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Design and Calculation of Synchronous Generator used in Micro Hydropower Project (Loi Unn Village)

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ABSTRACT

Myanmar has natural gifts of hydropower resources and most of area are a great distance far from national grid syatem. To develop throughout the country of courses, needs to fulfil the electricity requirements for cities as well as country sides or villages. Consequently, Micro-hydropower is cost effective, environmentally friendly and manufactured locally. This research has studied on the hydropower generating system and mainly emphasized on the design of synchronous generator for used in Micro hydropower project (Loi Unn village). In this paper, fixed-blade axial flow propeller turbine is suiTABLEfor this Mico hydropower project and the design data of 1-phase, 6-pole, 1000 r.p.m, 50 Hz, 3 kVA synchronous generator is mentioned. The calculated results are checked based on the design limits and these are regarded as appropriate values.

KEYWORDS: *Myanmar; Micro-hydropower; Fixed-blade axial flow propeller turbine; Run-of-river; Synchronous generator*

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I. INTRODUCTION

Hydropower has been used for centuries. It is the largest and the oldest renewable energy source of electricity generation. It can produce electricity 24 hours per day. Where water resources are available, hydropower stations are used to supply electrical energy to consumer. Hydropower plants have long lives relative to other forms of energy generation. Mico-hydropower scheme can produce power for house holding and reduces depend on fuel resources. Moreover, it is one of the most effective solutions for the production of electricity and thus preventing global warning [2].

Micro hydropower system may require water storage at noninvasive level, or may be configured as run-of-river and not require any damming [1]. Micro-hydropower system is a hydropower scheme with maximum power generation of 5kW that normally found at rural and hilly area. Common devices which can be powered by Micro-hydropower system are light bulbs, fluorescent lamps, radio, televisions, refrigerators and food processors. Hydropower plants provide inexpensive electricity and do not create air pollution. Water is plentiful, clean and will never run out [2].

II. OVERVIEW OF MICRO-HYDROPOWER PLANT

A. Power from Water

The amount of available energy depends on the amount of water flow rate, the gross head and the force of gravity. Power potential in a particular site can be calculated by using the following Equation (1) [1].

$$P = Q \times H \times g \times \eta , \qquad (1)$$

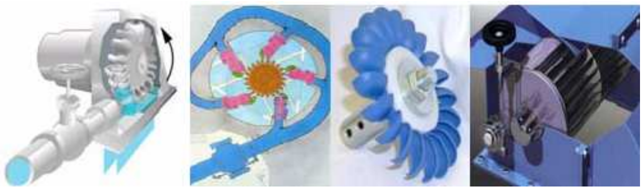
where, P = Power output (kW)
Q = Usable flow rate (m^3/s)
H = Gross head (m)
g = Gravitational constant (9.8 m/s^2)
η = Efficiency factor (0.5 to 0.7)

B. Hydraulic Turbines

Turbines can be crudely classified as high-head, medium-head, and low-head machines, as shown in TABLE1. Electricity generation usually requires a shaft speed to minimize the speed change between the turbine and the generator. Since the speed of any given type of turbine declines with head, low-head sites need turbines that are inherently faster under a given operating condition. Turbines are also divided by their principle of operation and can be either impulse or reaction turbines illustrated in Fig.1 and Fig.2 [1].

TABLE1. TURBINE TYPES BASED ON HEADS

Turbine Runner	High-Head (>50m)	Midium-Head (10-50m)	Low-Head (<10m)
Impulse	Pelton Turgo Multi-jet Pelton	Crossflow Turgo Multi-jet Pelton	Crossflow
Reaction		Francis PAT	Properller Kaplan



(a) (b) (c) (d)

Fig.1. Groups of Impulse Turbine:

A. Single-Jet Pelton
B. Multi-Jet Pelton
C. Turgo
D. Crossflow

Fig.2. Groups of reaction turbine:

A. Properl
B. Kaplan
C. Francis

Typical efficiency ranges of turbines are given in TABLE2. Turbines are chosen or are sometimes tail or made according to site conditions. Selecting the right turbine is one of the most important parts of designing a hydroelectric system, and the skills of an engineer are needed in order to choose the effective turbine for a site, taking into consideration cost, variations in head, flow, and the amount of sediment in the water and overall reliability of the turbine [11].

