



Faculty of Mechanical Engineering

**STREAMFLOW PREDICTIVE MODEL USING RELIABLE
DISTRIBUTION METHOD TO ENHANCE SMALL HYDROPOWER
SYSTEM PERFORMANCE**

Mashitah binti Razi

Master of Science in Mechanical Engineering

2019

**STREAMFLOW PREDICTIVE MODEL USING RELIABLE DISTRIBUTION
METHOD TO ENHANCE SMALL HYDROPOWER SYSTEM PERFORMANCE**

MASHITAH BINTI RAZI

**A thesis submitted
in fulfillment of the requirements for the degree of Master of Science
in Mechanical Engineering**

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2019

DECLARATION

I declare that this thesis entitled “Streamflow Predictive Model using Reliable Distribution Method to Enhance Small Hydropower System Performance” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Name : Mashitah binti Razi

Date :

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Mechanical Engineering.

Signature :.....

Supervisor Name : Dr. Mohd Asri bin Yusuff

Date :.....

DEDICATION

This thesis is dedicated to my beloved mother and father, families, my supervisor and friends for support me with affections love and their companionship for success in my life.

Thank you Almighty.

ABSTRACT

Nowadays, increasing electricity demand and rural electrification upgrading make renewable energy becomes more popular. Some examples of renewable energy applied in Malaysia are solar, biomass and hydropower. For hydropower, it can be classified into several types and schemes. For types, it depends on the power generated by the system, while schemes, it related to its operating mechanism. In Malaysia, generally, the small-hydropower system tied with 21 years Feed-In-Tariff (FiT) policy offered by Sustainable Energy Development Authority (SEDA) and for rural electrification, small-hydropower system based on run-of-river schemes is much better in terms of total electricity generated, sustainability, reliability and environmental friendly. Therefore, to make sure the sustainability and reliability of the system, understanding the character of the streamflow is a must. In this research, average daily streamflow data from January to December 2016 from Sungai Perting, Bentong, Pahang small hydropower system were used as data analysis. Statistical analysis in boxplot using R-Software provides first statistical order characteristic of the streamflow in terms of maximum, minimum, mean, median, first quartile and third quartile of the data. While, for distribution analysis, Probability Distribution Function (PDF) model of Gumbel, Weibull 2-parameter, Lognormal and GEV are used to represent the data. Most researchers used Lognormal, Gumbel and Weibull and less study on GEV distribution. Therefore, the GEV is introduced to increase the reliable method applied. Best fit distribution is finding by the help of MATLAB Software based on MLE value. To obtain the performance of the system, the study will focus on the turbine power generated related to the streamflow. From the results, 8 out of 12 months of the streamflow distribution exhibit GEV function and have maximum MLE values compared to the others. As for the performance of the system, streamflow is directly proportional to the power generated by the turbine.

