International Journal of Scientific & Engineering Research Volume 10, Issue 8, August-2019
ISSN 2229-5518

Design of Synchronous Generator

Than Than Swe

Abstract— This paper is to design of synchronous generator for hydrogenerating system.The synchronous generator is the most important of the electromechanical power conversion device,playing a key role both in the production of electricity and in certain special drive applications.Synchronous generator is driven by means of undershot water wheel.The position of generator is vertical because of direct coupling with the water wheel.In this paper, 2 kVA,salient pole,synchronous generator is designed for hydropower project.

Index Terms— hydropower, water wheel, salient pole, synchronous generator

1 Introduction

THe majority of hydroelectric installations utilize salient pole synchronous generators.Salient pole machines are employed because the hydraulic turbine in the hydroelectric plants operates at low speeds compared to steam plants,therefore generators requires large number of field poles to produce the rated frequency.Rotor of synchronous generator requires salient poles is mechanically best suited for low speed applications.Synchronous generators come with round rotor or with salient pole rotor.The number of poles ranges from two to almost one hundred.The type of the generator used is depends upon the head availability.For low head
It is of salient pole type and for high head it is of cylindrical core type. In this research, single phase, 6 poles, 50 Hz, 1000 rpm, salient pole synchronous generator is selected.

2 Selection of capacity for generator

The generating capacity of hydropower is a function of the head and flow rate of water as shown in following equation.

$$P = \eta \times Q \times 10 \times H \text{ kW} \quad (1)$$

where P = power
H = head
Q = discharge flow rate
η = plant efficiency

$P = 0.5 \times 0.2 \times 10 \times 1.6$
$= 1.6$ kW

Therefore, 2 k VA, power rating of the generator is selected.
A 1.6 kW, 0.8 power factor, generator has a volt ampere rating of 2 kVA.

2.1 Specification of Generator

Output power = 2 kVA
Number of phase = 1
Power factor = 0.8
Frequency = 50 Hz
Type of drive = water wheel
Speed = 1000 rpm
Terminal voltage = 230 V
Output power = 1.6 kW
Output capacity = kW/power factor
= 2 kVA
Speed = 120 f / pole
Pole = 120f/speed
Number of pole = 6

3 Design calculation

Design of electrical machines mainly consists of obtaining the dimensions of the various parts of the machine to suit given specifications, using available material economically and then to furnish these data to the manufactor of the machine. The aim of the designer is to obtain:

- Lower cost
- Smaller size
- Wider temperature limit
- Lower weight
- Minimum losses
- Better performance under no load and loaded conditions

3.1 Design of Stator Frame

Internal diameter and gross length of the stator frame are its main dimensions. The output equation is the basic tool to design of synchronous generator.
Output of generator,

$$Q = K' D^2 L\, n_s \quad (2)$$

where, K' = output coefficient
D = internal diameter of stator
L = gross length of stator core

Output coefficient,

$$K' = 11/3\, B_{av}\, q\, K_w \times 10^{-3} \quad (3)$$

where, B_{av} = specific magnetic loading
q = specific electric loading
K_w = winding factor for full pitch coil

In case of salient pole alternators, internal diameter of the stator is very large as compared to the axial length of the stator core.Round or rectangular poles are generally used for the alternators.For rectangular poles, the ratio of axial length of the core to pole pitch varies from 0.8 to 3.

3.2 Design of Stator Winding

Stator winding consists of single turn or multi turn coil, suitably arranged in slots and connected properly, so as to obtain the required phase grouping. The electromotive force induced in all the phases are of equal magnitude and frequency. Single layer or double layer winding may be used for the stator of synchronous machines depending upon the requirements of the machine.In this research, selected winding type is lab and double layer winding.

Generated e.m.f per phase, $E_{ph} = 4.44 f \varphi T_{ph} K_w \quad (4)$

ISSN 2229-5518

For number of stator turns per phase,

$T_{ph} = E_{ph} / 4.44 f\, \varphi\, K_w$ (5)

Air gap flux per pole, $\varphi = B_{av} \times \pi D L / pole$ (6)

Slot pitch, $\tau_s = \pi D /$ number of stator slot

Conductor per slot, $Z_s = 2\, T_{ph} /$ number of stator slot

For cross sectional area of conductor,

a_s = current rating/ current density

Number of teeth per pole arc,

Width of the slot, $b_t = \varphi / B_t \times L_{ic} \times N_t$ (7)

