Computer Aided Design of Synchronous Generator

PROJECT REPORT

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1997 - 98

IN PARTIAL FULFILMENT OF THE REQUIREMENTS
FOR THE AWARD OF THE DEGREE OF
BACHELOR OF ENGINEERING IN
ELECTRICAL & ELECTRONICS ENGINEERING
OF THE BHARATHIAR UNIVERSITY

DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING
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CERTIFICATE

This is to certify that the report entitled

COMPUTER AIDED DESIGN OF SYNCHRONOUS GENERATOR

Has been submitted by

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In partial fulfilment for the award of the degree of

BACHELOR OF ENGINEERING

In Electrical and Electronics Engineering Branch
of Bharathiar University during the academic year 1997-'98

Guide
Date : 6/4/98

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ACKNOWLEDGEMENT

We wish to convey our gratitude to our guide Dr. K.A. Palaniswamy, B.E., M.Sc (Engg.), Ph.D., MISTE., C.Eng (I), FIE, Professor and Head of the Department of Electrical and Electronics Engineering for his guidance and his expert suggestions throughout the course of the project.

We would like to record our sincere thanks to our Principal Dr. S. Subramanian, B.E., M.Sc. (Engg)., Ph.D., SMIEEE for providing the necessary facilities to complete this project in the College.

We would also like to express our thanks to Mr.Radhakrishnan, Lecturer, Computer Software College and Mr. V.C. Chandrasekaran, M.E., Senior Lecturer, Electrical and Electronics Department for their help.

SYNOPSIS

Electrical technology has developed amazingly in the recent past. The use of computer in the field of design of Electrical machine is land mark in the field of design. Computer Aided Design is used in the field of design to avoid time consuming manual calculation and to optimize the design.

In this project, it is proposed to develop CAD technique in the design of synchronous generator. The various design aspects of the synchronous generator is included. This software also includes the minimization of eddy current loss. Using this software, one can analyze the machine regarding O.C.C. and short circuit characteristics, loss and temperature rise calculations. Software also includes standard conductor sizes and B -H curve details for Stalloy, quality steel and Lohy's steel.

Another important aspect about the software is that, it gives the open circuit characteristics on screen using graphics.

Software is written in 'C' language and it can be run on 'C' or 'C++' compiler.

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Appendices

NOMENCLATURE

Input Variables

KW - Output power, kilowatts

pf - power factor

rpm - speed, rpm

head - water head, metre

Ve - exciter voltage, Volts

Bav - average air gap flux density, Tesla

ac - Ampere conductors per metre, A/m

V - line to line voltage, Volts

delta - stator current density, A/mm^2

f - frequency, Hertz

Main dimension variables

D - Diameter of stator bore, metre

p - number of poles

nd - Number of ventilating ducts

wd - width of the ventilating duct, mm

Q - output power, KVA

LbyTOV - Iron Length / pole pitch ratio

ns - speed, r.p.s

L - Core length, metre

Va - peripheral speed, m/s

polpitch - pole pitch, metre

polarc - pole arc, metre

Lg - gross iron length, metre

Li - Net iron length, metre

DSL - Product D^2L, m^3

Stator variables

S - Number of slots

As1 - Area of strip, mm^2

Wb - Width of the strip, mm

tb - Thickness of the strip, mm

As - Area of conductor, mm^2

Eph - Phase voltage, volts

Z - Number of stator conductor

Zs - Conductors / Slot

q - Slot / Pole / Phase

Ys - Slot pitch, metre

FI - Flux / Pole, weber

Iph - Phase current, Amperes

sl - Slot loading Amp. Conductors / Slot

slot d - Stator slot depth ,mm

slotw - Stator slot width, mm

Impedance variable

Keav - average eddy current loss factor

Lmts - Length of mean turn in stator, metre

Bt - flux density in teeth, Tesla

rac - a.c. resistance /phase, ohms

Racpu - per unit a.c. resistance

teew - teeth width, mm

Culoss - stator copper loss / phase, watts

Lamda - specific slot permeance, weber.A.m

xss - slot leakage reactance, ohms

Xo - overhang leakage reactance, ohms
Xl - total stator leakage reactance, ohms
Xlpu - per unit stator leakage reactance
ratio - coil span /pole pith
rdc1 - dc resistance of conductors embedded in the slots, ohms

Air gap and pole variable

Do - Outer diameter of stator, metre
Dc - depth of core, metre
Flsc - flux in stator core, weber
ATa - Armature mmf/pole, A
ATfo - No load field mmf/pole , A
ATfl - full load field mmf/pole , A
ATg - Mmf for sirgap, A
Bg - air gap flux density, Tesla
SCR - short circuit ratio
lg - length of air gap, mm
Dr - Outer diameter of rotor, metre
Flp - Flux in pole body, weber
Ap - Area of pole body, m^2
dp - width of pole body , metre
df - depth of the field winding, mm
Sr - Number of rotor slots
hf - Height of field winding, mm
theta - temperature rise in field coils, ^0C
Qf - loss in each field coil, watts
Ef - voltage across each field coil, volts
af - area of each field conductor, mm^2

Tf - Field winding turns
Rf - Resistance of each field winding, ohms
Su - Area of dissipating surface in stator, m^2
hpl - Radial length of pole, metre
Cf - stator cooling co-efficient
If - Field current, Amps
Lmtf - length of the mean turn (field), metre
Cs - coil span, slots/pole
temp_rise - temperature rise of armature, ^{0}C

Rotor Variables

Lmtfr - length of the mean turn (rotor), metre
afr - Area of each rotor field conductor, mm^2
Rfr - Resistance of each rotor field winding, ohm
Ysr - Rotor slot pitch, metre
Zsr - Rotor conductors/slot
Tfr - Rotor turns
Ifr - Rotor conductor current, Amps
MMF - Rotor mmf, A
slotwr - Rotor slot width, mm
slotdr - Rotor slot depth, mm

Damper & Yoke variables

Fly - flux in the yoke, weber
dy - depth of yoke, metre
Ay - Area of yoke, m^2
Ad - Total area of damper winding, m^2

Nd - Number of damper bars

ad - area of each damper bar, m^2

Dd - Diameter of damper bar, metre

hs - height of pole shoe at the tips, mm

hr - height of pole shoe at centre, mm

Ag - area of air gap, mm^2

Magnetic Circuit Variables

Wt13 - tooth width at 1/3rd height from narrow end, mm

Bt13 - flux density at 1/3rd height from narrower end, tesla

at13 - value of mmf per metre for Bt13 as obtained from B - 'at' curve

ATt - Total mmf required for teeth, A

ATc - Mmf for core, A

ATl - sum of mmfs for core, teeth and air gap, A

atc - value of mmf per metre for BC as obtained from B - 'at' curve

Bc - flux density in the core, Tesla

lc - length of the flux path in core, metre

Ac - area of core, m^2

Fl_min - minimum flux in the pole, weber

Fl_max - maximum flux in the pole, weber

ly - length of the flux path in yoke, metre

Bp_min - minimum flux density in the pole, Tesla

Bp_max - maximum flux density in the pole, Tesla

at_min - Value of mmf per metre for Bp_min as obtained from B - 'at' curve

at_max - Value of mmf per metre for Bp_max as obtained from B - 'at' curve

Kcs - carter's co-efficient for slots

Kcd - carter's co-efficient for ducts

Kgs - gap contraction factor for slots
Kgd - gap contraction factor for duets
Kg - gap contraction factor
ATy - mmf for yoke, A
ATp - mmf for pole, A
By - flux density in the yoke, Tesla
aty - value of mmf per metre for By as obtained from B - 'at' curve
hp - height of the pole body, metre

Loss variables

Loss - total copper loss in stator, watts
Stray - stray loss, watts
Dmid - diameter of armature at the middle of teeth, metre
iron_tee - iron loss in teeth, watts
iron_cor - iron loss in core, watts
iron_los - total iron loss, watts
fri_wind - friction and windage losses, watts
field_los - field copper loss, watts
brush_los - brush loss, watts
exc_los - excitation losses, watts
total_los - total losses, watts
Eff - efficiency, %
ys_mid - slot pitch at the middle of the teeth, metre
wt_mid - tooth width at the middle, metre

Cooling

ductrs - radial ducts in stator
ductrs - radial ducts in rotor
ductas - axial ducts in stator

ductar - axial ducts in rotor

Vair - Air velocity in ducts, m/sec

d, t, w, flux - local variables

local1, local2 - local variables

CHAPTER - I

INTRODUCTION

1.1 SYNCHRONOUS GENERATOR

A synchronous generator consists of two major parts

1. Armature
2. Field system

1.1.1 HYDRO ELECTIC GENERATOR

The hydro-electric generators are low speed machines, the speed depending upon the available head and the type of turbine used. The stator core is built up of laminations in order to reduce eddy current loss. Bar winding is used in stator. The winding may be single layer concentric type or double layer lap type. The salient poles are attached to the rotor body. Different types of pole construction are

- bolted pole construction
- Dove tail construction
- T - head
    - single T- head construction
    - multi T - head construction

" strip on edge " winding is used for the field coils. Damper windings are housed in the pole shoes. The slip rings are required to supply excitation to the field windings which are made of steel and are shrunk over cast iron sleeve with micanite as insulation between the two. Air cooling is provided.

1.1.2 TURBO - ALTERNATOR

The stator core is built up of laminations. Turbo - alternators are characterised by long lengths and short diameters . Double layer lap winding is used with the pitch of winding so adjusted as to reduce the 5th and 7th harmonics. The cylindrical or non-salient pole rotor is adopted with field winding distributed in slots. Air - cooling and hydrogen cooling are used.

1.2 COMPUTER AIDED DESIGN

The digital computer has completely revolutionised the field of design of electrical machines. The computer aided design eliminates the tedious and time consuming hand calculations thereby releasing the designer from numerical drudgery.

The use of computer makes possible more trial designs, and enables sophisticated calculations to be made without excessive time.

The advantages of use of a digital computer for the design of electrical machines may summed up as :

1. It has capabilities to store large amount of data, count integers, round of 6 results down to integers and refer to tables, graphs and other data in advance.
2. It is used to select the optimised design.
3. More no. of loops can be incorporated in program.
4. High speed and accuracy
5. Logical decisions of designed can be easily incorporated in program as loops.

The two concepts of common acceptable approaches to machine design are

i.) analysis method
ii.) synthesis method

1.2.1 ANALYSIS METHOD

In this method, the choice of dimensions, materials, and types of construction are made by the designer and these are fed to the computer as input data. The performance in calculated by the computer and is returned to the designer to examine. The designer examines the performance and makes another choice of input, if necessary, and the performance is recalculated. This procedure is repeated over and over again till the performance requirements are satisfied.

1.2.2 SYNTHESIS METHOD

The desired performance is given as input to the computer. The logical decisions required to modify the values of variables to arrive at the desired performance are incorporated in the program as a set of instructions. Unlike in the case of analysis method, the program or computer is therefore not interrupted for the designer to take logical decisions.

1.2.3. HYBRID METHOD

This method incorporate both the analysis as well as the synthesis methods in the program. Since the synthesis methods involve greater cost, the major part of the program is based upon analysis with a limited portion of the program being based upon synthesis. The program developed in this project is based on hybrid method.

CHAPTER - II

DESIGN OF SYNCHRONOUS GENERATOR

CHAPTER - II

DESIGN OF SYNCHORONOUS GENERATOR

2.1. DESIGN CONSIDERATIONS

2.1.1 SPECIFIC LOADING

- **Choice of specific magnetic loading**

In order to decrease iron loss and transient short circuit current low value of specific magnetic loading should be used. A lower value of gap density should be used in high voltage machines to avoid excessive values of flux density in teeth and core. On other hand, a higher value of specific magnetic loading increases the stability and results in satisfactory parallel operation.

Following are the normal values of average gap density

Salient pole machines	-	0.52 to 1.0 Tesla
Turbo alternator	-	0.54 to 1.0 Tesla

Lower values normally applied to small machines.

- **Choice of specific electrical loading**

A high value of specific electric loading increases the stray load losses, copper, losses, temperature rise and synchronous reactance. A higher value of ac leads to poor inherent voltage regulation. A higher value of ac can be used for low voltage machines since the space required for insulation is small.

The following are the usual values for specific electrical load

Salient pole machines	- 20,000 to 75,000 A/M
Turbo alternator	- 50,000 to 1,00,000 A/M

2.1.2 SHORT CIRCUIT RATIO

The short circuit ratio (SCR) of a synchronous machine is defined as the ratio of field current required to produce rated voltage on open circuit to field current required to circulate rated current at short circuit. For modern turbo - alternators, the SCR is normally between 0.5 to 0.7. for salient pole hydro generators SCR varies from 1.0 to 1.5.

A machine with a low value of SCR has a lower stability limit and a poor inherent voltage regulation. Machines with a low value of SCR are also difficult to operate in parallel because a high value of synchronous reactance gives a small synchronising power. On the other hand a higher value of SCR means a high value of short circuit current and field mmf. Hence a machine with a higher value of SCR is costlier to build. Present trend is to design the machine with a low value of SCR.

2.1.3 LENGTH OF AIRGAP

The length of air gap affects or changes the characteristic of generator. A large air gap reduces the effect of armature reaction. This result in a small value of synchronous reactance and a high value of SCR. Also cooling will be better in machine having large air gap. This result in less noise level and a negligible UMP (unbalanced magnetic pull). But with the increase in length of air gap, a large value of field mmf is required resulting in increase of cost of the machine.

2.1.4 OUTPUT CO-EFFICIENT

The volume of active parts in synchronous generator is inversely proportional to the value of output co- efficient Co. Thus an increase in the value of Co results in reduction in life and cost of machine. Since the output co-efficient is proportional to product of specific magnetic and specific electrical loading. We conclude that the size and hence also the cost of machine decreases if increased values of specific magnetic and specific electrical loading are used. Thus from commercial stand point, it is desirable to push the values of specific loading as high as possible to reduce the dimensions of the machine. How much high they should be pushed is decided by the designer by analysing the effect of increased loading on performance characteristics of machine. If high values of specific loading are used some performance characteristics like temperature rise, efficiency and power factor are adversely affected.

2.1.5 ELIMINATION OF HARMONICS

By choosing a proper value of chording angle, harmonics can be eliminated. Harmonics can also be reduced by using fractional slot windings and by skewing the pole face. If we use a large air gap length, the reluctance is increased and therefore the magnitude of slot harmonics is reduced.

2.1.6 STRAY LOSSES

Stray loss is caused by alternating stray fluxes that appear when a machine is loaded. Stray loss occurs in the pole faces, teeth, core and over hang. They increase eddy-current loss, produce rotational hysteresis and develop eddy loss is the end-plates. The higher harmonics mmf's of order 5,7,11,13, ... cause higher harmonic fields which travel over the pole face and include eddy currents there and thus increase the iron loss at load.

2.1.7 ARMATURE SLOTS

A smaller number of slots leads to high internal temperatures due to bunching of conductors. Also a smaller number of slots leads to slight saving of money. On the other hand it will lead to increased leakage reactance. If we use a large number of slots, there is a chance for getting a higher values flux densities in teeth which may be beyond the acceptable limits. The number of armature slots must be such a number that a balanced winding is obtained.

The depth of slot preferably should not exceed three times the width. Deeper slots may be used and sometimes slots are deliberately made deeper in order to have a high leakage reactance which limits short circuit currents.

2.2 MAIN DIMENSIONS

Diameter of stator bore and stator core length are called main dimensions of synchronous generator.

2.2.1 OUTPUT EQUATION

The output equation for poly phase a.c. machines is given by

$$Q = CoD^2Lns \qquad \text{------------------- (2.1)}$$

where

Q - output kVA

Co - output coefficient

$Co = 11 \text{ X } Bav \text{ X } ac \text{ X } Kw \text{ X } 10^{-3}$

Bav - average air gap flux density (Tesla)

ac - ampere conductor per metre

KW - winding factor

$Kw \cong 0.955$

D - diameter of stator bore (m)

L - stator core length (m)

ns - speed in rps

2.2.2 STATOR BORE DIAMETER AND CORE LENGTH

$$ns = \frac{R.P.M}{60}$$

$$\text{Number of poles} = p = \frac{2 \text{ X } f}{ns} \qquad \text{------------------- (2.2)}$$

f - frequency (Hz)

$$Q = \frac{\text{output in kw}}{\text{p.f}}$$

$$D^2L = \frac{Q}{CoXns} \qquad \text{------------------- (2.3)}$$

Rectangular pole is chosen for this project

L/τ ratio = 1 to 5 ------------------- (2.4)

τ - pole pitch in metre = π D/p

substituting (2.4) in (2.3) , D is calculated and L is calculated using the equation (2.4)

$$\text{Peripheral speed} = Va = \frac{\pi D}{ns} \text{ m/sec} \qquad \text{------------------ (2.5)}$$

Va < 45 m/sec for hydro - generator

Va < 160 m/sec for turbo - alternator

$$\text{Calculate pole pitch } \tau, \tau = \frac{\pi D}{p} \text{ metre} \qquad \text{------------------- (2.6)}$$

If Va > 55 m/sec, provide bolted on pole construction

If Va ≤ 55 m/sec, provide dove tailed and T-head construction.

$$\text{Let the ratio, } \frac{\text{pole arc}}{\text{pole pitch}} = 0.74$$

pole arc can be calculated from the above equation.