ABSTRAK

Dewasa ini, terdapat peningkatan dalam penggunaan elektrik termasuk menaik taraf kehidupan masyarakat luar bandar menjadikan sumber tenaga semulajadi semakin popular. Antara contoh sumber tenaga asli yang terdapat di Malaysia adalah tenaga suria, bio jisim dan hidro. Bagi sumber tenaga hidro, ia boleh diklasifikasikan kepada beberapa jenis mengikut jumlah kuasa elektrik yang dihasilkan dan juga cara sistem itu berfungsi. Di Malaysia, aplikasi penggunaan tenaga hidro terikat dibawah bidang kuasa pihak berkuasa Pembangunan Tenaga Lestari Malaysia (SEDA) di bawah program Tariff Galakan selama 21 tahun perjanjian konsesi. Bagi sistem elektrik luar bandar, sistem tenaga hidro kecil yang berasaskan skim aliran sungai mempunyai kelebihan yang baik dari segi jumlah tenaga elektrik yang dihasilkan, kemampanan, kebolehpercayaan dan mesra alam sekitar. Oleh itu, untuk memastikan kelestarian dan kebolehpercayaan sistem tersebut, kefahaman tentang sifat aliran sungai amatlah penting. Data aliran sungai yang dikaji adalah purata harian dari Januari sehingga Disember 2016 di Sungai Pertiing, Bentong, Pahang. Analisis statistik melalui aplikasi boxplot yang terdapat didalam perisian-R diguna pakai untuk memberikan ciri-ciri kadar aliran air dari segi, nilai aliran yang paling tinggi, rendah, purata, pertengahan, kuartil pertama dan kuartil ketiga. Bagi analisis taburan, perisian MATLAB pula digunakan bagi mendapatkan fungsi taburan kebarangkalian yang paling sesuai berdasarkan nilai MLE yang paling maksima bagi mewakili fungsi kebarangkalian data aliran sungai dari bulan Januari-Disember 2016. Kebanyakan penyelidik lebih memfokuskan fungsi taburan Lognormal, Gumbel, dan juga Weibull dua parameter berbanding taburan GEV, oleh itu, fungsi GEV diperkenalkan bagi memberikan kaedah kajian yang lebih mampan. Hasil kajian mendapati, 8 dari 12 bulan data aliran kajian yang dikaji menjurus ke arah fungsi taburan kebarangkalian GEV dengan nilai MLE yang paling maksima berbanding fungsi kebarangkalian yang lain dan aliran sungai berkadar terus dengan tenaga yang dihasilkan oleh turbin yang diguna pakai iaitu Turgo Turbin.

ACKNOWLEDGEMENTS

First and foremost, Alhamdulillah. Deepest and sincere acknowledgement to my, supervisor Senior Lecturer Dr. Mohd Asri bin Yusuff from the Faculty of Mechanical Engineering Universiti Teknikal Malaysia Melaka (UTeM) for essential supervision, support and encouragement towards the completion of this thesis. Special thanks to Kementerian Pendidikan Malaysia, FRGS/2/2014/TK06/FKM/03/F00235 grant funding for the financial support throughout this project. And also many thanks to UniKL (MFI) for the technical support and assist. Special thanks to my beloved families and all my peers for their endless moral support in completing this study.

TABLE OF CONTENTS

	PAGE
DECLARATION	
APPROVAL	
DEDICATION	
ABSTRACT	i
ABSTRAK	ii
ACKNOWLEDGEMENTS	iii
TABLE OF CONTENTS	iv
LIST OF TABLES	vi
LIST OF FIGURES	viii
LIST OF APPENDICES	xi
LIST OF ABBREVIATIONS AND SYMBOLS	xii
LIST OF PUBLICATIONS	xiv
CHAPTER	
1. INTRODUCTION	1
1.1 Background	1
1.2 Problem statement	5
1.3 Objectives	8
1.4 Scope of research	8
2. LITERATURE REVIEW	10
2.1 Introduction	10
2.2 Renewable energy	10
2.2.1 Application of renewable energy	13
2.2.2 Hydropower	16
2.2.3 Small hydropower system	19
2.3 Turgo Turbine	21
2.4 Statistical analysis	28
2.5 PDF model analysis	30
2.5.1 Selection of distribution	32
2.6 Monte Carlo Simulation	36
2.7 Summary	38
3. METHODOLOGY	40
3.1 Introduction	40
3.2 Research area	43
3.3 Equipment used	46
3.3.1 TIENET 310 Ultrasonic Level Sensor	46
3.3.2 Signature Flow Meter	47
3.4 Statistical analysis	49
3.4.1 Boxplot	50
3.4.2 Descriptive analysis	52
3.5 Selection of the distribution	54
3.6 Best fit distribution and parameter estimation	56
3.7 Monte Carlo Simulation	57
3.8 Validation of the research study	57
3.8.1 Validation for Monte Carlo Simulation	57