Flux density in stator teeth at gap surface,

$B_t = \varphi / b_t \times L_{ic} \times N_t$

where, L_{ic} = net iron length of stator core

Mean length of stator turn,

$L_{mt} = (2L + 2.5\, \tau_p + 0.05 \times kV + 0.15)m$ (8)

where τ_p = pole pitch

Stator winding, $R_s = \rho L_{mt}\, T_{ph} / a_s$ (9)

where, ρ = resistivity

a_s = sectional area of statorconductor

Copper losses of stator winding, $P_{cus} = I_{ph}{}^2 R_{ph}$ (10)

Eddy current losses, $P_{eds} = (K_{dav} - 1)\, P_{cus}$ (11)

where, K_{dav} = average loss factor

Total losses = copper + eddy current + stray load

Resistance drop = $I_{ph}\, R_{ph}\, K_{dav}$

Effective resistance = resistance drop / terminal voltage (12)

Depth of stator core, $d_c = \varphi_c / B_c\, L_{ic}$ (13)

Outer diameter of stator core, $D_o = D + 2\, (h_c + d_c)$ (14)

where, h_c = depth of conductor

Armature ampere turns per pole, $AT_a = 1.35\, T_{ph}\, I_{ph}\, K_w / p$ (15)

3.3 Design of Rotor

Design of field system of salient pole generator consists of the shape of pole face, the dimensions of pole, the depth of the rotor pole and no load field ampere turns for salient generator.

Cross-sectional area of pole body, $A_p = \varphi_p / B_p$ (16)

where, B_p = flux density in the pole body

φ_p = flux density

Width of the pole, $b_p = A_p / L_p$

where, L_p = axial length of the pole

Effective gap area, $A_g = K_f \tau_p L$

Gap flux density, $B_g = \varphi / A_g$

Gap coefficient for slot, $K_{gs} = \tau_s / \tau_s - b_s\, (1 - \delta_v)$

Gap coefficient for duct, $K_{gv} = L / L - \eta_v b_v\, (1 - \delta_v)$

Total air gap coefficient, $K_g = K_{gs}\, K_{gv}$

Air gap ampere turns, $AT_g = 0.796\, B_g\, K_g\, L_g \times 10^6$

Air gap length, $L_g = AT_g / 0.796\, B_g K_g \times 10^6$ (17)

Rotor diameter, $D_r = D - 2\, L_g$ (18)

Height of the pole, $h_f = I_f T_f / 10^4 (d_f\, S_f\, P_f)^{1/2}$ (19)

where, I_f = current in the field winding

$I_f\, T_f$ = ampere turns in the field winding

d_f = depth of the field coil

S_f = copper space factor

P_f = permissible loss

Depth of rotor core, $d_c = A_c / L_c$ (20)

where, A_c = cross-sectional area of core

L_c = axial length of rotor core

Total ampere turns for the teeth, $AT_t = H_t\, h_s$ (21)

Ampere turns for core, $AT_c = H_c\, L_c$ (22)

where, H_c = ampere turns per meter

L_c = Length of the flux path

Ampere turns for rotor core, $H_y\, L_y$ (23)

Total Ampere turns , $AT = AT_g + AT_t + AT_c$ (24)

Ampere turns for pole, $AT_p = (2/3\, H_{pmin} h_p) + (1/3\, H_{pmax}\, h_p)$

3.4 Regulation

Area of the field conductor,

$V_c = 0.8 \times$exciter voltage/no of field coil (25)

Sectional area of field conductor, $a_f = \rho L_{mtf}\, I_f\, T_f / V_c$ (26)

where, L_{mtf} = mean length of turns of field coil

Field current = $a_f \times$ current density

No of turns on the field winding,

T_f = full load ampere turns / field current

Resistance of the filed winding, $R_f = \rho L_{mtf}\, T_f / a_f$ (27)

Friction and windage losses = 1% of output

Total iron losses = losses in the teeth + losses in the stator core

Copper losses in the field, $P_{cu} = I_f{}^2 R_f$

Total losses in all the coils, $P_{totalcu} = P_{cu} \times$ no of pole

Total field copper losses = $P_{cu} + P_{totalcu}$ (28)

Efficiency, $\eta = P_{out} / P_{in} \times 100\%$ (29)

4 Design Data Sheet

Calculated design data is shown in the following Table 1 to 4.