2.2.3 GROSS AND NET IRON LENGTH

If L exceeds 0.1 metre, ventilating ducts are provided for every 70mm distance having 10mm width

Gross iron length = Lg = L - (nd X wd) ----------- (2.7)

nd - no. of ventilating ducts

wd - width of ventilating duct in metre

Net iron length = Li =0.9 X Lg

(stacking factor is taken as 0.9)

2.3 STATOR DESIGN

2.3.1 STATOR WINDING

Phase voltage, Eph = V for delta connection

Eph = V/√3 for star connection

φ = Flux/pole = Bav τ L ------------------- (2.8)

$$\text{Turns/phase} = \text{Tph} = \frac{\text{Eph}}{4.44\, f\, \varphi\, \text{Kw}} \qquad \text{------------------- (2.9)}$$

where, V - line to line voltage (volts)

f - frequency (Hz)

Kw- winding factor

2.3.2 NUMBER OF SLOTS

ys (slot pitch) is selected from the table 2.1

Table 2.1 : Slot pitch

Line to line voltage V(volts)	slot pitch ys(mm)
V < 3000	25
V < 6000 & V ≥ 3000	34
V > 6000	50

$$\text{Slot/pole/phase} = q = \frac{\pi D}{3\, p\, ys} \qquad \text{------------------ (2.10)}$$

q is chosen as the number of poles, p is divisible by (1/fractional part of q)

No. of armature slots = S = 3 q p ----------------- (2.11)

No. of armature conductors = Z = 6Tph ------------------ (2.12)

Conductors/slot = Zs = Z/S

Calculate Tph again,

$$\text{Bav(new)} = \frac{\text{Bav (old) X Tph (old)}}{\text{Tph (new)}} \qquad \text{------------------ (2.13)}$$

flux/pole = φ = Bav(new) τ L

ys = π D/S

$$\text{Iph = current/phase} = \frac{\text{Q X 1000}}{\sqrt{3}\ \text{X V}} \qquad \text{------------------ (2.14)}$$

slot loading = IphZs

2.3.3 CONDUCTOR SIZE

Current density is chosen between 3 to 5 A/mm^2

Area of cross section of armature conductor (mm^2) = Iph / current density

Use standard strip size and recalculate current density. Also calculate no. of strips used per slot.

2.3.4 SLOT DIMENSIONS

Slot width = width of strip (mm) + conductor insulation (2 X 0.5 mm)
+ main slot insulation (2 X 2.5 mm) + slack (1mm) ------ (2.15)

slot depth will differ for single layer winding and double layer winding.

Slot depth = No. of strips X thickness of strip (mm) +
No. of strips X 0.5mm X conductor insulation +
Main slot insulation (4 X 2.5 mm - double layer) +
(2 X 2.5 mm - single layer)
Separator for double layer winding only +
(1 X 2.5mm)
Tooth lip (1.5mm) + wedge (4mm) + slack (2mm) ---------(2.16)

2.3.5 CHECKS FOR STATOR DESIGN

1. Average eddy current loss factor should not be greater than 1.33

average eddy current loss factor = Ke (av)

$$Ke\,(av) = 1 + (\alpha h')^4 \times \frac{N^2}{9} \qquad \text{-------- (2.17)}$$

where $\alpha = 100\sqrt{\text{strip width/slot width}}$

h' = thickness of strip in metre

N = no. of strips/slot

As Ke (av) α $(h')^4$, Ke (av) can be reduced by selecting less thickness strips. In this way, we can reduce the eddy current loss.

2. Flux density in the teeth should not be greater than 1.8 Tesla.

Width of the teeth at gap surface = Wt = slot pitch - slot width

$$Bt = \text{flux density in teeth} = \frac{\varphi}{0.75 \times \frac{S}{p} \times Li \times Wt} \qquad \text{------------ (2.18)}$$

2.3.6 LENGTH OF THE MEAN TURN

Length of mean turn = L mts

$$L\,mts = 2L + 2.5\,\tau + 0.06\,KV + 0.2 \qquad \text{------------------ (2.19)}$$

2.3.7 STATOR RESISTANCE

D.C. resistance of conductors embedded in slots/phase

$$R1 = \frac{0.021 \times Tph \times 2L}{(\text{area of conductor/slot})} \qquad \text{------------------- (2.20)}$$

D.C. resistance of conductor in overhang/phase

$$R2 = \frac{0.021 \times Tph \times (2.5\tau + 0.06KV + 0.2)}{(\text{area of condcutor/slot})} \qquad \text{------------------ (2.21)}$$

$$\text{Copper loss} = Iph^2\,(Ke(av)\,(R1 + R2) \qquad \text{------------------- (2.22)}$$

$$\text{A.C. resistance/phase} = \frac{\text{copper loss}}{Iph^2}\ \text{ohms}$$

$$\text{Ra.c. (P.U.)} = \frac{\text{Iph X A.C Resistance /phase}}{\text{Eph}}$$

2.3.8 STATOR CORE

$$\text{Flux in stator core} = \phi c = \frac{\text{flux/pole}}{2}$$

Assuming a flux density of 1.2 Tesla in the core,

$$\text{Depth of core} = dc = \frac{\phi c}{1.2 \text{ X } Li} \qquad \text{------------------ (2.23)}$$

Outer diameter of stator laminations = Do

$$Do = D + 2\,(dc + ds\,) \qquad \text{------------------ (2.24)}$$

ds - Slot depth (m)

dc - Core depth (m)

D - Stator bore diameter (m)

2.4 LENGTH OF AIRGAP

Armature mmf per pole = ATa

$$ATa = \frac{2.7 \text{ X } Tph \text{ X } Iph \text{ X } Kw}{p} \qquad \text{------------------ (2.25)}$$

No load field mmf per pole

ATfo = SCR X ATa

Taking 80% of this mmf to be consumed in the air gap.

∴Mmf for air gap = ATg = 0.8 X ATfo

$$Bg = \frac{Bav}{Kf} \qquad \text{(Kf - field form)}$$

Assuming gap contraction factor kg = 1.15

Mmf required for air gap ATg =800,000 Bg kg lg ------------- (2.26)

$$\text{Length of air gap} = lg = \frac{ATg}{800000BgKg} \text{ metre}$$

Diameter of rotor = Dr

$$Dr = D - 2lg$$

For salient pole machines of normal construction and having open type slots,

$$\frac{\text{length of air gap}}{\text{pole pitch}} = \frac{lg}{\tau} = 0.01 \text{ to } 0.015$$

where lg is the length of air gap at the centre of poles. For turbo alternators, with massive rotors

$$\frac{\text{length of air gap}}{\text{pole pitch}} = \frac{lg}{\tau} = 0.02 \text{ to } 0.025$$

2.5 POLE DESIGN

2.5.1 WIDTH OF POLE

Assuming leakage factor as 1.2

flux in the pole body $\varphi p = 1.2 X \varphi$

Let, flux density in the pole body $Bp = 1.65$ Tesla

Area of the pole body $Ap = \frac{\varphi p}{Bp}$

$$\text{width of the pole} = bp = \frac{Ap}{0.98 X L} \quad \text{-------------------- (2.27)}$$

stacking factor is taken as 0.98

2.5.2 HEIGHT OF POLE

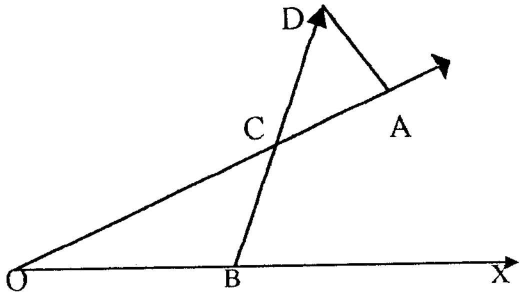


Fig. 2.1 Calculation of ATfo

In fig 2.1,

OB = ATfo, BC = 0.45 ATa, CD = 0.55 ATa

$\angle DBX = 90^\circ - \cos^{-1}$ (power factor) = θ

Calculation of ATfo

OC $= \sqrt{ATfo^2 + (0.45\ ATa)^2 + 2 \times ATfo \times 0.45\ ATa \times \cos\theta}$

From OCB,

$$\frac{OC}{\sin(\pi-\theta)} = \frac{OB}{\sin\theta_1} \qquad \text{------------------- (2.28)}$$

Find θ_1, in radians from equation 1

From CAD,

$$\cos\theta_1 = \frac{CA}{CD}$$

$$CA = 0.55ATa \cos\theta_1$$

Full load field mmf per pole (OA) = ATfl = OC+CA

Assume current density as 3A/mm^2 in field winding

Area of copper in field winding = $\frac{\text{ATfl}}{\text{Current density}}$ mm^2

Area of field winding = $\frac{\text{Area of cu in field winding}}{\text{Space factor}}$

[Space factor is taken as 0.83]

Depth of field winding df is chosen from the given in table 2.2

Table 2.2 Depth of winding

Pole pitch (m)	Depth of field winding (mm)
0.1	25
0.2	35
0.4	45

Height of the field winding = $\frac{\text{Area}}{\text{df}}$

Height of pole, hp = hf + 17 mm

[To this, we must add about 17mm which is taken up by flanges]

Total height (radial length of pole), hpl = hp + h1

where h1 - height of pole shoe at centre

2.6 DAMPER WINDING

Total area of damped bars per pole in mm^2

$$Ad = \frac{ac \times \text{pole pitch} \times 0.2}{\delta d} \qquad \text{------------------ } (2.29)$$

where pole pitch is in mm

δd is taken between 3 to 4 A/mm^2

Taking the pitch of damper bars to be 80 percent of stator slot pitch.

$$\text{No. of damper bars, } Nd = \frac{\text{Pole arc}}{0.8 \times ys} \qquad \text{------------------ } (2.30)$$

$$\text{area of each bar} \quad ad = \frac{Ad}{Nd}$$

$$\text{Diameter of each bar, } dd = 2 \sqrt{ad/\pi}$$

height of pole shoe at tips, hs = 2dd

2.7 YOKE DESIGN

Flux in the yoke = ϕy = $\phi/2$

Taking flux density of 1.2 Tesla,

Area of the yoke = Ay = $\phi y/1.2$

$$\text{Depth of the yoke} = dy = \frac{\text{Yoke area}}{0.98 \times \text{core length}}$$

[since stacking factor is taken as 0.98]

2.8 MAGNETIC CIRCUIT DESIGN

2.8.1 MMF FOR AIR GAP

Gap contraction factor for slots = Kgs

$$Kgs = \frac{ys}{ys - (Kcs \times \text{slot width})} \quad \text{-------------------- } (2.31)$$

where Kcs is carter's co-efficient for slots

Gap contraction factor for ducts = Kgd.

$$Kgd = \frac{L}{L - nd.wd.kcd} \quad \text{-------------------- } (2.32)$$

where, Kcd is carter's co-efficient for ducts

Gap contraction factor = Kg = Kgs X Kgd

Mmf required for airgap = ATg = 800000 KgBgLg

$$Kcs = 2/\pi\,[\tan^{-1}y - 1/y \log_{10}\sqrt{1+y^2}] \quad \text{-------------------- } (2.33)$$

$$y = \frac{\text{slot width}}{2\,lg}$$

$$kcd = 2/\pi\,[\tan^{-1}y - 1/y \log_{10}\sqrt{1+y^2}]$$

$$y = \frac{\text{duct width}}{2\,lg}$$

2.8.2 MMF FOR TEETH

Width of teeth at 1/3 height from narrower end = Wt 13

$$Wt13 = \left(\frac{\pi(D+2/3ds)}{S}\right) - \text{slot width} \quad \text{-------------------- } (2.34)$$

ds - slot depth (m)

S - no. of slots

D - dia of stator bore (m)

Flux density at $1/3^{rd}$ height from narrower end = Bt13

$$Bt13 = \frac{\phi}{0.74 X\ S/p\ X\ Li\ X\ wt13} \quad \text{------------------ (2.35)}$$

ϕ - flux / pole

(ratio pole arc/pole pitch is taken as 0.74)

S - no of slots

Li - net iron length(m)

mmf for teeth = at_t X ds

at_t - value of mmf/metre for Bt13 as obtained from B - 'at' curve

ds - slot depth (m)

2.8.3 MMF FOR CORE

Core area = Ac =depth of core X net iron length

flux density in the core = $\frac{\phi}{2Ac}$ = Bc

length of flux path in core = lc = $\frac{\pi (D+ 2ds + dc)}{2p}$ -------- (2.36)

mmf for core = Atc = at_c X lc

at_c - value of mmf/metre for Bc as obtained from B - 'at' curves

2.8.4 MMF FOR POLES

distance between adjacent pole shoes = Cs

$$Cs = \frac{\pi(Dr - hr)}{p} - bs \quad \text{------------------ (2.37)}$$

bs - pole shoe width (m)

Dr - rotor diameter (m)

hr - height of pole shoe at centre (m)

hp - height of the pole (m)

hs - height of the pole shoe at pole tips (m)

bp - pole width (m)

Distance between bodies of adjacent poles = Cp

$$Cp = \frac{\pi\,(CDr + hr - hp)}{p} - bp \quad \text{-----------------} \quad (2.38)$$

Leakage flux from pole shoes = ϕ sl

$$\phi\, sl = 4\mu_0\, ATl\, [L\, hs/Cs + 1.47\, hs \log_{10}(1 + \pi/2.\, bs/cs)] \quad \text{---} \quad (2.39)$$

$$ATl = ATg + ATt + ATc$$

$$\mu_0 = 4\pi \times 10^{-7}$$

Leakage flux between pole bodies = ϕpl

$$\phi pl = 2\mu_0 ATl\, [\,Lhp/cp + 1.47 \log_{10}(1+\pi/2\,.\, bp/cp)] \quad \text{----------} \quad (2.40)$$

Minimum flux in pole = ϕp(min) = $\phi + \phi$ sl

Maximum flux in pole = ϕp(max) = $\phi + \phi$ pl + ϕ sl

Minimum flux density in pole = Bp(min) = ϕp (min)/Ap

Maximum flux density in pole = Bp(max) = ϕp (max) / Ap

Ap - area of pole body (m)

ATp = mmf for pole

$$ATp = at_p(min) \times \frac{2\,hpl}{3} + at_p(max) \times hpl/3 \quad \text{------------------} \quad (2.41)$$

at_p (min) - value of mmf/metre for Bp (min) as obtained from B - ‘at’ curve

at_p (max) - value of mmf/metre for Bp (max) as obtained from B - ‘at’ curve

hpl - Radial length of pole (m)

2.8.5 MMF FOR YOKE

$$\text{Flux in yoke} = \frac{\phi + \phi sl + \phi pl}{2} \quad \text{------------------- (2.42)}$$

Area of yoke = Ay = 0.98 X dy X L

dy - yoke depth (m)

Flux density in yoke = By = ϕy / Ay

$$\text{length of flux path in yoke} = ly = \frac{\pi(Dr - 2hpl - dy)}{2p} \quad \text{------------------- (2.43)}$$

mmf for yoke = ATy = at_y X ly

at_y - value of mmf/metre for By as obtained from B - 'at' curve

No load field mmf /pole = ATfo

ATfo = ATp + ATg + ATt + ATc + ATy ------------------- (2.44)

2.9 ARMATURE LEAKAGE REACTANCE

height h1 = Ns X tb X Zs (Ns - 1) 0.25 + 2Ns + 0.5

Ns - No. of strips/slot

Zs - conductors/slot

tb - thickness of strip (mm)

h2 = (2.5 X 3) +2 mm for double layer

h2 = 2.5 X 2 mm for single layer

h3 = 4 mm

h4 = 1.5 mm

γs = specific slot permeance

$\gamma s = \mu_o$ [h1/3ws + h2/ws + 2h3/(ws + wt) + h4 /ws] -- (2.45)

wt - teeth width (mm)

ws - slot width (mm)

$$\text{slot leakage reactance} = Xss = \frac{8\pi f\, Iph^2\, L\, \gamma s}{pq} \quad \text{------------------ (2.46)}$$

Assuming current density of 2.6 A/mm^2, for field winding, field current

$$If = af/\delta f$$

Field winding turns = ATfl/If

Depth of the conductor =af/df

[depth of the field winding df = thickness of conductor)

Resistance of each field coil = Rf $= \frac{0.021 Tf Lmtf}{af}$ Ω ---------- (2.51)

Loss in each field coil = Qf = If^{2}Rf watts

Area of dissipating surface = Sf = 2Lmtf (hf + df) ---------- (2.52)

hf - height of the field winding (m)

df - depth of the field winding (m)

Coiling coefficient = Cf $= \frac{0.12}{1 + 0.1\ Va}$ ---------- (2.53)

Va - peripheral speed

Temperature rise = θ $= \frac{QfCf}{Sf}$ ---------- (2.54)

Type of insulation and maximum temperature rise is given in the Appendix. According to the temperature rise, insulation material can be selected.