3.8.2	Validation for selection distribution applied	58
3.9	Turgo Turbine power performances	59
3.10	Summary	61
4.	RESULT AND DISCUSSION	62
4.1	Introduction	62
4.2	Analysis of average daily streamflow for 2016 at Sungai Perting, Bentong, Pahang	63
4.2.1	Boxplot	63
4.2.2	Descriptive analysis	68
4.2.3	PDF analysis	73
4.2.4	Summary for average daily streamflow 2016 in Sungai Perting, Bentong, Pahang	90
4.3	Monte Carlo Simulation	94
4.3.1	Boxplot	95
4.3.2	Descriptive analysis	96
4.3.3	PDF analysis	97
4.4	Validation	101
4.4.1	Validation of selection distribution applied	101
4.4.2	Validation of Monte Carlo Simulation	112
4.5	Power performance of Turgo Turbine	113
4.6	Summary	115
5.	CONCLUSION AND RECOMMENDATIONS	117
5.1	Conclusion	117
5.2	Contribution to knowledge	119
5.3	Recommendations	120
	REFERENCES	121
	APPENDICES	141

LIST OF TABLES

TABLE	TITLE	PAGE
1.1	Categories and range of capacity applied in small hydropower system (Singh, 2009)	2
1.2	Annual power generation by small hydropower system in Malaysia (seda.gov.my 2017)	4
2.1	The contribution of primary sources for electricity/power generation (ktoe) (Energy Commission, 2017)	16
2.2	Classification of hydropower (Singh, 2009)	19
2.3	Classification of the head (Singh, 2009)	20
2.4	Types of turbines (Singh, 2009)	21
3.1	Details description of research area (Hamdan, 2008)	45
3.2	Component of Turgo Turbine in Sungai Perting, Bentong, Pahang small hydropower system	60
4.1	Descriptive streamflow data from January-December 2016 of Sungai Perting, Bentong, Pahang	72
4.2	Log-likelihood values based on its distribution for January-April 2016	77
4.3	Parameters affected the distribution for January-April 2016	79
4.4	Log-likelihood values based on its distribution for May-August	80

	2016	
4.5	Parameters affected the distribution for May-August 2016	83
4.6	Log-likelihood values for September-December 2016	87
4.7	Parameters affected the distribution for September-December 2016	89
4.8	Summary of streamflow from January - June 2016 of Sungai Perting, Bentong, Pahang	90
4.9	Summary of streamflow from July-December 2016 of Sungai Perting, Bentong, Pahang	93
4.10	Descriptive statistic in (a) January-June and (b) July-December	96
4.11	Parameters estimation based on its distribution for (a) January – June and (b) July – December of the predictive data	100
4.12	Descriptive statistic of Sungai Bentong from January – June 2016	104
4.13	Log-likelihood values of Sungai Bentong based on its distribution for January – June 2016	105
4.14	Descriptive statistic of Sungai Bentong from July – December 2016	109
4.15	Log-likelihood values of Sungai Bentong based on its distribution for July – December 2016	110
4.16	The percentage differences for validation of Monte Carlo Simulation	112

LIST OF FIGURES

FIGURE	TITLE	PAGE
2.1	Malaysia's electricity generation capacity and peak demand (Energy Commission, 2017)	14
2.2	Application range for impulse and reaction turbine (Gilbert Gilkes and Gordon Ltd., 2016)	22
2.3	Power (kW) and energy (MWh) production analysis of Francis and Turgo Turbine (Gilbert Gilkes and Gordon Ltd., 2016)	23
2.4	Plan view of typical configuration of twin jet Turgo Turbine (Gilbert Gilkes and Gordon Ltd., 2016)	24
2.5	Typical design of Turgo runner, inlet side (left) and outlet side (right) (Gilbert Gilkes and Gordon Ltd., 2016)	24
2.6	Description of boxplot (Montgomery et. al., 1998)	30
3.1	Flow chart of research methodology	41
3.2	Schematic diagram of run-of-river small hydropower operation	44
3.3	Location of water intake of research study at Sungai Perting, Bentong, Pahang	44
3.4	TIENET 310 Ultrasonic Level Sensor	47
3.5	Signature Flow Meter	48
3.6	Schematic diagram of connectivity between TIENET 310	49