TABLE2. EFFICIENCY RANGE OF TURBINES

Turbine Type	Efficiency Range
Impulse turbines: Pelton Turgo Crossflow	 80-90% 80-95% 65-85%
Reaction turbines: Francis PAT Propeller Kaplan	 80-90% 60-90% 80-95% 80-90%

C. Hydroelectric Generator

Electrical power can be generated in either AC or DC. AC has the advantage of allowing the use of common household appliances and tools and is much more economical for transmitting power to consumers. Thus, AC system is considered in this study [3]. There are two main types of an AC generator which are used in hydro-electric scheme. They are:

1. Synchronous generator and
2. Induction generator
3. Criteria for selection of generators are:
4. Maximum turbine power
5. Run away speed of turbine
6. Horizontal or vertical construction
7. Whether isolated or parallel operation
8. Constant load or variable load
9. Availability of grid supply
10. Reactive power supply

Synchronous generators are standard in electrical power generation and are used in most power plants. Asynchronous generators are more commonly known as induction generators. Both of these generators are available in three-phase or single-phase systems. And, both machines may have the same stator design but different rotor design as illustrated in Fig.4 and Fig.5. The rotor is a rotating part of a machine. There are two types of the rotor; salient pole type and cylinder rotor type or non-salient pole rotor type as shown in Fig.3. System capacity, type of load and length of the transmission/ distribution net-work dictate whether a single- or threephase generator should be used [11]. Selection of the generators based on size of scheme and different between poles and speed are shown in TABLE3 and TABLE4[1].

TABLE3. SELECTION OF GENERATOR

Size of Scheme	Up to 10 kW	10 to 25 kW	More than 25 kW
Type of Generator and Phase	Induction or Synchronous, Single or threephase	Induction or Synchronous, Three-phase	Synchronous, Three-phase

TABLE4. DIFFERENT BETWEEN POLES AND SPEED

Number of poles	rpm for 50 Hz	rpm for 50 Hz
2	3000	3600
4	1500	1800
6	1000	1200
8	750	900
10	600	720
12	500	600
14	429	514
16	375	450
18	333	400
20	300	360
40	150	180

Full load load efficiencies of synchronous generators vary from 75 to 90 percent, depending on the size of the generator. Efficiency of induction generator is approximately 75 percent at full load and decreases to as low as 65 percent at part load [11]. If high portions of loads are likely to be inductive loads, such as motor and fluorescent lamps, a synchronous generator is better than an induction generator. Induction generators in standalone application mode cannot supply the high-surge power required by motor loads during start up [1].

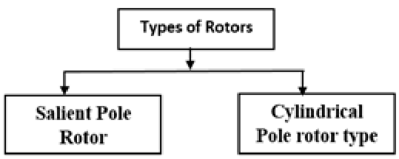
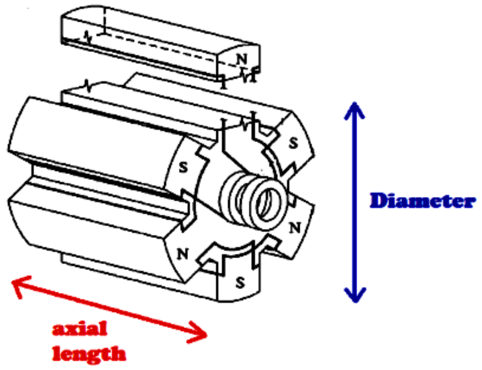
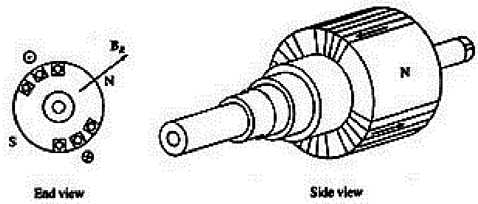


Fig.3.Types of Rotors



(a)



(b)

Fig.4. Types of Rotor Constrtuction

A. Salient pole rotor
B. Cylindrical-pole rotor (Non salient pole)

(a)

(b)

Fig.5. Different Rotor Design

A. Salient-pole rotor
B. Cylindrical-pole rotors

By using synchronous generator, there is no affection against grid when parallel running. On the other hand, big over-current will rush and voltage drop of grid will occur if induction generator is applied [5].