2.11 LOSSES

2.11.1 COPPER LOSS

Total copper loss = 3 X (copper loss including eddy loss per phase)

stray loss = 20% of total copper loss

field copper loss = pIf^{2}Rf

2.11.2 IRON LOSS

- **Teeth**

Diameter of armature at the middle of the teeth

Dmid $= D + 2(ds/2)$

ds- slot depth (m)

Slot pitch at the middle of the teeth $= \dfrac{\pi \times Dmid}{S} = Ymid$

S - Number of slot

Tooth width at the middle $= Wtmid = Ymid - Ws$

Ws - slot width (m)

Weight of stator teeth in kg $= S \times Li \times ds \times Wtmid \times 7.8 \times 10^3$

Specific iron loss in teeth in watts/kg $= 6.5 \times (Bt13)^2$ ------- (2.55)

Iron loss in teeth in watts = weight of stator teeth in kg X specific iron loss in teeth in watts / kg

- **Core**

Mean Core diameter $= D + 2ds + dc$

dc - Core depth (m)

ds - slot depth (m)

weight of stator core in kg $= \pi \times (D + 2ds + dc) \times 7.8 \times 10^3 \times Li \times dc$

Li - net iron length (m)

Specific iron loss in core $= 4.7\,(Bc)^2$ watts/kg ---------------- (2.56)

Iron loss in core = weight of stator core in kg X specific iron loss in core

Total iron loss = iron loss in core + iron loss in teeth

2.11.3 OTHER LOSSES

Friction and windage losses = 0.7% of output KVA

Brush content loss $= 2 \times 1 \times If$

Voltage drop across brush is taken as 1 Volts

Exciter input = field copper loss + brush contact loss

let exciter efficiency = 88%

Excitation losses = $\frac{\text{exciter input}}{0.88}$

2.11.4 EFFICIENCY

Total loss in watts = copper loss including eddy loss + stray load loss + iron loss + friction and windage losses + excitation losses

Rated output in watts = KVA X pf X 1000

Input = Rated output + total loss

Efficiency at full load = $\frac{\text{Rated output}}{\text{input}}$ ---------------- (2.57)

2.12. STATOR TEMPERATURE RISE

1. Outer cylindrical surface of core = πDoL

Cooling co-efficient = 0.03

Loss dissipated from back of stator core = $\frac{\pi DoL}{0.03}$ w/^{0}C -------- (2.58)

2. Inner cylindrical surface of stator = πDL

Cooling co-efficient = $\frac{0.03}{1 + 0.1\ Va}$

Va - peripheral speed (m/sec)

Loss dissipated from inner surface = $\frac{\pi DL}{(0.03/1 + 0.1Va)}$ w/^{0}C ----- (2.59)

3. Area of end surfaces including ducts = $\pi/4\ (Do^2 - D^2)\ (nd + 2)$

nd - number of ventilating ducts

cooling co-efficient = 0.1/0.1Va = 1/Va

Loss dissipated from ducts = $\frac{\{\pi/4\ (Do^2 - D^2)\ (nd + 2)}{(1/Va)}$--------------(2.60)

[velocity of ducts = 0.1 Va]

Total loss dissipated in w/^{0}C = (2.58) + (2.59) + (2.60)

4. Copper loss in slot portion of conductor

$$= 3 \times \{ Keav\,(Iph)^2 \times (\frac{0.021 \times Tph \times L)}{\text{area of conductor in mm}^2} \quad \text{------------} \quad (2.61)$$

Keav - average eddy current loss factor

Iph - phase current (Amps)

Tph - Turns/phase

L - Iron length (m)

$$\text{stator temperature rise} = \frac{\text{copper loss in slot portion of conductor} + \text{iron loss in stator}}{\text{Total loss dissipated}}$$

2.13 OPEN CIRCUIT CHARACTERISTICS

Open circuit characteristics is drawn between no load field mmf per pole and open circuit voltage. O.C.C is drawn after creating a equivalent circuit or model. Flux density and voltage are varied from 0 to 2 per units, instep of 0.2. Each time ATfo is calculated and the results are tabulated. Then graph is drawn between voltage in per unit and ATfo in per unit using 'C' graphics.

2.14 SHORT CIRCUIT CHARACTERISTICS

Mmf corresponding to leakage reactance (Xl) in P.U. from O.C.C = AT1

Field mmf equivalent to armature mmf

$$AT2 = \rho_d ATa$$

$$\rho_d = \frac{\alpha + \sin\alpha}{L1 \sin(\alpha/2)}$$

α = $\psi\pi$ radians

ψ = pole arc/pole pitch

$$Aa = \frac{0.7 X V_H}{2}$$

[since assuming 90% of the air enters the stator via axial ventilating ducts and the rest 80% enters the machine via air gap and rotor axial ducts]

Let the air or hydrogen gas velocity be 25m/sec

$$\text{No. of radial ducts in stator} = \frac{(1/3)\,(Aa/25)}{\pi(\,0.02)^2} \quad \text{------------------ (2.65)}$$

[since radius of radial ducts = 20 mm]

$$\text{No. of axial ducts in stator} = \frac{(2/3)(Aa/25)}{\pi(\,0.015)^2} \quad \text{------------------ (2.66)}$$

[since radius of axial ducts = 15mm]

Area of ventilating holes required in rotor

$$Ab = (0.3V/2X25) \ - (\pi/4\,[D^2 - Dr^2])$$

V - volume of air of hydrogen gas required (m^3/sec)

D - stator bore diameter (m)

Dr - rotor diameter (m)

$$\text{Radial ducts in rotor} = \frac{(1/3\ Ab)}{\pi\,(0.025)^2} \quad \text{———————— (2.67)}$$

[radius of radial ducts = 25 mm]

$$\text{Axial ducts in rotor} = \frac{(2/3)\ X\ Ab}{\pi(0.015)^2} \quad \text{———————— (2.68)}$$

[radius of axial duct = 15 mm]

CHAPTER III

COMPUTER AIDED DESIGN OF SYNCHRONOUS GENERATOR

The use of computer makes many possible designs and gives accurate results without excessive time. The design equations given in chapter II are incorporated in the program. Program for the design of synchronous generator is developed in C language using hybrid method. Logical decisions that should have been taken for the good design can be easily introduced in program as loops and subroutines.

3.1 OBJECTIVE FUNCTION

Main objective of the program is to design a synchronous generator. The another objective function is to minimise the losses in the generator and obtain the performance characteristics.

3.2 CONSTRAINTS

3.2.1 Current Density

Current density in the stator varies between 3 to 5 A/mm^2. Maximum limit is taken as 5 Amp/mm^2. Current density in the rotor ie., field winding varies between 2.5 - 3.5 Amp/mm^2. Maximum limit is taken as 3.5 Amp/mm^2.

3.2.2 Magnetic flux density

As tooth area is very small, maximum flux density occurs at teeth. The maximum flux density at the teeth should not be greater than 1.8 Tesla.

3.2.3 Average temperature rise

Maximum temperature rise for different insulation materials are given in the appendices. In our design class - B insulation has been selected. Maximum temperature rise for class - B is 85°C.

3.2.3 Air gap length

As we have seen earlier, large air gap increases the cost of machines. So minimum length of air gap is taken as 6mm. Designing the machine with larger air gap has more advantages.

3.2.4 Physical dimensions and shaft diameter

There is a lower and upper limit for physical dimensions and the diameter of shaft. But, in our design we assumed that, whatever may be dimensions of D,L and shaft diameter, shaft can be produced.

3.2.5 Percentage regulation and efficiency

Actually these are not taken as constraints. But, we can obtain the values of efficiency and regulation through design. From these values we can say that whether the design is correct or not. The maximum value of regulation is 15% and the efficiency of synchronous generator is above 94%.

3.3 ALGORITHM

The various steps involved in the computer aided design of synchronous generator are given below.

Step 1: The inputs such as, output KW, frequency, line to line voltage, type of generator, power factor, exciter voltage, Bav, ac, winding choice and material choice are given.

Step 2: The stator bore diameter and peripheral speed are calculated. If peripheral speed exceeds certain limit vary the ampere conductor per metre to reduce the peripheral speed.

Step 3: D, L, net and gross iron length, pole arc, pole pitch and number of ventilating ducts are calculated.

Step 4: Turns/phase, number of conductors, conductors/slot and number of slots are calculated. The actual value of Bav is calculated.

Step 5: Slot pitch, slot loading, coil span and phase current are calculated

Step 6 : Assuming suitable current density, area of conductors are calculated. Standard conductor is chosen from the table given in appendix corresponding to the area of the conductor calculated.

Step 7 : Slot width, slot depth and teeth width are fixed.

Step 8 : Average eddy current loss factor, per unit ac and dc resistance and copper loss per phase in stator are calculated.

Step 9 : Flux density in the teeth is calculated. If Bt exceeds 1.8 Tesla, decrease the teeth width.

Step 10 : Air gap length is fixed

Step 11 : Rotor design is similar to that of stator design for turbo alternator. Height of the pole is calculated for hydro-electric generator by calculating full load field mmf per pole. Field winding is designed and pole dimensions are calculated.

Step 12 : The damper winding is designed. Number of damper bars required are calculated.

Step 13 : Mmf for yoke, core, pole, teeth and air gap are calculated. From those results, no load and full load field mmf per pole is calculated.

Step 14 : Various losses are calculated temperature rise in field coils and armature are calculated.

Step 15 : Efficiency is calculated

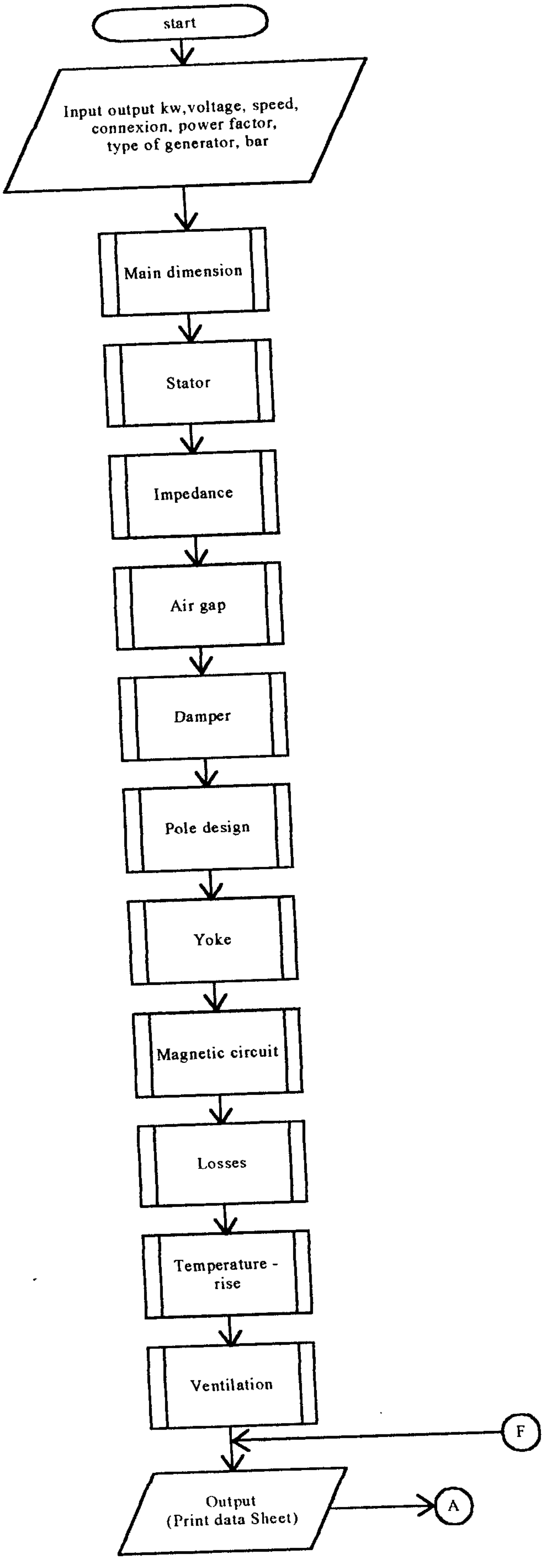
Step 16 : Ventilating system for turbo-alternator is designed

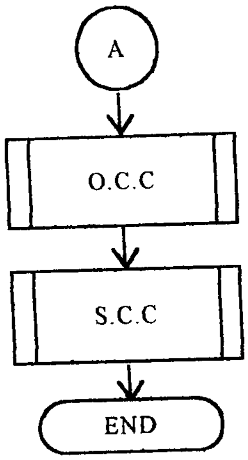
Step 17 : O.C.C. and S.C.C are drawn using graphics. SCR is calculated.

Step 18 : Design data sheet and characteristics of synchronous generator are printed.

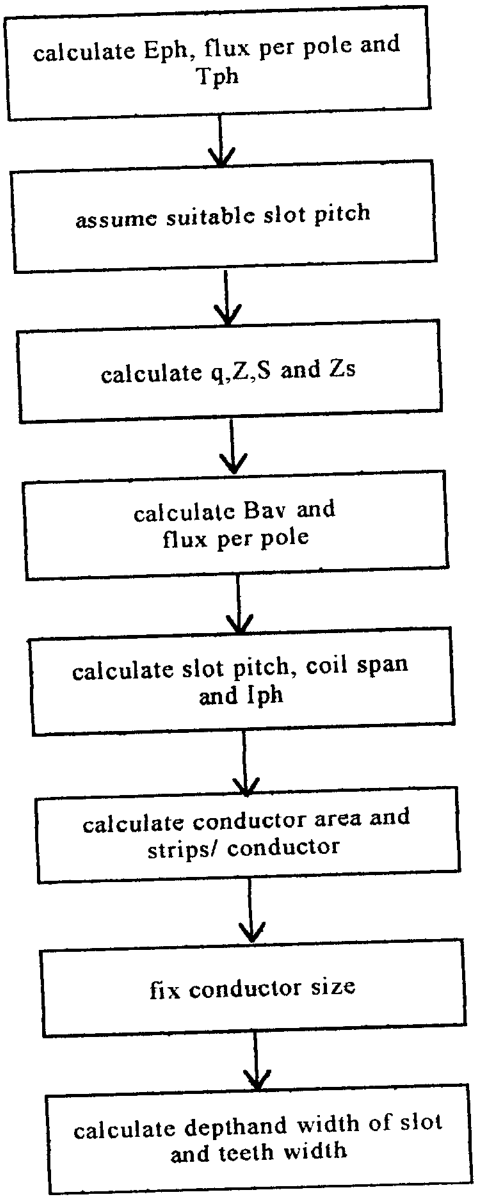
The flow chart is shown in fig 3.1. The CAD program developed in 'C' language is given at the end of this chapter.