Ultrasonic Level Sensor and Signature Flow Meter

3.7	Boxplot diagram (towardsdatascience.com accessed on 25 March 2019)	51
3.8	Shape of the boxplot diagram	51
3.9	Flow chart of the validation of suitable distribution applied	59
4.1	Boxplot of streamflow in 2016 (a) January-April, (b) May-August and (c) September-December	64
4.2	Histogram of streamflow 2016 (a) January-March, (b) April-June, (c) July-September and (d) October-December	67
4.3	PDF of average daily streamflow (m^3/s) for January-April 2016	73
4.4	PDF of average daily streamflow (m^3/s) for May-August 2016	80
4.5	PDF of average daily streamflow (m^3/s) for September-December 2016	84
4.6	PDF model of streamflow from January-June 2016 of Sungai Perting, Bentong, Pahang	92
4.7	PDF model of streamflow from July – December 2016 of Sungai Perting, Bentong, Pahang	94
4.8	Boxplot of predictive data for (a) January-June and (b) July-December	95
4.9	PDF model for predictive data from January-July	99
4.10	PDF model for predictive data from July-December	99
4.11	Boxplot of Sungai Bentong streamflow from January – June 2016	103
4.12	PDF Sungai Bentong, Pahang (i) and PDF Sungai Perting,	107

	Pahang (ii) February–June 2016	
4.13	Boxplot July-December of 2016 for Sungai Bentong	108
4.14	PDF Sungai Bentong, Pahang (i) and PDF Sungai Perting, Pahang (ii) July – December 2016	111
4.15	Percentage differences (%) of mean standard deviation for average daily streamflow October-December 2016 and 2018	113
4.16	Scatter graph of power performance of turbine (kW) and streamflow (m ³ /s)	114
5.1	Predictive model of 21 years simulated data for January – December	118

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Streamflow (m ³ /s) of Sungai Perting, Bentong, Pahang for 2016	141
B	Streamflow data of Sungai Bentong Pahang (Station: SF3519426) for 2016	143

LIST OF ABBREVIATIONS AND SYMBOLS

ASCII	-	American Standard Code for Information Interchange
FDC	-	Flow duration curve
FiT	-	Feed-in-Tariff
$f(x)$	-	PDF function for Lognormal/Gumbel/Weibull/GEV
GDP	-	Gross Domestic Product
GEV	-	Generalize Extreme Values
GRACE	-	Gravity Recovery and Climate Experiment
IQR	-	Inter quartile range
ktoe	-	Thousands tonnes of oil equivalent
kW	-	Kilo Watt
kV	-	Kilo Volt
km	-	Kilometre
km ²	-	Kilometre per square
kWh	-	Kilo Watt hour
kg/m ³	-	Kilogram per meter cubic
MLE	-	Maximum Likelihood Estimation
MW	-	Mega Watt
MWh	-	Mega Watt hour
m	-	Metre
m ³ /s	-	Meter cube per second
m/s ²	-	Meter per second square
mm	-	Millimeter
mm/yr	-	Millimeter per year
PDF	-	Probability distribution function
Q1	-	First quartile
Q3	-	Third quartile

REPPA	-	Renewable Energy Power Purchase Agreement
ROI	-	Return of Investment
SCADA	-	Supervisor Control and Data Acquisition
SCORE	-	Special Commission on Renewable Energy
SEDA	-	Sustainable Energy Development Authority
SOFC	-	Solid Oxide Fuel Cell
SREP	-	Small and Renewable Energy Program
S	-	Standard deviation
TNB	-	Tenaga Nasional Berhad
TWh	-	Tera Watt hour
Whr/m ²	-	Watt hour per square meter
\bar{x}	-	Arithmetic mean
x_{md}	-	Median
%	-	Percentage
ξ	-	Shape parameter for GEV
β	-	Shape parameter for Weibull 2-parameter
η	-	Scale parameter for Weibull 2-parameter
μ	-	Mean for Lognormal and Location parameter for Gumbel and GEV
σ	-	Standard deviation for Lognormal and Scale parameter for Gumbel and GEV

LIST OF PUBLICATIONS

Razi, M., Yusuff, M. A., Zakaria, K. A. and Putra, A., 2018. Stream Flow Analysis for Small Hydropower System based on Run-of-River Schemes. *ARPN Journal of Engineering and Applied Sciences*, 13(3), pp. 1115-1118.