III. MICRO-HYDROPOWER PROJECT (LOI UNN)

The resource of the micro-hydropower is existed at Loi Unn stream which is located near Loi Unn village which is 0.8 km far from Kut Kai town in Northern Shan State, Myanmar. Loi Unn stream is shown in Fig .6.

Fig.6. Loi Unn Stream

There are about 140 houses in Loi Unn village and its population is about 1000.The location of this village is very far from the national grid system and the natural resource for micro-hydropower is existed in this area. So, the hydropower plants are constructed in Loi Unn village.

Moreover, it is already avoided the uneconomical transmission system and diesel-electric generation system in that village. Micro-hydropower plants can be installed at three possible locations, they are: waterfall, small-dam and site-channel. In this study, hydropower plants are installed at a concrete small-dam which is constructed across the Loi Unn stream as mentioned in the following Fig.7 and Fig.8.

Fig.7. Turbine -generator set (Before Inatallation)

Fig.8. Loi Unn Micro-Hydropower Project

Total number of turbine-generator sets which are installed at Loi Unn stream is seven. The capacity of each synchronous generator is 3kVA. The turbine-generator set is installed in the concrete spiral casing as shown in the following Fig .9.

Fig.9. Top View of Generator in Spiral casing

The type of each turbine is fixed-blade, axial flow, propeller type which is included in the group of reaction turbine. The 4-blade propeller runner of Loi Unn project is mentioned in the following Fig .10.

Fig .10. Propeller Runner of Loi Unn Project

The rated speed of the propeller runner is 1000 r.p.m. According to the theory of synchronous generator, the number of poles of generator is six-poles. The stator and salient pole rotor of synchronous generator of Loi Unn project is shown in Fig .11. The runner of propellers turbine and the rotor of synchronous generator can be connected with the same shaft because the speed of two machines are matched.

Fig.11. Six-Poles Synchronous Generator

The electrical power generated from seven Mico-hydropower plants are transmitted to seven houses which are located at the load-center of Loi Unn village. Voltage-drop problem is overcome by using 3kVA autotransformer at these seven houses. Then, the electrical power is sub-transmitted to other houses from these seven houses. Some specifications of Loi Unn micro-hydropower project is mentioned in the following TABLE5.

TABLE5. SPECIFICATIONS OF MICRO-HYDROPOWER PROJECT (LOI UNN VILLAGE)

Turbine type	Fixed-blade axial flow propeller
No. of turbine blade	4
Head (h)	3 m
Flow rate (q)	0.16 m^3/s
Generator drive system	Direct-coupled
Generator type	Salient pole synchronous
Generator capacity	3 kVA
Sypply system	Single-phase A.C
Rated speed	1000 r.p.m
No.of poles of generator	6
Power factor	0.8
Frequency	50 Hz
Voltage	230 V

IV. DESIGN THEORY OF SYNCHRONOUS GENERATOR

The main parts construction of the 6-pole, synchronous generator is mentioned in Fig.12. It consists of stator, rotor and losses. Design of stator has main dimension of stator frame, stator winding and depth of stator core.

Design of rotor has axial length of pole, width of pole, high of pole, air-gap length and outer diameter of the rotor. Losses consist of total losses of stator winding, total iron losses, total field copper losses, exciter losses and friction and windage losses [5].