Fig.3.1 FLOW CHART

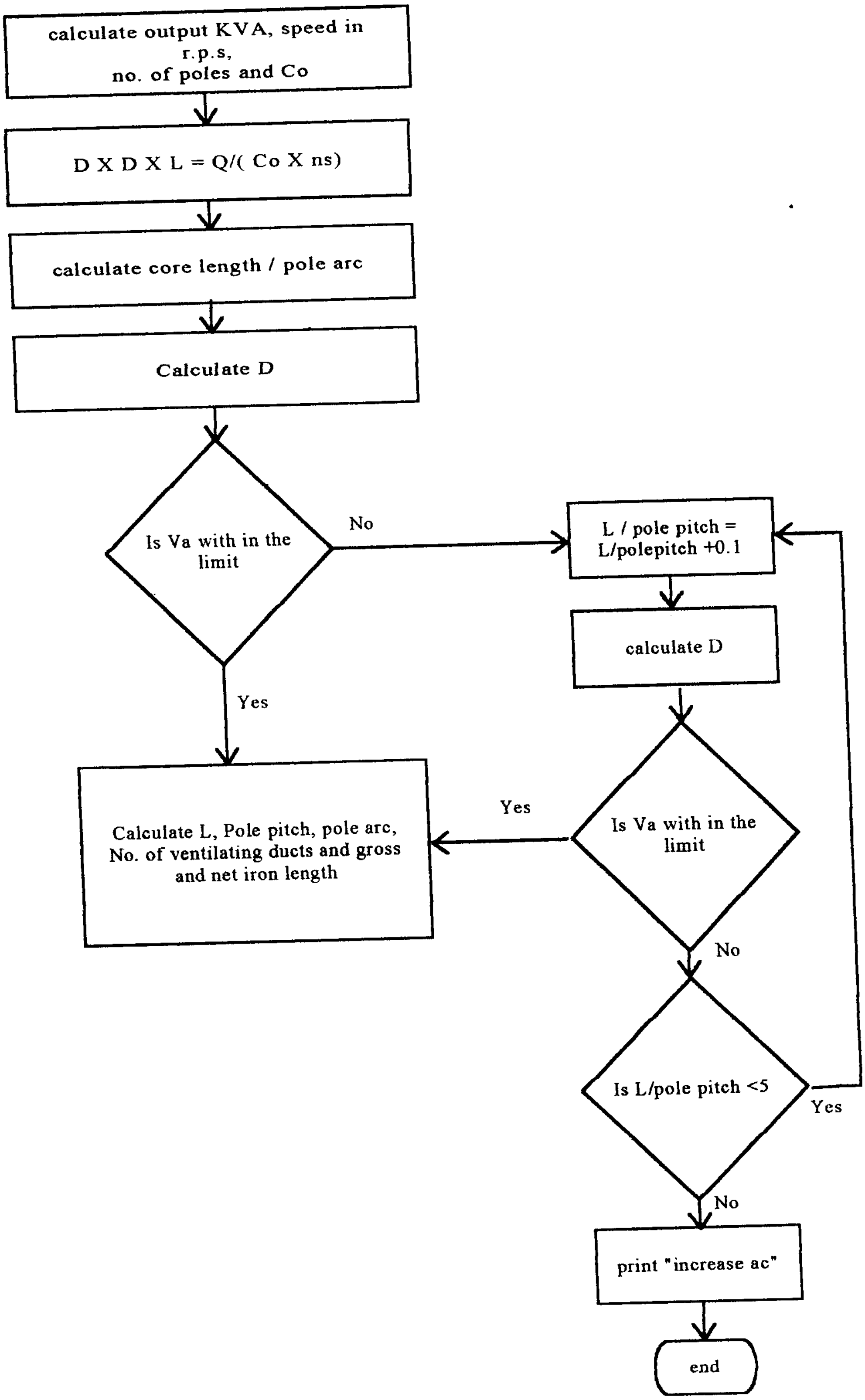




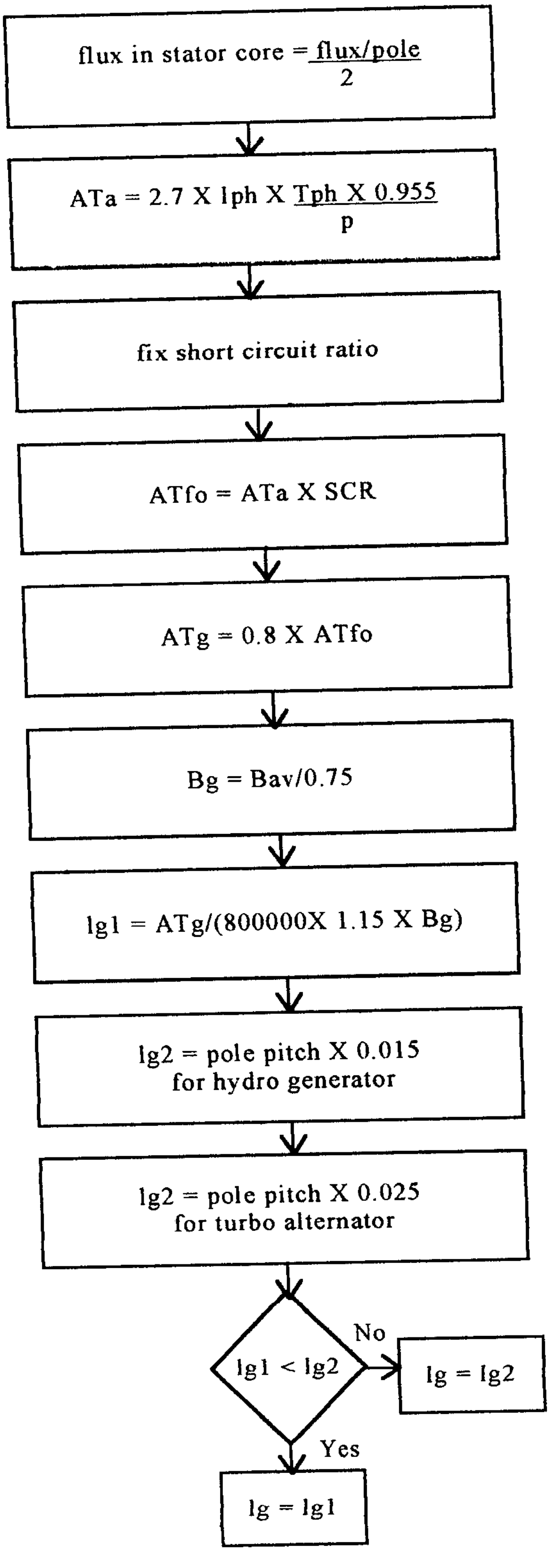
Subroutine for stator



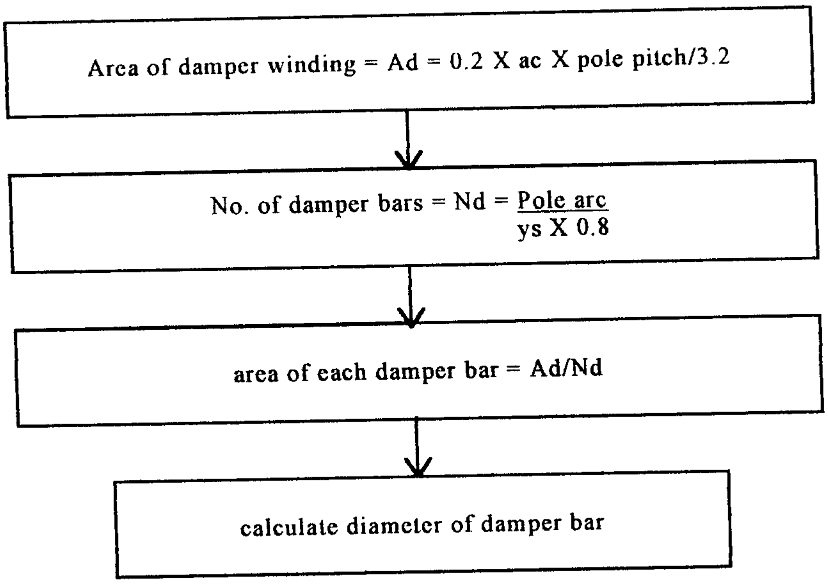
Subroutine for main dimension



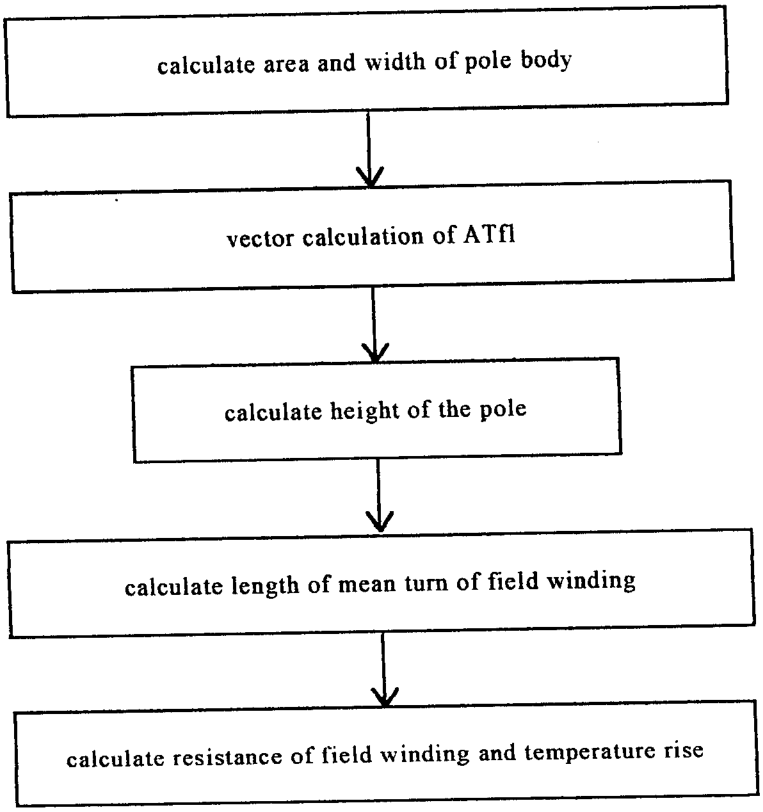
Subroutine for air gap



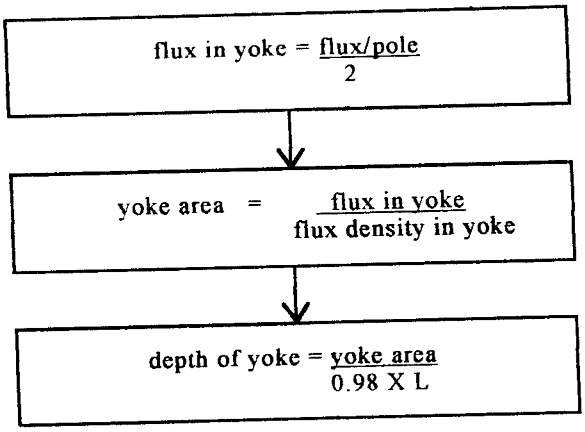
Subroutine for damper



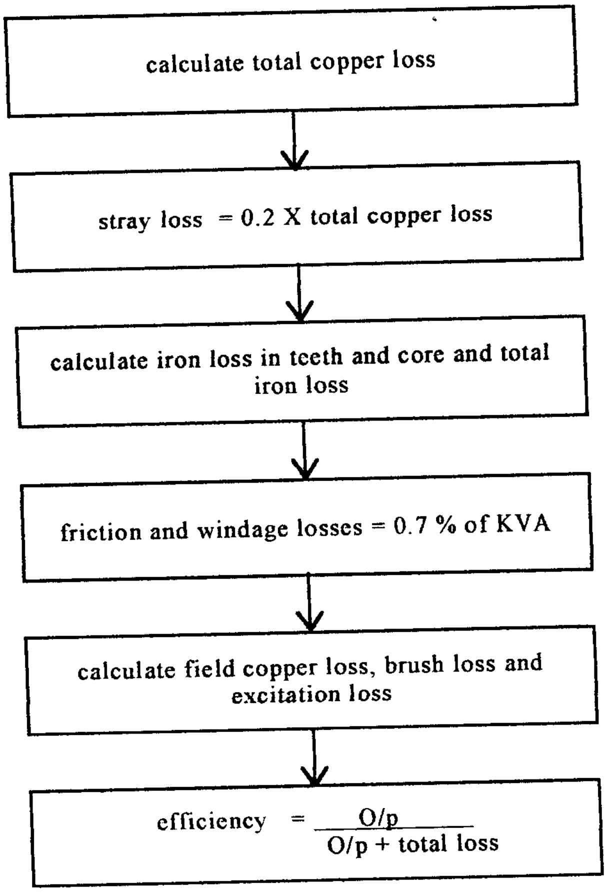
Subroutine for pole



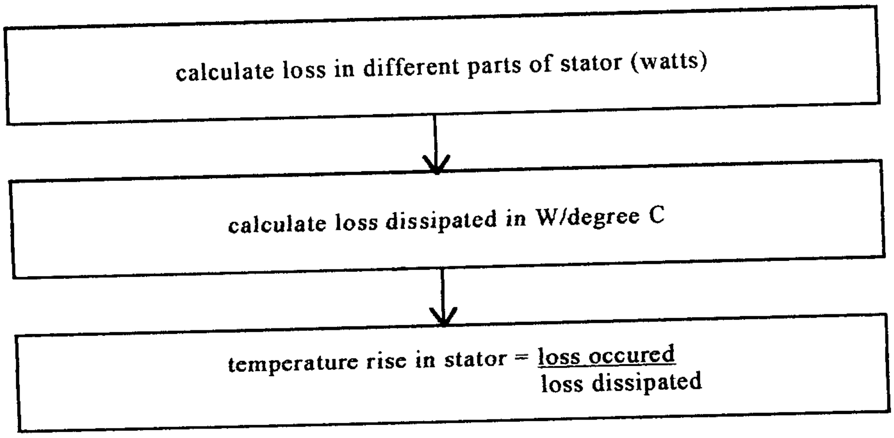