Razi, M., Yusuff, M. A., Tee, B. T. and Zakaria, K. A., 2017. A Significance Approach Between Patterns of Water River Flow Rate to the Exploitation of Power Generated in Small Hydropower System.. *International Review of Mechanical Engineering (IREME)*, 11(11), pp. 831-835.

Razi, M., Yusuff, M. A., Tee, B. T. and Zakaria, K. A., 2017. Prediction of Available Power Being Generate in Small Hydropower System at Sungai Perting Bentong Pahang. Putrajaya, Malaysia, *MATEC Web Conference*.

CHAPTER 1

INTRODUCTION

1.1 Background

This chapter discussed on the background of the studies, problem statements, objectives aimed in this research and the scope. Renewable energy resources become one of the important key of global energy, environmental and sustainability. It also includes reduction of Greenhouse Gas emissions and safe energy provision in a hastily manner. There are several types of renewable energy applied such as solar, biomass, hydropower and geothermal (Kosa et. al., 2011). In Malaysia, there are three main most popular types of renewable energy resources which are solar, hydro and biomass (Shamsuddin, 2012). The application of biomass is due to abundant of the palm oil plantation industry in Malaysia with quantity of 38900tonnes/year and the maximum potential energy is 320 MW.

The use of solar energy is due to location of Malaysia at the Equatorial region with average solar radiation between 4000-5000 Whr/m² for 4-8 hours per day. Majority of it is in form of solar PV and individual used (Mekhilef, 2010). For hydro energy resources in Malaysia, potential of electrification came from the landscape of hilly topography and abundant numbers of flowing streams to foot hills with 150 river systems in Peninsular and 50 rivers in Sabah and Sarawak. As for then rainfall, the estimated average annualis2400 mm compared to world's average annual which is 750 mm (Raman et. al., 2009). Based on the facts, hydro energy resources can be considered as one of the most available renewable energy resources for rural electrification in Malaysia.

Basic principle of hydropower generation is, when the water can be conveyed into a pipe or flow from higher to a lower level, then it will produce water pressure that can performed work of the mechanical component. Then, the movement of the mechanical components will turn the conversion of the water energy flow into mechanical energy and it can be used to drive an electricity generator. This generation of energy needed suitable location as it required an adequate amount of water flow and effective head to maximize the utilization of the hydropower system itself (Basar et. al., 2011). Hydropower energy can be classified as one of the oldest energy forms that are economical, reliable, predictable and clean in generating electricity.

It is also known to be one of the best commercially viable on large scale and small scale application in Malaysia. As a long term application, it can store large amount of electricity at lower cost and can be adjusted accordingly to the customer demands (Ong et. al., 2011). Hydropower can be divided into two segments which are large scale and small scale technology. For large scale hydropower the capacity of electricity can be up to 100 MW and for small scale technology with range of capacity 1–15 MW it can be divided into more categories. In hydropower system, there are also several schemes applied which are run-off-river, dam and integrated water canal or water supply pipe. Table 1.1 shows the categories of the small hydropower scale system that can be applied.

Table 1.1: Categories and range of capacity applied in small hydropower system (Singh, 2009)

Categories of small hydropower scale system	Capacity of the system
Mini	100 kW-1 MW
Micro	5 kW-100kW
Pico	Watts up to 5 kW

For small hydropower technology, it can be one of the best alternatives solutions in providing electricity for rural communities and applications hence, improving the quality of life. Most of the small hydropower technology applied worldwide is based on run-of-river schemes where it can be standalone system in isolated areas or grid connected to local grids or national grid used. The run-of-river system is free CO₂ emissions and one of the oldest electricity generations. Total potential capacity in Malaysia is around 500 MW for the long run projects especially in run-of-river schemes. In 2013, total capacity installed was 26063 MW as 21628 MW in Peninsular Malaysia, 1303 MW in Sabah and 3132 MW in Sarawak. Besides, the hydroelectric production used was around 14.73% and the small hydropower contributed 0.17% (Abdullah et. al., 2016).