Table 1

Main Dimensions

Specification	Symbol	Unit	Value
Full load output	Q	kVA	2
Line voltage	V	Volts	230
Frequency	f	Hz	50
Number of phase			1
Speed	N	rpm	1000
Number of pole	p		6
Output coefficient	K'		25.282
Internal diameter of stator	D	m	0.18
Gross length of Stator	L	m	0.14
Peripheral speed	v	m/s	9.424

Table 2

Stator Data Sheet

Specification	Symbol	Unit	Value
Flux per phase	φ	Wb	0.0050
Conductor per phase	Z_s		8
Turns per phase	T_{ph}		210
Number of slots	S		24
Teeth per pole arc	N_t		3
Conductor c.s.a	a_s	mm^2	3
Size of conductor	mm×mm		10×0.3
Width of slot	b_s	m	0.011
Depth of slot	h_s	m	0.0145
Resistance of winding	R_{ph}	Ω	0.396
Effective resistance		p.u	0.015
Effective reactance		p.u	0.035
Winding type (lab)			Double
Width of stator tooth	b_t	m	0.012

Table 3

Rotor Data Sheet

Specification	Symbol	Unit	Value

ISSN 2229-5518

Short circuit ratio	SCR	-	0.9
Air gap length	l_g	m	0.0011
Axial length of pole	l_p	m	0.13
Width of pole	b_p	m	0.033
Height of pole	h_p	m	0.079
Total no load ampere tyrns	AT	-	574
Full load field ampere turns	AT_{fl}	-	1120
Sectional area of conductor	a_f	mm^2	0.395
Field current	I_f	A	1.18
Field turns per coil	T_F		945
Resistance of field winding	R_f	Ω	12
Rotor diameter	D_r	m	0.18

Table 4
Losses and Efficiency

Specification	Symbol	Unit	Value
Copper losses in stator winding	P_{cus}	W	29.97
Exciter loss	-	W	5
Eddy current losses in conductors	P_{eds}	W	0.59×10^{-3}
Stray load losses	P_s	W	4.49
Iron losses	-	W	71
Rotor copper losses	-	W	102
Friction & windage losses	-	W	16
Total full load losses	-	W	228
Efficiency	η	%	88

4 Conclusion

In Myanmar, most of areas are a great distance far from national grid system.It is not easy to supply electricity to the rural communities because of uneconomical transmission line cost and insufficient capacity of national grid system. To develop throughout the country of courses, needs to fulfill the electricity requirements for cities as well as country sides or villages. Myanmar has national gifts of encomous hydro energy resources.Almost all the resources are situated in remote area and hence there is a change to solve the electricity requirements of those areas.

Hydro-electric generators are used to convert the mechanical energy output of the turbine to electrical energy. It is classified into two main types: the synchronous generator and an asynchronous generator. The single operation, the voltage regulation and the power factor regulation are possible in synchronous generator. Synchronous generator can generate active and reactive power independently and have an important role in voltage control.Single phase, 6 pole ,50 Hz, 0.8 power factor , 2 kVA salient pole synchronous generator is designed and calculated. Suitable specific magnetic loading and specific electrical loading is chosen. Salient pole generator can be designed with slightly higher values of short circuit ratio, varying from 0.9 to 1.3. The most wide spread type of winding for synchronous generator is the double layer distributed winding with short pitch coil. Head of water is included within the low head range. Therefore, water wheel is chosen as the prime mover of the generator.

Acknowledgements

The author would like to express many thanks to the Prorector, Prof. Dr. Min Min Oo from Technological University (Banmaw). The author is deeply grateful to Professor Dr. Aung Ze Ya from Yangon Technological University (Yangon).The author also wishes deeply to thank Associate Professor Dr. Aye Aye from Technological University (Banmaw). Finally, the author is dedicated to her beloved parents and teachers who supported and all persons who helped directly or indirectly towards the completion of this paper.

References

[1] Tsuyoshi Higuchi: Design Analysis of a Novel Synchronous Generator, (2014)
[2] Delhi: Design of Electricsl Machines, (2000), Standard Publishers Ditributors
[3] Dr. Suad Ibrahim Shaw: Design of Synchronous Generators, (2004)
[4] Samuel Ayanrohanmu Olusegun: Design, Modelling and Optimisation of an Isolated Small Hydropower Plant, (2015)
[8] Power Paul: Low Head Micro hydroelectric Generator, (2004), Power Paul Company Limited
[9] Adam Harvey: Micro-hydro Design Manul, (1998), International Technology Publications.