Subroutine for yoke



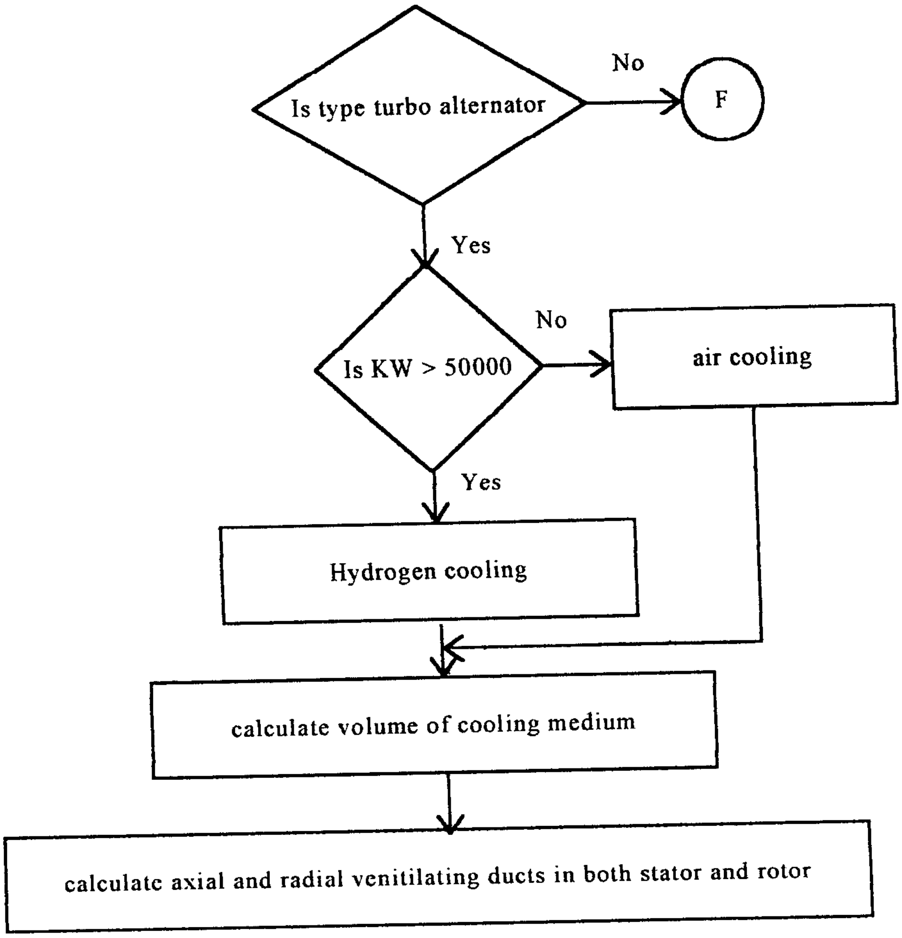
Subroutine for losses



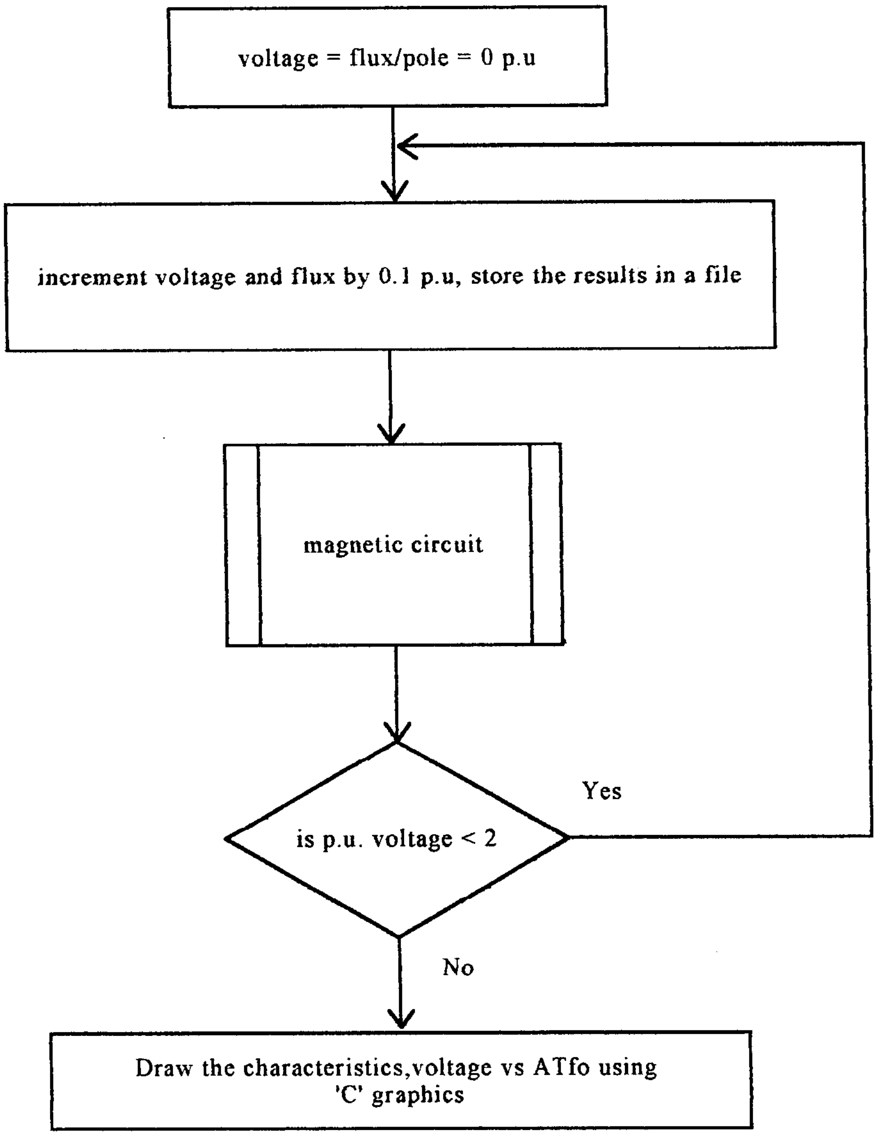
Subroutine for temperature rise



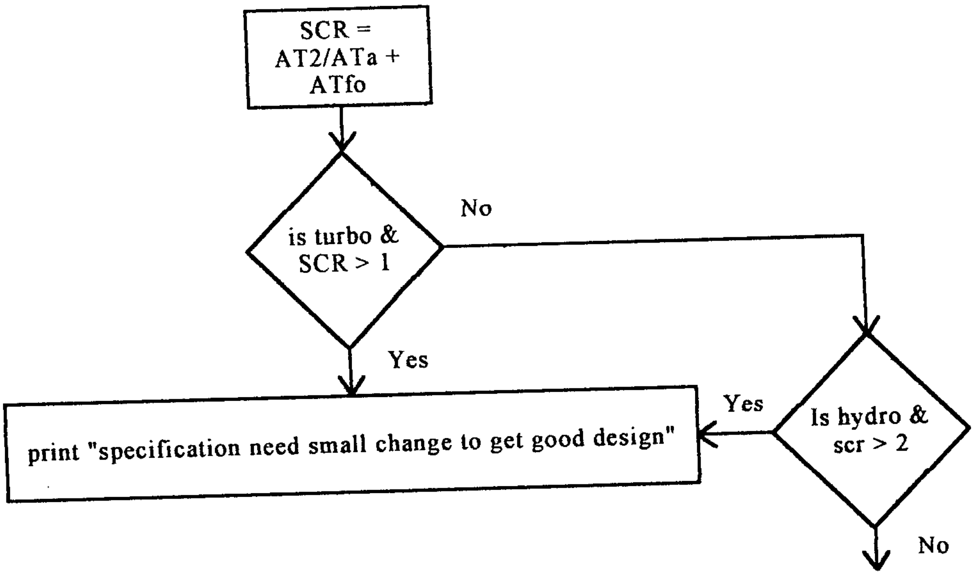
Subroutine for ventilation



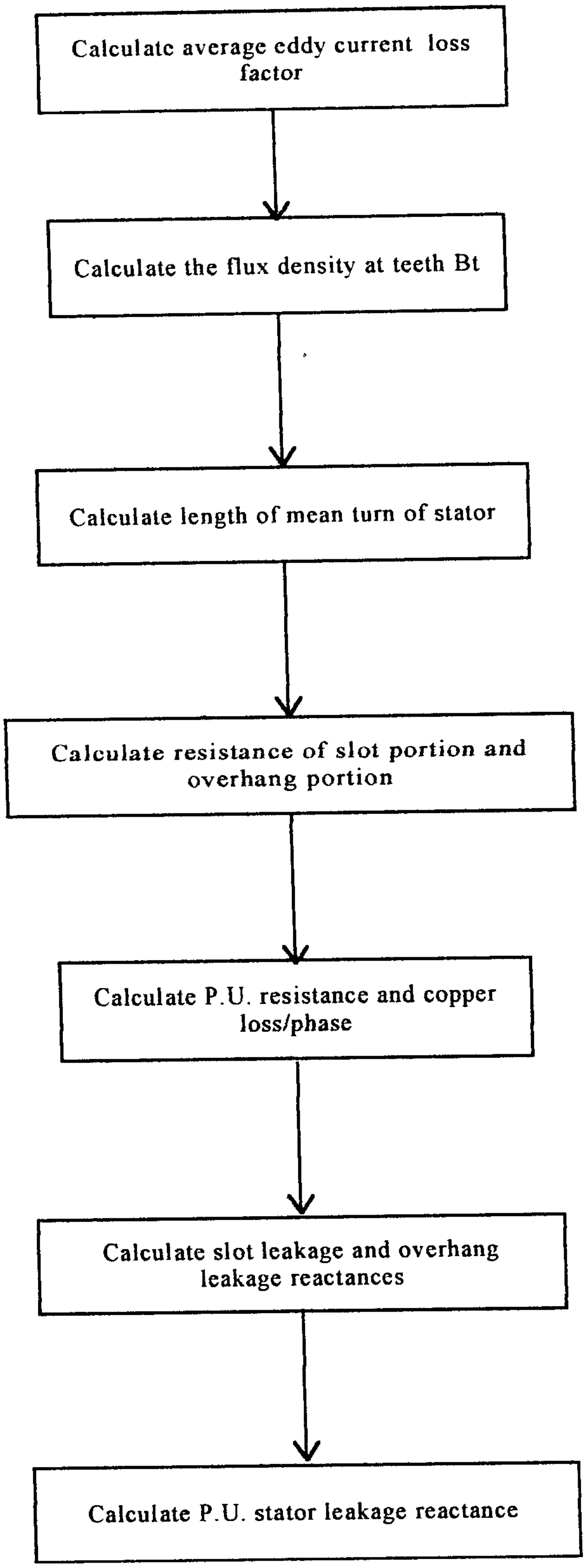
Subroutine for open circuit charactertics



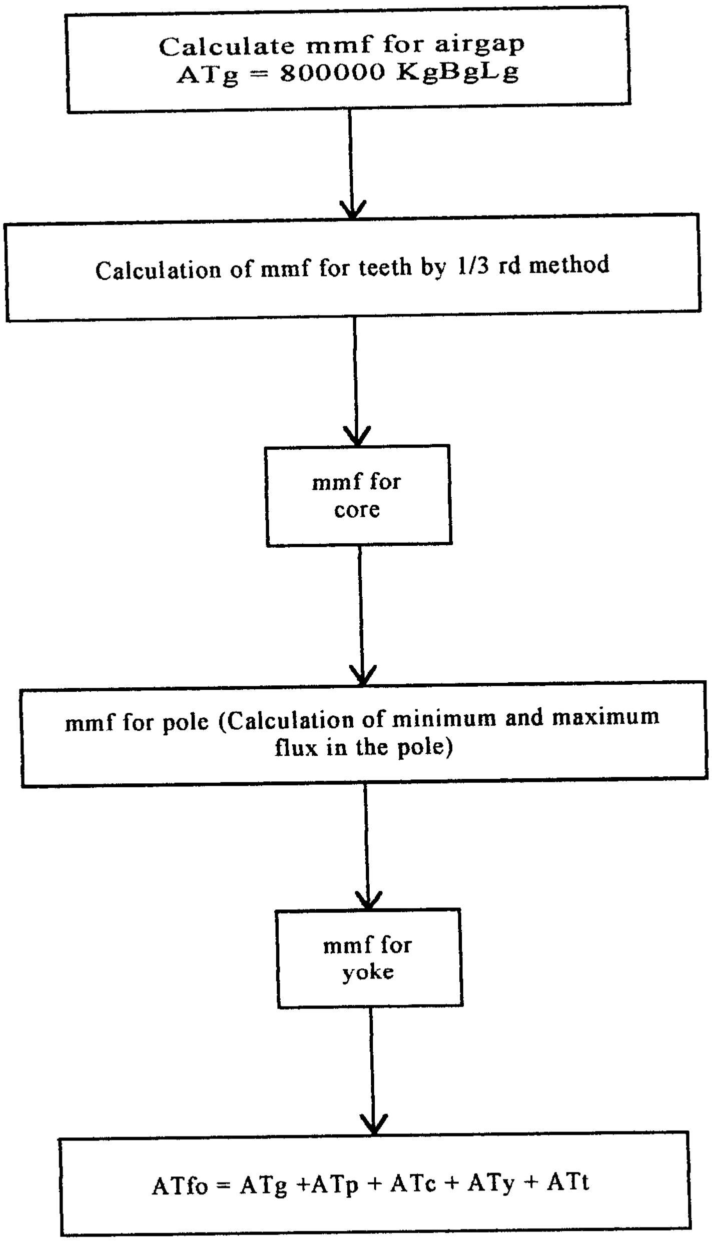
Subroutine for short circuit characteristics