Small and Renewable Energy Program (SREP) was first launched in May 2001, with the coordinating and oversight Special Commission on Renewable Energy (SCORE). This program is to increase the development of renewable energy projects under SREP which allows renewable projects up to 10 MW to sell their output such as solar, hydro, biomass, biogas, municipal waste and wind at specific fixed premium price and duration to the utility, under 21-year license agreements Feed-in-Tariff (FiT).

To increase the utilization of the renewable energy resources towards national electricity supply and sustainable socioeconomic development, government of Malaysia has established the National Renewable Energy Policy and Action Plan on 2009 while Renewable Energy Act 2011 is more focused on the establishment and implementation of a special tariff system to catalyze the generation of renewable energy (Nasab, 2012). The duration of FiT is based on the characteristics of the renewable resources and technologies. For biomass and biogas resources are 16 years while 21 years for small hydropower and solar photovoltaic technologies (SEDA, 2019). Table 1.2 shows the annual power generation (MWh) of small hydropower system generated under FiT system in Malaysia

from 2012 until 2017.

Table 1.2: Annual power generation by small hydropower system in Malaysia
(seda.gov.my 2017)

Year	Annual power generation (MWh)
2017	58715.60
2016	47798.28
2015	55406.38
2014	64549.65
2013	79081.75
2012	25629.78

The run-of-river small hydropower plants have several key advantages over conventional dam storage application in terms of flexibility, suited for small head and have smaller social economics impact which are better for remote area application as it give better way for providing the electricity for the rural. Conventional method of the hydro generation relies on large area of dam which influences the change of the environment landscape as it permanently altered the downstream flow regime compared to run-or-river schemes. On the other hand, the run-of-river does not significantly induced in permanent alteration to environment and require low weir (Ramos et. al., 2000). Besides, the volume of the water flow diverted to the weir will be released back to the river of the intake and give less impact to the regulation of the river flow ecosystem. Thus, this scheme is considered as better technology for rural application and acceptable for social and environmental application such as the landscape of the flora and fauna of the ecosystem.

Streamflow is the volume of water flow passes through a specific point on a given period. Understanding the measurement of the streamflow analysis helps in monitoring the flood or even manages the water quality of aquatic habitat, pollution concentration and land erosion. Besides, it also important for a stream ecosystem and responsible for the

physical characteristic of the river small hydropower system itself. Enough water river flow rate or streamflow and sufficient head are needed as it is the major key component in small hydropower installation in order to produce enough amount energy to the site to be utilized. As the head of the small hydropower systems are practically constant, the streamflow are crucial elements and the available flow is highly variable. Besides, the power generation of the system during its lifetime mainly depends and controlled by the availability of the streamflow of the system itself (Basso and Botter, 2012).

The streamflow analysis is also important as the performance of the hydro-turbine such as power produced by the turbine, rotational speed of the rotor (rpm), wear and capitations of the turbine blade are mainly depends on it (Acakpovi et. al., 2014). Besides, in the fields of hydrology application, feasibility and availability studies of the streamflow are necessary as it can be used in determine the efficiency and productivity of the projects itself. Streamflow observed at the intake of the river cross section system are strongly fluctuating in time at multiple timescales showing the complexity of the hydro climatic processes and volume of streamflow also affected by the climate change of the region.

1.2 Problem statement

In Malaysia, small hydropower system based on run-of-river schemes of sizes 1 MW to 10 MW is rarely being applied for community's purposes. Yet it can be one of the best alternative renewable energy in generating electricity especially in remote area application to fulfill the consumer demand. The natural topography of hilly running almost passes through the entire length of the country and abundant numbers of streams flowing to foothills increased the potential of application the small hydropower system (Hoskin et. al., 2013). To access the suitability of a potential site for a hydropower or small hydropower, feasibility study and statistical analysis in term of hydrology of the sites needs to be