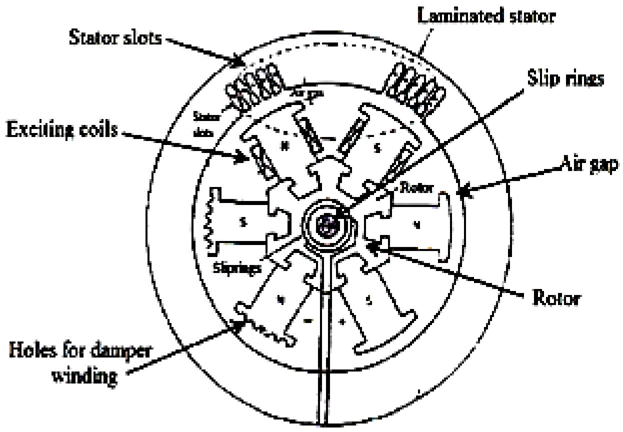


Fig.12. Main parts of 6-pole synchronous generator

A. Main Dimension of Stator Frame

Internal diameter and gross length of the stator frame are its main dimensions. The output equation is the basic tool to initiate the design of synchronous machine, which relates the output of the machine with the main dimensions of the stator [11].

Output of 1-phase synchronous machine,

$Q = K' D2Ln_s$, (2)

where, D - Internal Diameter of the Stator

L - Gross Length of Stator Core

Output coefficient of 1-phase synchronous machine,

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

where, B_{av} - Specific Magnetic Loading

q - Specific Electric Loading

K_w - Winding Factor

For rectangular poles, the ratio of axial length of the core to pole pitch varies from 0.8 to 3. A suiTABLEratio may be assumed for axial length to pole pitch depending upon the design specifications [5].

$L / \tau_P = 0.8 \text{ to } 3$ (4)

Air-gap length,

$lg = (0.012 \text{ to } 0.016) \times \text{pole pitch}$ (5)

B. Design of Stator Winding

Air-gap flux per pole,

$\varphi = B_{av}\ \tau_P\ L$ (6)

Number of stators turns per phase,

$T_{ph} = E_{ph} / (4.44\ f\ \varphi\ K_w)$ (7)

Slot pitch

$\tau_S = \pi D / \text{number of stator slots}$ (8)

Conductors per slot,
$Z_S = 2\ T_{ph}$ / number of stator slots (9)

Cross-sectional area of the conductor,
a_S = Full-load current / Current density (10)

Number of stator teeth per pole arc,
N_t = Pole arc / τ_S (11)

Width of stator tooth at air gap surface,
$b_t = \varphi / (B_t L_{ic} N_t)$, (12)

where, B_t - flux density in the stator tooth
L_{ic} - net iron length of stator core

Width of the stator slot,
$b_s = \tau_S - b_t$ (13)

Mean length of the stator winding,
$L_{mt} = 2L + 2.5\tau_P + 0.05\ kV + 0.15$ (14)

Resistance of the stator winding,
$R_s = \rho\ L_{mt}\ T_{ph} / a_S$ (15)

Copper losses of stator winding,
$P_{cus} = I_{ph}^2 \times R_{ph}$ (16)

Eddy current losses in the stator winding,
$P_{eds} = (K_{dav} - 1)\ P_{cus}$ (17)

where, K_{dav} = average loss factor

Total losses of the stator winding,
$P_{ts} = P_{cus} + P_{eds} + P_{ss}$ (18)

where, P_{ss} = stay load losses
Effective resistance of the stator winding,
Resistance drop = $I_{ph} \times R_{ph} \times K_{dav}$ (19)

Depth of stator core,
$d_c = \varphi_c / B_c \times L_{ic}$ (20)

Outer diameter of the stator core,
$D_o = D + 2h_c + 2d_c$ (21)

C. Design of Rotor

Air gap length,
$L_g = AT_g / 0.796\ B_g\ K_g\ 10^6$ (22)

Rotor diameter,
$D_r = D - 2L_g$ (23)

Width of the pole,
$b_p = A_p / L_p$ (24)

where L_p = axial length of the pole
Heigh of the pole,

$$h_F = \frac{T_f I_f}{10^4 \sqrt{d_f S_f P_f}} \quad (25)$$

Cross-sectional area of the rotor core,
$A_c = 0.5\ \varphi_p / B_c$ (26)

Depth of rotor core,
$d_c = A_c / L_c$ (27)

D. Regulation

Area of conductor,

$$V_c = \frac{0.8 \text{ exciter voltage}}{\text{no of field coil}} \quad (28)$$

Resistance of field winding,

$$R_F = \frac{\rho L_{mtf} T_f}{a_f} \quad (29)$$

Copper losses in the field winding,
$P_{cu,loss} = I_f^2 \times R_f$ (30)

Total losses in all the coil,
$P_{total,cu} = P_{cu,loss} \times$ pole (31)

Total field copper losses,
$P_{t,f} = P_{cu,loss} + P_{total,cu}$ (32)

Friction and windage losses = 1% of output (33)
Efficiency,

$$\eta = \frac{P_{out}}{P_{in}} \times 100\% \quad (34)$$

V. CALCULATED RESULTS

The calculated results of the designed generator are mentioned in the following TABLE6 to TABLE9.