Subroutine for impendance



Subroutine for magnetic circuit



SOFTWARE

```
# include<graphics.h>
# include<stdio.h>
# include<conio.h>
# include <math.h>
# include <ctype.h>
# define PHI 3.1428571428571
# define square 1.7320508080

          /* Global variables */

float   /* input variables */
          KW,pf,rpm,head,Ve,Bav,ac,V,delta,f,error=0,
          /* main dimension variables */
          D,d,p,nd,wd,Q,LbyTOV,ns,L,Va,polpitch,polarc,Lg,Li,DSL,Co,
          /* stator variables */
          S,As1,wb,tb,t,w,As,Eph,Tph,Z,Zs,q,ys,FI,Iph,sl,slotd,slotw,
          /* impedance variables */
          Keav,Lmts,Bt,rac,racpu,teew,CuLoss,lamda,xss,xo,Xl,Xlpu,ratio,rdc1,
          /* airgap & pole variables */
          Do,dc,FIsc,ATa,ATfo,ATg,Bg,SCR,lg,Dr,FIp,Ap,bp,ATfl,df,Sr,
          hf,theta,Qf,Ef,af,Tf,Rf,Su,hpl,Cf,If,Lmtf,Cs,temp_rise,
          /* rotor parameters */
          Lmtfr,afr,Rfr,ysr,Zsr,Tfr,Ifr,MMF,slotwr,slotdr,
          /* damper & yoke variables */
          FIy,dy,Ay,Ad,Nd,ad,Dd,hs,hr,bs,Ag,flux,local1,local2,local3,
          /* magnetic circuit variables */
          Wt13,Bt13,at13,ATt,ATc,ATl,atc,Bc,lc,Ac,FI_min,FI_max,Kcs,Kgs,Kcd,
          Kgd,Kg,at_min,at_max,Bp_min,Bp_max,ly,ATy,hp,ATp,By,aty,reg,ration,
          /* loss variables */
          Loss,Stray,Dmid,iron_tee,iron_cor,iron_los,fri_wind,field_los,
          brush_los,exc_los,total_los,Eff,ys_mid,Wt_mid,
          /* cooling variables (for turbo alternator) */
          ductrs,ductrr,ductas,ductar,Vair;

  int     N,countdown=0,M,con,mat;

  char    type ;

  main() {
                 clrscr();
                 input();
                 maind();
                 if(error==1)
                   goto last;
                 stator();
```

```
                impedance();
                airgap();
                damper();
                pole();
                yoke();
                mag_circuit();
                losses();
                temp();
                ventilation();
                output();
                scc();
                occ();
                graph();
        last:   thankU();
                return 0;
}

thankU() {
          clrscr();
          printf("\n\n\n\t\t * * * * * * * * * * * * * * * * * * * * * * *");
          printf("\n\n\n\t\t\t\t   THANK YOU ");
          printf("\n\n\n\t\t\t\t  Enter  again");
          printf("\n\n\n\t\t\t * * * * * * * * * * * * * * * * ");
          getch();
}

 input() {
         printf("\n\t\tDESIGN OF SYNCHRONOUS GENERATOR");
         printf("\n\nEnter the following specifications\n");
         printf("\nGive your choice\n1.HYDRO-GENERATOR
                                              2.TURBO-ALTERNATOR\n");
         printf("\nPrint h for hydro generator & t for turbo alternator\t");
         scanf("%c",&type);
         type=tolower(type);
         if(type=='h') {
                     printf("\navailable head is\t");
                     scanf("%f",&head);
         }
         printf("\nfull load KW\t");
         scanf("%f",&KW);
         printf("\nPower Factor\t");
         scanf("%f",&pf);
         printf("\nvoltage in volts\t");
         scanf("%f",&V);
         local1=V;
```

```
        printf("\nfrequency in Hertz\t");
        scanf("%f",&f);
        printf("\nspeed in rpm\t");
        scanf("%f",&rpm);
        printf("\nexiter voltage in volts\t");
        scanf("%f",&Ve);
        clrscr();
        printf("\n\nIF YOUR CHOICE IS HYDRO-GENERATOR\n\n");
        printf("choose the values for Bav & ac from the following range \n");
        printf("Bav - 0.52  to  1.0 Tesla\nac  -  20,000  to  80,000 A/m\n\n");
        printf("IF YOUR CHOICE IS TURBO-ALTERNATOR\n\n");
        printf("choose the values for Bav & ac from the following range\n");
        printf("Bav - 0.54  to  1.0 Tesla\nac  -  50,000  to 1,00,000 A/m\n\n");
        printf("Enter the value of Bav\t");
        scanf("%f",&Bav);
        printf("\nEnter the value of ac\t");
        scanf("%f",&ac);
        printf("\nPress 1 for star & 2 for delta connection\t");
        scanf("%d",&con);
        printf("\nchoose current density between 3 to 5 A/square mm\t");
        scanf("%f",&delta);
        printf("\nEnter the choice of (steel)material for stator & rotor\n");
        printf("\nEnter 1 for lohys & 2 for stalloy & 3 for quality\t");
        scanf("%d",&mat);
}

dia() {
        /* Subrotine for calculating core dia */
        float j=0.33333333;

        d=(p*DSL)/(LbyTOV*PHI);
        D= pow(d,j) ;
        Va=(PHI*D*ns);
}

strip() {
        /* record contains standard strip sizes */
        float val[1500];
        int x;

        FILE *ptr;
        ptr=fopen("conductr.txt","r");
        for(x=0;x<1189;x++) {
                        fscanf(ptr,"%f",&val[x]);
                        if((x%4)==0) {
```

```
                                        if(As1==val[x])
                                              goto lop;
                         }
          }
lop :   fscanf(ptr,"%f",&val[x+1]);
          fscanf(ptr,"%f",&val[x+2]);
          fscanf(ptr,"%f",&val[x+3]);
          As1=val[x+1];
          wb=val[x+2];
          tb=val[x+3];
          fclose(ptr);
 }

 float BHgraph(float fdensity) {
          /* B-H Curve for ordinary steel plate */
          float  amp_turns[75];
          int i;

          FILE *ptr;
          if(mat==1)
            ptr=fopen("B_H_Grap.txt","r");
          if(mat==2)
            ptr=fopen("stalloy.txt","r");
          if(mat==3)
            ptr=fopen("quality.txt","r");
          for(i=0;i<72;i++) {
                         fscanf(ptr,"%f",&amp_turns[i]);
                         if((i%3)==0)
                                   if(amp_turns[i]==fdensity) {
                                             fscanf(ptr,"%f",&amp_turns[i+1]);
                                             fscanf(ptr,"%f",&amp_turns[i+2]);
                                             break;
                                   }
          }
          fclose(ptr);
          return(amp_turns[i+2]);
   }

   float round(float A) {
          /* function used for rounding purpose */
          A=floor(100.0*A);
          if( ((10*ceil(A/10))-A) > 5 )
            A=floor(A/10);
          else
            A=ceil(A/10);
```

```
        return A;
}

maind() {
        /* design of main dimension */
        float Va1,ns1;

        if(type=='h')
          Va1=55.0;
        if(type=='t')
          Va1=170.0;
        ns=rpm/60.0;
        Q=KW/pf;
        p=(int)((2*f)/ns);
        if(p==1 || p==0)
          p=2.0;
        ns1=(2*f)/p;
        ns=ns1;
        /* winding factor is taken as 0.955 */
        Co=0.010505*Bav*ac;
        DSL=Q/(Co*ns);
        LbyTOV=1.5;
        dia();
        /* check for peripheral speed */
        if(Va>Va1) {
                for(;LbyTOV<=5; LbyTOV+=0.1) {
                                        dia();
                                        if(Va<=Va1)
                                            break;
                }
        }
        if(Va>Va1) {
           clrscr();
           printf("\n\tVa\t%0.3f",Va);
           printf("\n\tHigh value of peripheral speed ");
           printf("\n\n\n\tUSE HIGH VALUE OF ‘ac’”);
           error=1;
           getch();
           goto end;
        }
        L=(LbyTOV*PHI*D)/p;
        polpitch=(PHI*D)/p;
        /* ratio (polearc/pole pitch) is taken as 0.75 */
        polarc=0.75*polpitch;
        nd=0;
```

```
        wd=0;
        /* if core length is greater than .1 m ventilating ducts are fixed */
        if(L>0.1) {
                nd=(int)(L/0.07);
                wd=0.01;
        }
        Lg=L-(nd*wd);
        Li=0.9*Lg;
  end : clrscr();
}
stator() {
         /* design of stator part */
         float round(float);
         float n,Z1,Bav1,Tph1;

         if(con==1)
           Eph=V/square;
         else
           Eph=V;
         FI=Bav*polpitch*L;
         Tph=(Eph/(4.2402*f*FI));
         if(V< 2000)
             ys=25.0;
         if(V<6000 && V>=2000)
             ys=34.0;
         if(V>6000)
             ys=56.0;
         q=(PHI*D)/(0.003*p*ys);
         for(n=p;n>=2;n--)
              if( (1/n)>(q-(int)(q)) )
                   break;
         q=(int)(q)+(1/n);
         S=(int)(3.0*q*p);
         if(type=='t') {
             if(p==2)
                   Sr=S-5;
             if(p==3||p==4)
                   Sr=S-7;
             if(p==5)
                   Sr=S-8;
             if(p>=6)
                   Sr=S-3;
         }
         Z1=6.0*Tph;
         Zs=Z1/(S*10);
```

```
    Zs=round(Zs);
    if(Zs==0)
      Zs=1;
    Z=Zs*S;
    Tph1=Z/6;
    Bav1=Bav*Tph/Tph1;
    FI=Bav1*polpitch*L;
    Bav=Bav1;
    ys=PHI*D/S;
    Cs=S/p;
    Iph=(Q*1000)/(V*square);
    sl=Iph*Zs;
    As=Iph/delta;
    /* Maximum area of strip is taken as 30.7 sq.mm */
    for(N=1;N<=30;N++) {
                As1=As/N;
                if(As1<=30.7)
                  break;
    }
    As1=round(As1);
    strip();
    t=tb;
    w=wb;
    As=As1*N;
    delta=Iph/As;
    slotw=wb+6.2;
    if( ((int)(Zs)%2) != 1  )
         slotd=(N*Zs*tb)+((N-1)*Zs*0.125)+(2*N*Zs*0.5)+20;
    else
         slotd=(N*Zs*tb)+(Zs*(N-1)*0.125)+(2*N*Zs*0.5)+12.5;
    /* teeth width should not be negative */
    if(slotw<(ys*1000))
      teew=(ys*1000)-slotw;
    else
      slotw=0.8*ys*1000;
}

impedance() {
        /* per unit resistance & reactance calculation */
        float rdc2,h1,h2,h3,h4;

        Keav=1+(pow((100* sqrt(wb/slotw) *tb/1000),4))*((N*Zs*Zs*N)/9);
        teew=(ys*1000)-slotw;
        Bt=FI/(0.75*teew*0.001*Li*(S/p));
        /* Maximum flux density in the teeth is taken as 1.8 Tesla */
```

```
    for(;teew<(ys*999);teew+=0.1) {
                    Bt=FI/(0.75*teew*0.001*Li*(S/p));
                    if(Bt<=1.8)
                    break;
    }
    Lmts=(2*L)+(2.5*polpitch)+(0.00006*V)+0.2;
    rdc1=0.021*Tph*2*L/As;
    rdc2=0.021*Tph*(Lmts-(2*L))/As;
    CuLoss=(Iph*Iph)*((Keav*rdc1)+rdc2);
    rac=CuLoss/(Iph*Iph);
    racpu=Iph*rac/Eph;
    h1=(N*Zs*tb)+(Zs*(N-1)*0.25)+(2*Zs*N*0.5);
    if(((int)(Zs)%2)!=1)
      h2=8.5;
    else
      h2=4.5;
    h3=4.0;
    h4=1.5;
    lamda=4*PHI*pow(10,-7)*
        ((h1/(3*slotw))+(h2/slotw)+(2*h3/(teew+slotw))+(h4/slotw));
    xss=8*PHI*f*Tph*Tph*L*lamda/(p*q);
    ratio=(int)(Cs)/Cs;
    xo=32*pow(10,-7)*PHI*f*Tph*Tph*ratio*polpitch*polpitch/(ys*p*q);
    Xl=xo+xss;
    Xlpu=Iph*Xl/Eph;
}

airgap() {
        /* calculation of airgap length */
        float lg1,lg2;
        FIsc=FI/2;
        dc=FIsc/(1.2*Li);
        Do=D+(2*(slotd/1000+dc));
        ATa=2.7*Iph*Tph*0.955/p;
        if(type=='h')
          SCR=1.33;
        else
          SCR=0.55;
        ATfo=ATa*SCR;
        /* ATg is taken as 80% of ATfo */
        ATg=0.8*ATfo;
        Bg=Bav/0.75;
        lg1=ATg/(800000*1.15*Bg);
        if(type=='h')
          lg2=0.015*polpitch;
```

```
        if(type=='t')
          lg2=0.025*polpitch;
        if(lg1<lg2)
          lg=lg1;
        else
          lg=lg2;
        if(lg>0.007)
          lg=0.00678;
        Dr=D-(2*lg);
}

pole() {
        /* design of poles */
        float OA,AB,Af,afr1;

        FIp=1.25*FI;
        Ap=FIp/1.6;
        bp=Ap/(0.98*L);
        /* vector calculation of ATfl */
        OA=sqrt((ATfo*ATfo)+(.2025*ATa*ATa)+
                                (.9*ATa*ATfo*cos((PHI/2)-acos(pf))));
        AB=cos(asin(ATfo*sin((PHI/2)+acos(pf))/OA))*0.55*ATa;
        ATfl=OA+AB;
        if(type=='t') {
            /* rotor design for turbo alternator */
            Lmtfr=(2*L)+(2.3*polpitch)+0.24;
            afr=(ATfl*0.021*Lmtfr)/(175/p);
            Zsr=(int)((350/p)/(2.7*0.021*Lmtfr*0.7*Sr));
            if(Zsr==0)
                 Zsr=1;
            ysr=PHI*Dr/Sr;
            Tfr=(350/p)/(2.7*0.021*Lmtfr*p);
            Rfr=Tfr*0.021*Lmtfr/afr;
            Ifr=175/(p*Rfr);
            MMF=Ifr*Tfr;
            for(M=1;M<=15;M++) {
                    afr1=afr/M;
                    if(afr1<=30.7)
                            break;
            }
            afr1=round(afr1);
            strip();
            afr=As1*M;
            slotwr=wb+6.2;
            if( ((int)(Zsr)%2) != 1  )
```

```
                slotdr=(M*Zsr*tb)+((M-1)*Zsr*0.125)+(2*M*Zsr*0.5)+20;
            else
                slotdr=(M*Zsr*tb)+(Zsr*(M-1)*0.125)+(2*M*Zsr*0.5)+12.5;
        }
        Af=ATfl/(2.5*0.83);
        if(polpitch<=.1)
            df=.025;
        if(polpitch>.1&&polpitch<=.27)
            df=0.035;
        if(polpitch>.27)
            df=.045;
        hf=Af/(1000000*df);
        hp=hf+0.017;
        hpl=hp+(hr/1000);
        Lmtf=(1.8*L)+PHI*(bp+0.01+df);
        Ef=0.833*Ve/p;
        af=ATfl*0.021*Lmtf/Ef;
        If=af*3;
        Tf=(int)(ATfl/If);
        Rf=Tf*0.021*Lmtf/af;
        Qf=If*If*Rf;
        Su=2*Lmtf*(hf+df);
        Cf=0.1/(1+(0.1*Va));
        /* theta is temperature rise in the field coils */
        theta=Qf*Cf/Su;
}

damper() {
            /* design of damper winding */
            float H1;

            Ad=0.2*ac*polpitch/3.2;
            Nd=(int)(polarc/(ys*.8));
            ad=Ad/Nd;
            Dd=2*sqrt(ad/PHI);
            hs=2*Dd;
            H1=hs+(0.3*hs);
            hr=H1;
            bs=PHI*Dr/(1.35*p);
 }

 yoke() {
            /* prelimnary yoke design */
            FIy=FI/2;
            Ay=FIy/1.2;
```

```
        dy=Ay/(0.98*L);
        flux=FI;
        /* gap area */
        Ag=FI/Bg;
}

mag_circuit() {
        /* Mmf calculation for various magnetic parts */
        float round(float);
        float BHgraph(float);
        float on,on1,C1,C2,FI1,FI2;

        /* Mmf for air gap */
        if(wd!=0) {
          on=(slotw/1000)/(2*lg);
          Kcs=(2/PHI)*(atan(on)-((1/on)*log10(sqrt(1+((on)*(on))))));
          Kgs=ys/(ys-(Kcs*(slotw/1000)));
          on1=wd/(2*lg);
          Kcd=(2/PHI)*(atan(on1)-((1/on1)*log10(sqrt(1+((on1)*(on1))))));
          Kgd=L/(L-(nd*wd*Kcd));
          Kg=Kgs*Kgd;
         }
         else {
          on=(slotw/1000)/(2*lg);
          Kcs=(2/PHI)*(atan(on)-((1/on)*log10(sqrt(1+((on)*(on))))));
          Kgs=ys/(ys-(Kcs*(slotw/1000)));
          Kg=Kgs;
         }
         ATg=800000*(FI/Ag)*Kg*lg;
         /* Mmf for teeth */
         Wt13=(PHI*(D+((2/3)*(slotd/1000)))/S)-(slotw/1000);
         Bt13=FI/(0.74*(S/p)*Li*Wt13);
         if( countdown==0 && Bt13>2.4 && Bt13<5.0 )
           Bt13=2.4;
         Bt13=round(Bt13);
         Bt13=Bt13*10;
         at13=BHgraph(Bt13);
         ATt=at13*(slotd/1000);
         /* Mmf for core */
         Ac=dc*Li;
         Bc=FI/(2*Ac);
         Bc=round(Bc);
         Bc*=10;
         atc=BHgraph(Bc);
         lc=PHI*(D+(2*(slotd/1000))+dc)/(2*p);
```

```
    ATc=atc*lc;
    ATl=ATg+ATt+ATc;
    /* Mmf for poles */
    C1=(PHI*(Dr-(hr/1000))/p)-bs;
    C2=(PHI*(Dr+(hr/1000)-hp)/p)-bp;
    if(C2<0)
        C2=C2-(2*C2);
    FI1=16*PHI*pow(10,-7)*ATl*
       (((L*(hs/1000))/C1)+(1.47*(hs/1000)*log10(1+((PHI*bs)/(2*C1)))));
    FI2=4*PHI*pow(10,-7)*ATl*
       ( ((L*hp)/C2) + (1.47*hp*log10(1+((PHI*bp)/(2*C2)))) );
    FI_min=FI+FI1;
    FI_max=FI+FI1+FI2;
    Bp_min=FI_min/Ap;
    Bp_max=FI_max/Ap;
    Bp_min=round(Bp_min);
    Bp_max=round(Bp_max);
    Bp_min*=10;
    Bp_max*=10;
    if(countdown==0 && Bp_min>240)
       Bp_min=240;
    if(countdown==0 && Bp_max>240)
       Bp_max=240;
    at_min=BHgraph(Bp_min);
