13 SAT

(ii) <u>Effect of change in mechanical i/p</u>

Suppose the alternator is delivering power to infinite bus bars under stable condition so that a certain power angle δ exists betw V & E. E lead V.

Now suppose excitation kept const & power i/p to prime mover is increased.

* Increase in power i/p would tend to accelerate rotor and E would move further ahead of V i.e angle δ increase. results in large $I_a = E-V/X_s$ and power φ as in fig 10.75. ∴ Alternator will deliver more active power to infinite bus bars.

14 SUN

<u>Note</u>:- mechanical I/p to the prime mover cannot change speed of alternator because it is fixed by system frequency. Increasing mech I/p increases the speed of alternator temporarily till such time the power angle δ increases to value required for stable operation. Once this condition is reached, alternator continues to run at synchronous speed