TABLE6. MAIN DIMENSIONS

Specification	Symbol	Unit	Value
Full load output	Q	kVA	3
Line voltage	V	Volts	230
Number of Phase	-	-	1
Frequency	f	Hz	50
Speed	N	rpm	1000
Number of poles	p	-	6
Output coefficient	K'	-	25.282
Internal diameter of stator	D	m	0.26
Gross length of stator	L	m	0.11
Peripheral speed	v	m/s	13.6136

TABLE7. STATOR DESIGN

Specification	Symbol	Unit	Value
Flux per phase	φ	Wb	5.69×10^{-3}
Turns per phase	T_{ph}	-	190.64
Conductor per slot	Z_S	-	16
Number of slots	Z_s	-	24
Conductor c.s.a	a_s	mm^2	4.33
Size of conductor	-	mm	10 × 0.3
Width of slot	b_s	m	0.016
Width of stator tooth	b_t	m	0.018
Teeth per pole arc	N_t	-	2.8
Depth of slot	h_s	m	0.0116
Winding Type	-	-	Double layer, Lap
Resistance of winding	R_{ph}	Ω	0.277
Effective resistance	-	p.u	0.016
Effective reactance	-	p.u	0.04

TABLE8. ROTOR DESING

Specification	Symbol	Unit	Value
Rotor diagram	D_r	m	0.26
Air-gap length	L_g	m	0.0015
Axial length of pole	L_p	m	0.1
Width of pole	b_p	m	0.049
Height of pole	h_p	m	0.0943
Short circuit ratio	SCR	-	0.9
Total no load ampere turns	AT	AT	881
Full load field ampere turns	AT_{fl}	AT	1120
Sectional area of field conductor	a_f	mm^2	0.266
Field current	I_f	A	0.798
Field turns per coil	T_f	-	1404
Resistance of field winding	R_f	Ω	18

TABLE9. LOSSES AND EFFICIENCY

Specification	Symbol	Unit	Value
Exciter loss	-	W	8
Copper losses in stator winding	P_{cus}	W	46.77
Eddy current losses in conductors	P_{eds}	W	0.9354×10^{-3}
Stray load losses	P_s	W	7.02
Iron losses	-	W	106
Rotor copper losses	-	W	71
Friction & windage losses	-	W	24
Total full load losses	-	W	254
Efficiency	η	%	91

VI. CONCLUSION

Today, rural electrification plays an important role in rural development. Myanmar has high potential of hydropower resources. According to the following reasons, rural electrification recognized as key to rural development. Therefore, micro-hydropower system is installed at Loi Unn stream in order to fulfil the requirements of electrical power of villagers.

This paper mentions the design data of Loi Unn Micro-hydropower project. 1-phase, 6 pole, 1000 r.p.m, 50 Hz, 3 kVA synchronous generator. Choice of the suiTABLE values of specific magnetic loading and specific electric loading are important. Since the designed generator is salient pole machine, the internal diameter of the stator is larger than the axial length of the stator core. The length of air gap in synchronous machines is also an important design parameter.

Moreover, the number of stator slots should be properly chosen, as if affects the cost and the performance of synchronous machine. The flux density in the stator tooth at the gap surface should not exceed 1.8 Tesla for alternators. Otherwise, the tooth losses will be excessive. Furthermore, the choice of the proper value of the current density is also important. The high current density can be chosen for economical consideration. But, the resistance of the stator winding increases, resulting in higher copper loses in the stator winding, thus reducing the efficiency of the machine. Usual values for the current density in the stator winding can be assumed varying from 3 to 5 A/mm^2.

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