    at_max=BHgraph(Bp_max);
    ATp=(at_min * ((2/3)*hpl) ) + (at_max*hpl/3);
    /* Mmf for yoke */
    FIy=(FI+FI1+FI2)/2;
    Ay=0.98*dy*L;
    By=FIy/Ay;
    By=round(By);
    By*=10;
    if(countdown==0 && By>240)
       By=240;
    aty=BHgraph(By);
    ly=PHI*(Dr-(2*hpl)-dy)/(2*p);
    ATy=aty*ly;
    if(ATy<0)
      ATy=ATy-(2*ATy);
    ATfo=ATg+ATt+ATc+ATp+ATy;
}

losses() {
        /* Efficiency calculation */
        Loss=3*CuLoss;
```

```
        Stray=0.2*Loss;
        Dmid=PHI*(D+(0.5*(slotd/1000.0)));
        ys_mid=PHI*Dmid/S;
        Wt_mid=ys_mid-(slotw/1000);
        iron_tee=S*Li*(slotd/1000)*Wt_mid*7800*6.5*(Bt13/10000)*Bt13*0.01;
        iron_cor=PHI*(D+(2*dc))*dc*7800*Li*4.7*(Bc/10000)*Bc*0.01;
        iron_los=iron_tee+iron_cor;
        fri_wind=0.007*Q;
        field_los=p*If*If*Rf;
        brush_los=2*If;
        exc_los=(field_los+brush_los)/0.88;
        total_los=Loss+Stray+iron_los+fri_wind+field_los+brush_los+exc_los;
        Eff=KW/(KW+(total_los/1000));
}

temp() {
        /* Temperature rise calculations ( Armature ) */
        float loss_dis1,loss_dis2,loss_dis3,loss_diss,loss_stator;

        loss_dis1=PHI*Do*L/0.035;
        loss_dis2=PHI*D*L*(1+(0.1*Va))/0.45;
        loss_dis3=PHI*((Do*Do)-(D*D))*(nd+2)*Va/4.5;
        loss_diss=loss_dis1+loss_dis2+loss_dis3;
        loss_stator=iron_los+(3*Iph*Iph*Keav*rdc1);
        temp_rise=loss_stator/loss_diss;
}

ventilation() {
        float Aaxial,airr;

        if(type=='t') {
           if(KW<50000)
                   Vair=(0.78*(total_los/1000.0)*293)/(25.0*273);
           else
                   Vair=(0.8*(total_los/1000.0)*293*760)/(25.0*273*2300);
                   Aaxial=0.7*Vair/50;
                   ductrs=(Aaxial*(1.0/3))/(PHI*0.02*0.02);
                   ductas=(Aaxial*(2.0/3))/(PHI*0.015*0.015);
                   airr=(0.3*Vair/50)-(PHI*((D*D)-(Dr*Dr))/4);
                   ductrr=(airr*(1.0/3))/(PHI*0.025*0.025);
                   ductar=(airr*(2.0/3))/(PHI*0.015*0.015);
        }
}
```

```
occ() {
        /* readings of open circuit char.. stored in a file "oc_curve.txt"*/
        float j;

        FILE *str;
        FILE *ptr;
        ptr=fopen("out4.txt","w");
        str=fopen("oc_curve.txt","w");
        clrscr();
        fprintf(ptr,"\n\t\t\tOpencircuit characteristics\n");
        fprintf(ptr,"\n  per unit voltage\t    V\t\tflux/pole\t    ATfo\n\n");
        for(j=0.2;j<=2.2;j+=0.2) {
                V=local1*j;
                FI=flux*j;
                mag_circuit();
                fprintf(ptr,"\n\t%0.2f\t\t%f\t%f\t%f",j,V,FI,ATfo);
                fprintf(str,"\n%f\t%f",V,ATfo);
        }
        fclose(str);
        fprintf(ptr,"\n\n\tSCR\t%0.3f",SCR);
        fclose(ptr);
}

graph() {
        /* graph for open circuit characteristics */
        FILE *str;
        int i,gdriver=DETECT,gmode;
        float a[100],b[100],j,rat,reg;
        char word[25],*words;
        int q=450,w=33,s=40;

        /* graphics mode initialization */
        initgraph(&gdriver,&gmode,"c:\\tc\\bgi\\");
        setcolor(getmaxcolor());
        str=fopen("oc_curve.txt","r+");

        for(i=0;i<=20;i++)
                fscanf(str,"%f",&a[i]);

        line(40,0,40,450);
        line(40,450,640,450);

        for(i=0;i<=20;i++) {
                if((i%2)==0)
                        b[i]=(int)(floor(a[i]*200/local1));
```

```
        else
              b[i]=(int)(floor(a[i]*200/local2));
}

sprintf(word,"OPEN CIRCUIT CHARACTERISTICS");
outtextxy(200,40,word);
sprintf(word,"SCALE");
outtextxy(390,65,word);
sprintf(word,"1 per unit = 200 pixels");
outtextxy(390,80,word);
sprintf(word,"X axix - voltage");
outtextxy(390,95,word);
sprintf(word,"Y axix - No load MMF");
outtextxy(390,110,word);
sprintf(word,"0.0");
outtextxy(20,460,word);

for(j=0.2;j<=3.0;j+=0.2) {
        sprintf(word,"%0.1f -",j);
        q=q-40; w=w+40;s=s+40;
        outtextxy(5,q,word);
        sprintf(word,"%0.1f",j);
        outtextxy(w,460,word);
        sprintf(words,"|");
        outtextxy(s,447,words);
  }

  line(40,450,40+b[1],450-b[0]);

  for(i=0;i<=17;i+=2) {
          if( ((b[i+3]-b[i+1])< 0) ) {
                  if((40+b[i+1])<640)
                          line(40+b[i+1],450-b[i],635,450-b[i]);
                  break;
          }
          line(40+b[i+1],450-b[i],40+b[i+3],450-b[i+2]);
  }
  getch();
  closegraph();
  /* Regulation calculation */
  if(ration<2.9) {
          printf("\n\nEnter the full load voltage(pu)\t\t");
          scanf("%f",&rat);
          reg=(rat-1.0)/rat;
          printf("\n\nRegulation(aprox..)\t\t\t%0.2f %",reg*100);
```

```
        }
        else {
                printf("\n\nHigh value of per unit ATfo (%0.2f)",ration);
                printf("\nRegulation cann't be found out using OCC");
        }
        getch();
}

scc() {
        float rho,var,AT1,AT2;

        rho=((0.75*PHI)+(sin(0.75*PHI)))/(4*sin(0.375*PHI));
        V=Xl;
        var=V/local1;
        FI=flux*var;
        AT2=ATfo;
        mag_circuit();
        AT1=(rho*ATa)+ATfo;
        SCR=AT2/AT1;
 }

 output() {
      /* printing  of design data sheet */
      float rho;
      FILE *ptr;
      ptr=fopen("output4.txt","w");

      fprintf(ptr,"\n\t\t\t\tDESIGN SHEET\n");
      if(type=='t')
            fprintf(ptr,"\n\t\t\tTURBO-ALTERNATOR\n");
      else
            fprintf(ptr,"\n\t\t\tHYDRO-GENERATOR\n");
      fprintf(ptr,"\nKVA - %.0f\t\tVoltage - %.0f V\t\tPhase - 3\n",Q,V);
      if(con==1) {
            fprintf(ptr,"\nFrequency - %0.0f Hz\tConnection - *",f);
            fprintf(ptr,"\t\t\tCurrent - %0.0f Amps",Iph);
      }
      else {
            fprintf(ptr,"\nFrequency - %0.0f Hz\tConnexion - delta",f);
            fprintf(ptr,"\t\tCurrent - %0.0f Amps",Iph);
      }
      fprintf(ptr,"\n\nRPM - %0.2f\t\tPower Factor - %0.2f lagging",rpm,pf);
      if(type=='h') {
            fprintf(ptr,"     Water head - %0.2f m",head);
            if(head<70)
```

```
        fprintf(ptr,"\n\n\t\t\tTurbine used - Kaplan turbine");
      if(head>70 && head <270)
        fprintf(ptr,"\n\n\t\t\tTurbine used - Francis turbine");
      if(head>270)
        fprintf(ptr,"\n\n\t\t\tTurbine used - Pelton wheel");
}
/* rating of the machine */
fprintf(ptr,"\n\nRating\n");
fprintf(ptr,"\n1. Full load KVA\t\t\tQ\t\t%.0f",Q);
fprintf(ptr,"\n2. Full load Power,KW\t\t\tP\t\t%0.0f",KW);
fprintf(ptr,"\n3. Line voltage\t\t\t\tV\t\t%0.0f V",V);
fprintf(ptr,"\n4. Phase voltage\t\t\tEph\t\t%0.0f V",Eph);
fprintf(ptr,"\n5. PowerFactor\t\t\t\tpf\t\t%0.2f lagging",pf);
fprintf(ptr,"\n6. Frequency\t\t\t\tf\t\t%0.0f Hz",f);
fprintf(ptr,"\n7. Speed\t\t\t\tns\t\t%0.3f r.p.s.",ns);
fprintf(ptr,"\n8. No. of poles\t\t\t\tp\t\t%.0f",p);
/* main dimension */
fprintf(ptr,"\n\nMain Dimensions\n");
fprintf(ptr,"\n1.Specific magnetic loading\t\tBav\t\t%0.2fTesla",Bav);
fprintf(ptr,"\n2. Specific eletricloading\t\tac\t\t%.0f A/m",ac);
fprintf(ptr,"\n3. Stator bore\t\t\t\tD\t\t%0.3f m",D);
fprintf(ptr,"\n4. Core length\t\t\t\tL\t\t%0.3f m",L);
fprintf(ptr,"\n5. Gross iron length\t\t\tLg\t\t%0.3f m",Lg);
fprintf(ptr,"\n6. Net iron length\t\t\tLi\t\t%0.3f m",Li);
fprintf(ptr,"\n7. Pole pitch\t\t\t\t  \t\t%0.3f m",polpitch);
fprintf(ptr,"\n8. Current per phase\t\t\tIph\t\t%.1f A",Iph);
if(mat==1)
      fprintf(ptr,"\n9. Steel used for stator & rotor\t\t\tLohys");
if(mat==2)
      fprintf(ptr,"\n9. Steel used for stator & rotor\t\t\tstalloy");
if(mat==3)
      fprintf(ptr,"\n9. Steel used for stator & rotor\t\t\tquality");
if(type=='h') {
    fprintf(ptr,"\n10. Radial ducts : No.\t\t\tnd\t\t%.0f",nd);
    fprintf(ptr,"\n       Width\t\t\twd\t\t%.0f mm",(wd*1000));
 }
fprintf(ptr,"\n11.Output Co-efficient Co 0.2fKVA/(cubic m *r.p.s.)",Co);
/* stator */
fprintf(ptr,"\n\nStator\n");
if(((int)(Zs) % 2)==0)
      fprintf(ptr,"\n1. Winding\t\t\t\t\t\tDouble layer lap");
else
      fprintf(ptr,"\n1. Winding\t\t\t\t\t\tSingle layer concentric");
if(sl<=1500)
        fprintf(ptr,"\n2. Number of parallel paths\t\ta\t\t1");
```

```
else
      fprintf(ptr,"\n2. Number of parallel paths\t\ta\t\t2");
fprintf(ptr,"\n3. No. of slots\t\t\t\tS\t\t%0.0f",S);
fprintf(ptr,"\n4. Slots /pole/phase\t\t\tq\t\t%.3f",q);
fprintf(ptr,"\n5. Conductors/slot\t\t\tZs\t\t%0.0f",Zs);
fprintf(ptr,"\n6. Coil span\t\t\tCs\t\t%.0f slots,(1-%.0f)",Cs,Cs+1);
fprintf(ptr,"\n7. Coil span/pole pitch\t\t\t\t\t%.3f",ratio);
fprintf(ptr,"\n8. Conductor : size\t\t\t\t%d*(%.2f*%.2f) sq.mm",N,w,t);
fprintf(ptr,"\n              area\t\t\tAs\t\t%.3f square mm",As);
fprintf(ptr,"\n9. Current density\t\t\t\t\t%.3f A/(square mm)",delta);
fprintf(ptr,"\n10.Length of mean turn\t\t\tLmts\t\t%.3f m",Lmts);
fprintf(ptr,"\n11.Slot pitch      \t\t\t  \t\t%0.3f m",ys);
fprintf(ptr,"\n12.Slot size : width\t\t\tWs\t\t%.3f mm",slotw);
fprintf(ptr,"\n               depth\t\t\tds\t\t%.3f mm",slotd);
fprintf(ptr,"\n13.Teeth width      \t\t\t  \t\t%0.3f mm",teew);
fprintf(ptr,"\n14.Core depth\t\t\tdc\t\t%.3f m",dc);
fprintf(ptr,"\n15.Outer diameter of stator\t\tDo\t\t%.3f m",Do);
fprintf(ptr,"\n16.Resistance/phase\t\t\trac\t\t%.3f Ohms",rac);
fprintf(ptr,"\n17.Total copper loss\t\t\t\t\t%.3f kW",Loss/1000);
fprintf(ptr,"\n18.Thickness of the stamping\t\t\t0.5 mm");
fprintf(ptr,"\n19.No.of stampings\t\t\t%0.0f",(Lg*1000)/0.5);
/* rotor*/
fprintf(ptr,"\n\nRotor\n");
if(type=='h') {
     fprintf(ptr,"\n1. Type of pole\t\t\t\t\t\tRectangular pole");
     if(Va>=50) {
            fprintf(ptr,"\n2. Pole construction\t\t\t\tbolted on pole,");
            fprintf(ptr,"\n                    \t\t\t\t\tlaminated");
     }
     else {
            fprintf(ptr,"\n2. Pole construction\t\t\t\t\tdovetail,");
            fprintf(ptr,"\n                    \t\t\t\t\tlaminated");
     }
     fprintf(ptr,"\n3. Pole arc\t\t\t\tb\t\t%0.3f m",polarc);
     fprintf(ptr,"\n4. Pole section\t\t\t\t\t%0.3f*%0.3f square m",bp,L);
     fprintf(ptr,"\n5. Radial length of pole\t\thpl\t\t%0.3f m",hpl);
     fprintf(ptr,"\n6. Turns/pole\t\t\t\tTf\t\t%0.0f",Tf);
     fprintf(ptr,"\n7. Conductor : size\t\t\t%0.3f*%0.3f square m",df,hf);
     fprintf(ptr,"\n              area\t\taf\t\t%f square mm",af);
     fprintf(ptr,"\n8. Full load current\t\t\tIf\t\t%0.3f A",If);
     fprintf(ptr,"\n9.Current density\t\t\t%0.1f A/(square mm)\n",If/af);
     fprintf(ptr,"10.Length of mean turn\t\t\tLmtr\t\t%0.2f m",Lmtf);
     fprintf(ptr,"\n11.Field copper loss\t\t\t\t\t%0.3f W",(p*Qf));
     fprintf(ptr,"\n12.Peripheral speed\t\t\tVa\t\t%0.3f m/sec",Va);
     fprintf(ptr,"\n13.Airgap length  \t\t\t  \t\t%0.3f mm",lg*1000);
```

```
        fprintf(ptr,"\n14. Damper winding : No. of bars\tNd\t\t%.0f",Nd);
        fprintf(ptr,"\n                 Dia of each bar\tDd\t\t%.3f m",Dd);

}
if(type=='t') {
        fprintf(ptr,"\n1. Turns/pole\t\t\t\tTf\t\t%0.0f\n",Tfr);
        fprintf(ptr,"2. Conductor : size\t\t\t%d*(%.2f*%0.2f) sq.mm",M,wb,tb);
        fprintf(ptr,"\n               area\t\t\taf\t\t%0.3f sq.mm",afr);
        fprintf(ptr,"\n3. Conductor/slot\t\t\tZr\t\t%0.0f",Zsr);
        fprintf(ptr,"\n4. Length of mean turn\t\t\tLmtr\t\t%0.2f m",Lmtfr);
        fprintf(ptr,"\n5. Slot pitch\t\t\t\tys\t\t%0.3f m",ysr);
        fprintf(ptr,"\n6. Rotor conductor current\t\tIf\t\t%0.3f A",Ifr);
        fprintf(ptr,"\n7. Current density\t\t\t\t\t%0.1f A/(sq. mm)",Ifr/afr);
        fprintf(ptr,"\n8. Copper loss      \t\t\t\t\t%0.3f W",(Ifr*Ifr*Rfr));
        fprintf(ptr,"\n9. Slot size : width\t\t\tWs\t\t%.3f mm",slotwr);
        fprintf(ptr,"\n              depth\t\t\tds\t\t%.3f mm",slotdr);
        fprintf(ptr,"\n10.Peripheral speed\t\t\tVa\t\t%0.3f m/sec",Va);
        fprintf(ptr,"\n11.Airgap length   \t\t\t  \t\t%0.3f mm",lg*1000);
        fprintf(ptr,"\n12.Thickness of the stamping\t\t\t0.4 mm");
        fprintf(ptr,"\n13.No.of stampings\t\t\t%0.0f",(Lg*1000)/0.4);
 }
 /* cooling */
 if(type=='t') {
     fprintf(ptr,"\nCooling");
     if(KW>=50000)
        fprintf(ptr,"\n\n1.Type of cooling\t\t\tHydrogen cooling");
     else
        fprintf(ptr,"\n\n1.Type of cooling\t\t\tAir cooling");
     fprintf(ptr,"\n\n2.Stator");
     fprintf(ptr,"\n\n\n(i). Radial ducts of 40mm dia \t%0.0f nos",ductrs);
     fprintf(ptr,"\n(ii).Axial ducts of 30mm dia \t\t%0.0f nos",ductas);
     if(ductrr>0) {
     fprintf(ptr,"\n\n3.Rotor");
     fprintf(ptr,"\n\n\n(i). Radial ducts of 50mm dia \t%0.0f nos",ductrr);
     }
     if(ductar>0)
     fprintf(ptr,"\n(ii).Axial ducts of 30mm dia \t\t%0.0f nos",ductar);
     if(KW<50000)
        fprintf(ptr,"\n\n4.Volume of air\t\t\t\t%0.3f Cubic m/sec",Vair);
     else
        fprintf(ptr,"\n\n4.Volume of hydrogen\t\t%0.3f Cubic m/sec",Vair);
     if(KW<50000)
     fprintf(ptr,"\n\n5.Power required by the fan %.2f kW",(1.5*Vair/0.3));
     }
   /* magnetization */
```

```
fprintf(ptr,"\n\nMagnetization");
fprintf(ptr,"\n\n1.Flux per pole\t\t\t\t\t\t%0.3f Webers",FI);
fprintf(ptr,"\n2.Core :\tarea\t\t\tAc\t\t%0.3f square m",Ac);
fprintf(ptr,"\n        \t\tdensity\t\t\tBc\t\t%0.3f Tesla",Bc/100);
fprintf(ptr,"\n        \t\tmmf\t\t\tATc\t\t%0.2f A",ATc);
fprintf(ptr,"\n3.Teeth :\tarea(1/3)\t\tAt\t\t%0.6f sq.m",(FI/Bt13));
fprintf(ptr,"\n        \tdensity\t\t\tBt1/3\t\t%0.3f Tesla",Bt13/100);
fprintf(ptr,"\n        \tmmf\t\t\tATt\t\t%0.2f A",ATt);
fprintf(ptr,"\n4.Gap :\t\tarea\t\t\tAg\t\t%0.3f sq.m",Ag);
fprintf(ptr,"\n      \t\tcontraction factor\tKg\t\t%0.3f",Kg);
fprintf(ptr,"\n      \t\tdensity\t\t\tBg\t\t%0.3f Tesla",Bg);
fprintf(ptr,"\n      \t\tmmf\t\t\tATg\t\t%0.2f A",ATg);
fprintf(ptr,"\n5.Pole :\tarea\t\t\tAp\t\t%0.3f sq.m",Ap);
fprintf(ptr,"\n        density\t\t\tBp(max)\t\t%0.3f Tesla",Bp_max/100);
fprintf(ptr,"\n        \t\t\t\tBp(min)\t\t%0.3f Tesla",Bp_min/100);
fprintf(ptr,"\n        \t\tmmf\t\t\tATp\t\t%0.2f A",ATp);
fprintf(ptr,"\n6.Yoke :\tarea\t\t\tAy\t\t%0.3f sq.m",Ay);
fprintf(ptr,"\n        \t\tdensity\t\t\tBy\t\t%0.3f Tesla",By/100);
fprintf(ptr,"\n        \t\tmmf\t\t\tATy\t\t%0.2f A",ATy);
fprintf(ptr,"\n7.Total MMF per pole.. No load\t\tATfo\t\t%0.2f A",ATfo);
local2=ATfo;
local3=ATfl;
fprintf(ptr,"\n                        Full load\tATfl\t\t%0.2f A",ATfl);
fprintf(ptr,"\n8.Armature mmf per pole\t\t\tATa\t\t%0.2f A",ATa);
rho=(((0.75*PHI)+(sin(0.75*PHI)))/(4*sin(0.375*PHI)))*ATa;
fprintf(ptr,"\n9.Field mmf equivalent to armature mmf per pole%f",rho);
/* Efficiency  */
fprintf(ptr,"\n\nEfficiency");
fprintf(ptr,"\n\n1. Core loss\t\t\t\t\t%0.2f kW",iron_los/1000);
fprintf(ptr,"\n2. Copper loss\t\t\t\t\t%0.2f kW",Loss/1000);
fprintf(ptr,"\n3. Stray load loss\t\t\t\t%0.2f kW",Stray/1000);
fprintf(ptr,"\n4. Excitation loss\t\t\t\t%0.2f kW",exc_los/1000);
fprintf(ptr,"\n5. Friction & Windage loss\t\t\t%0.3f kW",fri_wind/1000);
fprintf(ptr,"\n6. Total loss\t\t\t\t\t%0.2f kW",total_los/1000);
fprintf(ptr,"\n7. Efficiency\t\t\t\t\t%0.2f %",Eff*100);

/* Temperature rise */
fprintf(ptr,"\n\nTemperature rise\n\n");
fprintf(ptr,"1. Temperature rise of field coils\t\t%0.2f deg.C",theta);
fprintf(ptr,"\n2. Teperature rise of armature\t%0.2f deg.C",temp_rise);
ration=floor((local3/local2)*10)/10;
if(ration<2.9) {
fprintf(ptr,"\n\nFull load MMF\t\t\t\t\t%0.2f A",local3);
fclose(ptr);
clrscr();
```

```
        printf("\n\nNote down the PU voltage (for calculation of regulation)");
        printf("\ncoressponding to no load MMF of %0.1f from OCC",ration);
        getch();
        }
}
```

CHAPTER IV

SIMULATION RESULTS

Simulation results of one hydro-electric generator and one turbo-alternator are presented in this report.

1. A 210 MW, 11 KV 0.8pf lagging 50Hz, 3000 R.P.M. , star connected, 3 phase, turbo alternator is designed and design values are presented in this chapter.

2. A 100MW, 11 KV, 0.8 pf lagging, 50Hz, 3 phase, 100 r.p.m., star connected hydro-electric generator is designed and design values are also given in this chapter.

DESIGN SHEET

TURBO-ALTERNATOR

KVA - 262500 Voltage - 11000 V Phase - 3

Frequency - 50 Hz Connection - * Current - 13778 Amps

RPM - 3000.00 Power Factor - 0.80 lagging

Rating

1. Full load KVA	Q	262500
2. Full load Power,KW	P	210000
3. Line voltage	V	11000 V
4. Phase voltage	Eph	6351 V
5. Power Factor	pf	0.80 lagging
6. Frequency	f	50 Hz
7. Speed	ns	50.000 r.p.s.
8. No. of poles	p	2

Main Dimensions

1.Specific magnetic loading	Bav	0.29Tesla
2. Specific electric loading	ac	75000 A/m
3. Stator bore	D	1.076 m
4. Core length	L	5.751 m
5. Gross iron length	Lg	4.931 m
6. Net iron length	Li	4.438 m
7. Pole pitch		1.691 m
8. Current per phase	Iph	13777.7 A
9. Steel used for stator & rotor		stalloy

Stator

1. Winding		Single layer concentric
2. Number of parallel paths	a	2
3. No. of slots	S	63
4. Slots /pole/phase	q	10.500
5. Conductors/slot	Zs	1
6. Coil span	Cs	32 slots,(1-32)
7. Coil span/pole pitch		0.984
8. Conductor : size		31*(22.00*1.40) sq.mm
area	As	948.600 square mm

9. Current density		14.524 A/(square mm)
10.Length of mean turn	Lmts	16.591 m
11.Slot pitch		0.054 m
12.Slot size : width	Ws	28.200 mm
depth	ds	90.650 mm
13.Teeth width		25.498 mm
14.Core depth	dc	0.268 m
15.Outer diameter of stator	Do	1.793 m
16.Resistance/phase	rac	0.001 Ohms
17.Total copper loss		655.220 kW
18.Thickness of the stamping		0.5 mm
19.No.of stampings		9862

Rotor

1. Turns/pole	Tf	99
2. Conductor : size		10*(22.00*1.40) sq.mm
area	af	306.000 sq.mm
3. Conductor/slot	Zr	4
4. Length of mean turn	Lmtr	15.63 m
5. Slot pitch	ys	0.058 m
6. Rotor conductor current	If	761.582 A
7. Current density		2.5 A/(sq. mm)
8. Copper loss		66638.446 W
9. Slot size : width	Ws	28.200 mm
depth	ds	120.500 mm
10.Peripheral speed	Va	169.150 m/sec
11.Airgap length		6.780 mm
12.Thickness of the stamping		0.4 mm
13.No.of stampings		12328

Cooling

1.Type of cooling	Hydrogen cooling
2.Stator	
(i). Radial ducts of 40mm dia	44 nos
(ii).Axial ducts of 30mm dia	155 nos
3.Rotor	
(i). Radial ducts of 50mm dia	8 nos
(ii).Axial ducts of 30mm dia	45 nos
4.Volume of hydrogen	11.732 Cubic m/sec

Magnetization

1.Flux per pole			2.853 Webers
2.Core :	area	Ac	1.189 square m
	density	Bc	1.200 Tesla
	mmf	ATc	479.46 A
3.Teeth :	area(1/3)	At	0.025935 sq.m
	density	Bt1/3	1.100 Tesla
	mmf	ATt	25.38 A
4.Gap :	area	Ag	7.296 sq.m
	contraction factor	Kg	1.534
	density	Bg	0.391 Tesla
	mmf	ATg	3254.26 A
5.Pole :	area	Ap	2.229 sq.m
	density	Bp(max)	1.500 Tesla
		Bp(min)	1.300 Tesla
	mmf	ATp	957.72 A
6.Yoke :	area	Ay	1.189 sq.m
	density	By	1.400 Tesla
	mmf	ATy	978.32 A
7.Total MMF per pole..	No load	ATfo	5695.14 A
	Full load	ATfl	75181.41 A
8.Armature mmf per pole		ATa	54697.62 A
9.Field mmf equivalent to armature mmf per pole			45335.339844

Efficiency

1. Core loss	5.48 kW
2. Copper loss	655.22 kW
3. Stray load loss	131.04 kW
4. Excitation loss	127.79 kW
5. Friction & Windage loss	1.837 kW
6. Total loss	1033.82 kW
7. Efficiency	99.51 %

Temperature rise

1. Temperature rise of field coils	15.52 deg.C
2. Temperature rise of armature	20.94 deg.C

Open circuit characteristics

```
per unit voltage         V              flux/pole      ATfo

     0.20          2200.000000         0.570580     735.537354
     0.40          4400.000000         1.141160     1441.848145
     0.60          6600.000488         1.711740     2191.125244
     0.80          8800.000000         2.282320     3168.483154
     1.00          11000.000000        2.852899     5695.135742
     1.20          13200.000977        3.423479     18697.953125
     1.40          15400.000977        3.994059     1105957.375000
     1.60          17600.001953        4.564639     1132477.875000
     1.80          19800.001953        5.135219     1426304.500000
     2.00          22000.001953        5.705799     2437870.000000

     SCR   0.126
```

DESIGN SHEET

HYDRO-ELECTRIC GENERATOR

KVA - 119048 Voltage - 11000 V Phase - 3

Frequency - 50 Hz Connection - * Current - 6248 Amps

RPM - 150.00 Power Factor - 0.84 lagging Water head - 235.00 m

Turbine used - Francis turbine

Rating

1. Full load KVA	Q	119048
2. Full load Power,KW	P	100000
3. Line voltage	V	11000 V
4. Phase voltage	Eph	6351 V
5. Power Factor	pf	0.84 lagging
6. Frequency	f	50 Hz
7. Speed	ns	2.500 r.p.s.
8. No.of poles	p	40

Main Dimensions

1.Specific magnetic loading	Bav	0.36Tesla
2. Specific eletric loading	ac	40000 A/m
3. Stator bore	D	6.948 m
4. Core length	L	2.347 m
5. Gross iron length	Lg	2.017 m
6. Net iron length	Li	1.816 m
7. Pole pitch		0.546 m
8. Current per phase	Iph	6248.4 A
9. Steel used for stator & rotor		Lohys
10. Radial ducts : No.	nd	33
Width	wd	1 mm

Stator

1. Winding		Single layer concentric
2. Number of parallel paths	a	2
3. No. of slots	S	390
4. Slots /pole/phase	q	3.250
5. Conductors/slot	Zs	1

6. Coil span	Cs	1 slots,(1-11)
7. Coil span/pole pitch		0.923
8. Conductor : size		31*(22.00*1.40) sq.mm
area	As	948.600 square mm
9. Current density		6.587 A/(square mm)
10.Length of mean turn	Lmts	6.920 m
11.Slot pitch		0.056 m
12.Slot size : width	Ws	28.200 mm
depth	ds	90.650 mm
13.Teeth width		27.792 mm
14.Core depth	dc	0.106 m
15.Outer diameter of stator	Do	7.341 m
16.Resistance/phase	rac	0.004 Ohms
17.Total copper loss		426.506 kW
18.Thickness of the stamping		0.5 mm
19.No.of stampings		4035

Rotor

1. Type of pole		Rectangular pole
2. Pole construction		bolted on pole, laminated
3. Pole arc	b	0.409 m
4. Pole section		0.157*2.347 square m
5. Radial length of pole	hpl	0.256 m
6. Turns/pole	Tf	15
7. Conductor : size		0.045*0.203 square m
area	af	407.127197 square mm
8. Full load current	If	1221.382 A
9.Current density		3.0 A/(square mm)
10.Length of mean turn	Lmtr	4.89 m
11.Field copper loss		225769.375 W
12.Peripheral speed	Va	54.592 m/sec
13.Airgap length		6.780 mm
14. Damper winding : No. of bars	Nd	9
Dia of each bar	Dd	13.893 m

Magnetization

1.Flux per pole			0.461 Webers
2.Core :	area	Ac	0.192 square m
	density	Bc	1.200 Tesla
	mmf	ATc	170.54 A
3.Teeth :	area(1/3)	At	0.003545 sq.m
	density	Bt1/3	1.300 Tesla

	mmf	ATt	72.52 A
4.Gap :	area	Ag	0.961 sq.m
	contraction factor	Kg	1.505
	density	Bg	0.479 Tesla
	mmf	ATg	3913.42 A
5.Pole :	area	Ap	0.360 sq.m
	density	Bp(max)	1.300 Tesla
		Bp(min)	1.300 Tesla
	mmf	ATp	68.40 A
6.Yoke :	area	Ay	0.192 sq.m
	density	By	1.200 Tesla
	mmf	ATy	149.40 A
7.Total MMF per pole..	No load	ATfo	4374.28 A
	Full load	ATfl	18988.99 A
8.Armature mmf per pole		ATa	9415.10 A
9.Field mmf equivalent to armature mmf per pole			7803.569336

Efficiency

1. Core loss	10.47 kW
2. Copper loss	426.51 kW
3. Stray load loss	85.30 kW
4. Excitation loss	259.33 kW
5. Friction & Windage loss	0.833 kW
6. Total loss	1010.66 kW
7. Efficiency	99.00 %

Temperature rise

1. Temperature rise of field coils	35.97 deg.C
2. Teperature rise of armature	30.91 deg.C

Open circuit characteristics

per unit voltage	V	flux/pole	ATfo
0.20	2200.000000	0.092171	818.129150
0.40	4400.000000	0.184341	1654.040771
0.60	6600.000488	0.276512	2473.931641
0.80	8800.000000	0.368682	3402.611084
1.00	11000.000000	0.460853	4374.276855
1.20	13200.000977	0.553024	6024.261719
1.40	15400.000977	0.645194	10617.647461
1.60	17600.001953	0.737365	26900.019531
1.80	19800.001953	0.829535	79653.953125
2.00	22000.001953	0.921706	107139.617188

SCR 0.561

CHAPTER V

CONCLUSION

A Computer Aided Design has been developed for the design of synchronous generator. The program has been developed in 'C' language. Simulation results of design of a hydro-electric generator and a turbo-alternator are presented in this report. The results obtained are found to be almost equal to the values given in standard text books. In this CAD program, loss is minimised. The program can be modified easily to design for cost minimisation.

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B-H CURVE DETAILS

Ref No.	B	at/m		
-	Tesla	Lohy's	Quality	Stalloy
10	0.1	30.0	40.0	30.0
20	0.2	45.0	50.0	35.0
30	0.3	65.0	55.0	40.0
40	0.4	90.0	60.0	50.0
50	0.5	125.0	70.0	60.0
60	0.6	155.0	80.0	75.0
70	0.7	170.0	90.0	90.0
80	0.8	200.0	120.0	115.0
90	0.9	300.0	135.0	150.0
100	1.0	370.0	165.0	200.0
110	1.1	480.0	225.0	280.0
120	1.2	600.0	325.0	400.0
130	1.3	800.0	463.0	650.0
140	1.4	1200.0	920.0	1400.0
150	1.5	2000.0	2200.0	3300.0
160	1.6	3600.0	4500.0	6500.0
170	1.7	4700.0	8400.0	11000.0
180	1.8	8000.0	14500.0	18500.0
190	1.9	12700.0	24500.0	32000.0
200	2.0	25000.0	42000.0	65000.0
210	2.1	38000.0	73000.0	135000.0
220	2.2	62000.0	138000.0	275000.0
230	2.3	90000.0	255000.0	560000.0
240	2.4	140000.0	475600.0	1100000.0

49	4.94	3.50	1.50
50	5.01	2.80	1.90
51	5.11	3.80	1.40
52	5.19	4.50	1.20
53	5.29	3.50	1.60
54	5.39	4.00	1.40
55	5.45	3.20	1.40
56	5.64	4.50	1.30
57	5.71	6.50	0.90
58	5.79	5.00	1.20
59	5.86	7.50	0.80
60	5.99	3.50	1.80
61	6.09	3.20	2.00
62	6.26	8.00	0.80
63	6.29	5.00	1.30
64	6.39	5.50	1.20
65	6.49	4.00	1.70
66	6.61	7.50	0.90
67	6.73	3.20	2.20
68	6.79	5.00	1.40
69	6.89	4.50	1.60
70	6.99	6.00	1.20
71	7.06	9.00	0.80
72	7.19	5.00	1.50
73	7.29	4.00	1.90
74	7.39	3.50	2.20
75	7.49	5.50	1.40
76	7.59	6.00	1.30
77	7.69	4.00	2.00
78	7.79	4.50	1.80
79	7.94	5.50	1.50
80	8.04	7.50	1.10
81	8.05	3.80	2.20
82	8.20	3.50	2.50
83	8.25	4.00	2.20
84	8.41	3.20	2.80
85	8.49	5.50	1.60
86	8.59	8.00	1.10
87	8.69	9.00	1.10
88	8.79	7.50	1.20
89	8.89	7.00	1.30
90	9.04	5.50	1.70
91	9.10	5.00	1.90
92	9.25	5.00	1.90
93	9.29	6.00	1.50

94	9.39	8.00	1.20
95	9.54	7.50	1.30
96	9.59	5.50	1.80
97	9.69	9.00	1.10
98	9.86	10.00	1.00
99	9.89	6.00	1.70
100	9.95	3.50	3.00
101	10.10	6.50	1.60
102	10.20	7.00	1.50
103	10.30	13.00	0.80
104	10.50	6.00	1.80
105	10.50	6.00	1.80
106	10.60	9.00	1.20
107	10.70	12.00	0.90
108	10.80	10.00	1.10
109	10.90	11.00	1.00
110	11.00	8.00	1.40
111	11.10	8.00	1.40
112	11.40	6.50	1.80
113	11.40	6.50	1.80
114	11.40	6.50	1.80
115	11.50	6.00	2.00
116	11.60	5.50	2.20
117	11.70	7.00	1.70
118	11.90	12.00	1.00
119	11.90	12.00	1.00
120	12.00	5.00	2.50
121	12.10	4.50	2.80
122	12.30	4.00	3.20
123	12.30	4.00	3.20
124	12.40	9.00	1.40
125	12.50	8.00	1.60
126	12.70	6.00	2.20
127	12.70	6.00	2.20
128	12.80	10.00	1.30
129	12.90	13.00	1.00
130	13.00	12.00	1.10
131	13.20	7.50	1.80
132	13.20	7.50	1.80
133	13.30	8.00	1.70
134	13.50	15.00	0.90
135	13.50	15.00	0.90
136	13.80	10.00	1.40
137	13.80	10.00	1.40
138	13.80	10.00	1.40

139	13.90	14.00	1.00
140	14.10	9.00	1.60
141	14.10	9.00	1.60
142	14.20	12.00	1.20
143	14.30	16.00	0.90
144	14.50	7.50	2.00
145	14.50	7.50	2.00
146	14.70	10.00	1.50
147	14.70	10.00	1.50
148	14.90	7.00	2.20
149	14.90	7.00	2.20
150	15.00	9.00	1.70
151	15.20	11.00	1.40
152	15.20	11.00	1.40
153	15.40	13.00	1.20
154	15.40	13.00	1.20
155	15.50	5.00	3.20
156	15.70	10.00	1.60
157	15.70	10.00	1.60
158	15.90	16.00	1.00
159	15.90	16.00	1.00
160	16.00	7.50	2.20
161	16.10	18.00	0.90
162	16.20	11.00	1.50
163	16.30	15.00	1.10
164	16.30	15.00	1.10
165	16.60	14.00	1.20
166	16.60	14.00	1.20
167	16.70	13.00	1.30
168	16.80	9.00	1.90
169	17.00	7.00	2.50
170	17.00	7.00	2.50
171	17.10	8.00	2.50
172	17.30	11.00	1.60
173	17.30	11.00	1.60
174	17.40	16.00	1.10
175	17.50	9.00	2.00
176	17.70	9.00	2.00
177	17.70	9.00	2.00
178	17.80	15.00	1.20
179	17.90	18.00	1.00
180	18.00	14.00	1.30
181	18.20	7.50	2.50
182	18.20	7.50	2.50
183	18.30	6.00	3.20

184	18.40	11.00	1.70
185	18.60	13.00	1.40
186	18.60	13.00	1.40
187	18.70	10.00	1.90
188	18.90	12.00	1.60
189	18.90	12.00	1.60
190	19.00	16.00	1.20
191	19.10	7.00	2.80
192	19.20	13.00	1.50
193	19.30	15.00	1.30
194	19.40	14.00	1.40
195	19.50	11.00	1.80
196	19.60	18.00	1.10
197	19.60	18.00	1.10
198	19.90	20.00	1.00
199	19.90	20.00	1.00
200	20.10	12.00	1.70
201	20.10	12.00	1.70
202	20.10	12.00	1.70
203	20.50	13.00	1.60
204	20.50	13.00	1.60
205	20.50	13.00	1.60
206	20.60	16.00	1.30
207	20.70	14.00	1.50
208	20.80	15.00	1.40
209	20.80	15.00	1.40
210	21.10	5.50	4.00
211	21.10	5.50	4.00
212	21.30	12.00	1.80
213	21.30	12.00	1.80
214	21.40	18.00	1.20
215	21.50	11.00	2.00
216	21.60	5.00	4.50
217	21.80	20.00	1.10
218	21.80	20.00	1.10
219	21.90	8.00	2.80
220	22.00	8.00	2.80
221	22.10	14.00	1.60
222	22.20	16.00	1.40
223	22.20	16.00	1.40
224	22.50	12.00	1.90
225	22.90	12.00	1.90
226	22.90	12.00	1.90
227	22.90	12.00	1.90
228	23.10	13.00	1.80

274	27.50	14.00	2.00
275	27.50	14.00	2.00
276	27.80	20.00	1.40
277	27.80	20.00	1.40
278	27.80	20.00	1.40
279	27.90	9.00	3.20
280	28.10	13.00	2.20
281	28.10	13.00	2.20
282	28.20	15.00	1.90
283	28.40	22.00	1.30
284	28.40	22.00	1.30
285	28.50	18.00	1.60
286	28.50	18.00	1.60
287	28.50	18.00	1.60
288	29.10	7.50	4.00
289	29.10	7.50	4.00
290	29.10	7.50	4.00
291	29.10	7.50	4.00
292	29.40	5.50	5.50
293	29.40	5.50	5.50
294	29.40	5.50	5.50
295	29.50	15.00	2.00
296	29.70	20.00	1.50
297	29.70	20.00	1.50
288	29.70	20.00	1.50
299	30.10	16.00	1.90
300	30.10	16.00	1.90
301	30.10	16.00	1.90
302	30.30	18.00	1.70
303	30.30	18.00	1.70
304	30.60	22.00	1.40
305	30.60	22.00	1.40
306	30.60	22.00	1.40
307	30.60	22.00	1.40

TYPES OF INSULATION

Class of insulation	Maximum temperature rise °C
All classes immersed in oil	60
All classes immersed in bituminous compound	50
Classes not immersed in oil or bituminous compound	
Y	45
A	60
E	75
B	85
F	110
H	135