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OPTIMIZATION OF HYDROPOWER RESERVOIR SYSTEM USING GENETIC ALGORITHM FOR VARIOUS CLIMATIC SCENARIOS

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OPTIMIZATION OF HYDROPOWER RESERVOIR SYSTEM USING
GENETIC ALGORITHM FOR VARIOUS CLIMATIC SCENARIOS

By

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Energy is an essential input for social and economic development. Due to the
generalization of industrial and domestic activities, the energy demand has
considerably increased. This causes a rapid growing in the level of greenhouse
gas emissions and consequently increment in fuel prices. This principle was
the driving force behind attempts to use clean and renewable energy sources
such as hydropower. There are many reservoir systems around the world that
have been constructed for hydropower generation. Also, hydropower provides
a cheap source of electricity with less carbon emission. Although the renewable
energy such as hydropower has obvious advantages, many of hydropower
reservoir system are not operated efficiently and still being operated based on
experience, rules of thumb or static rules appointed at the time of construction.
It is noticeable that even small improvement in the operation rules can increase
efficiency of a hydropower system. Accordingly, different operation policies
were constructed and evaluated in this research. Generally, this research is
divided into two main stages. The main scope of stage I is to maximize the
power generation output by using the historical data (2003-2012). Accordingly,
different forms of release policies, namely One Point Hedging Policy (1PHP),
Two Point Hedging Policy (2PHP), Three Point Hedging Policy (3PHP),
Discrete Hedging Policy (DHP), Standard Hedging Policy for Hydropower
Generation (SHPHP), Binary Standard Operating Policy for Hydropower
Generation (BSOPHP), and Standard Operating Policy for Hydropower
Generation (SOPHP) were formulated and constructed using Matlab
simulation. The developed models have been applied to the Cameron Highland
and Batang Padang Hydro Scheme (CHBPHS) in Cameron Highland,
Malaysia. CHBPHS is a cascade hydropower reservoir systems, which
comprise of two reservoirs (Ringlet and Jor) and two power stations. In order
to increase the system efficiency and maximize the power generation,
constructed operation models were optimized. To determine the optimum
solution in each policy, real coded genetic algorithm is used as an optimization
technique. Thus, to enhance the functional efficiency in hydropower production,
maximization of the total power generation over the operational periods is
chosen as an objective function, while physical and operational limitations were
satisfied. The results declared that by using the optimized hedging policies, the output of power generation could increase around 13% in the studied reservoir system compared to present operating policy (TNB operation). This considerable increase in power production will contribute in economic development. Moreover, the discrepancies of monthly mean power generation output between highest and lowest months by using hedging policies are around 10% in Ringlet reservoir and 26% in Jor reservoir, while this variation in power productions by TNB operation rules are about 30% and 49% respectively. Since hedging policies are usually applied to distribute the water supply, the power-supply also scatter in the simulation period. This is attributed to the effect of water distribution on power output. It can be concluded that these policies increase the stability of the system. The main scope of stage II is the prediction of future power generation by using generated weather data. Accordingly, the first aspect to point out is the generation of future climate parameters. Long Ashton Research Station-Weather Generator (LARS-WG) model is used firstly which was calibrated and validated using daily observed sunshine hours, rainfall, minimum and maximum temperature data. Afterwards, the minimum and maximum values of temperature and rainfall historical record were synthesized by the scenario file in order to predict the future climate parameters (Rainfall, minimum and maximum temperature) under possible scenarios. All scenarios reveal that climate change increases temperature around 0.3-0.7°C at the location of the reservoir system. The increase in temperature could influence time and magnitude of rainfall by shifting dry and wet seasons. Moreover, the output results indicate a decrease in monthly rainfall. The output of LARS-WG model is used as an input of Artificial Neural Network (ANN). An ANN was subsequently applied as a rainfall-runoff modelling to predict the future stream flow feeding the reservoir systems. To explain more, ANN modelling comprised of two steps. The first step, ANN was calibrated and validated by using daily observed evapotranspiration, rainfall, and stream flow (2003-2012). In order to estimate daily evapotranspiration, daily observed Min and Max temperature was used in the estimation based on Hargreaves-Samani equation. By using the daily observed data, ANN can map the relationship between rainfall-runoff. The results indicate that the ANN model has good ability to capture the non-linearity of input/output in both training and test sets. In the second step, the future rainfall (output of LARS-WG) and future evapotranspiration (convert future minimum and maximum temperature generated by LARS-WG into future evapotranspiration by Hargreaves-Samani formula) are exported to ANN to predict the future stream flow under possible scenarios. After generating the future climate parameters, the predicted stream flow by ANN and estimated future evaporation (convert future minimum and maximum temperature generated by LARS-WG into future evaporation by Penman formula) are exported to the constructed models to predict the future power generation output. The results declare that the future output of power generation will decrease under all possible climate scenario in both reservoir. According to the given results, the application of 3PHP for Ringlet reservoir and SHPHP policy for Jor reservoir, will give the highest amount of power that could be produced in the future and can be used to mitigate the negative effects of climate change.
Keywords: Optimization, Hydropower reservoir operation, Hedging policies, Genetic algorithm, Climate change, LARS-WG, Rainfall-Runoff modelling, Artificial neural networks.
Abstract tesis yang dikemukakan kepada Senate Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENGOPTIMUMAN SISTEM TAKUNGAN HIDROKUASA MENGGUNAKAN GENETIK ALGORITMA UNTUK PELBAGAI SENARIO CUACA

Oleh

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Tenaga merupakan sumber terpenting bagi pembangunan sosial dan ekonomi. Disebabkan generalisai aktiviti industri dan domestik, permintaan sumber tenaga telah naik secara mendadak. Ini menyebabkan pertumbuhan pantas pada tahap penghasilan gas rumah hijau dan natijahnya harga minyak terus meningkat. Isu ini merupakan daya yang memacu disebalik banyak percubaan penggunaan sumber tenaga bersih dan boleh diperbaharui, seperti hidrokuasa. Terdapat banyak sistem takungan di dunia ini telah dibina untuk penghasilan hidrokuasa. Hidrokuasa menyediakan sumber elektrik yang murah dengan penghasilan karbon yang kecil. Walaupun penggunaan tenaga diperbaharui seperti hidrokuasa mempunyai kelebihan yang jelas dan nyata, kebanyakan operasi sistem takungan hidrokuasa tidak dijalankan secara berkesan dan masih dijalankan berasaskan pengalaman, undang-undang lazim atau undang-undang statik yang ditentukan semasa pembinaan. Boleh diperhatikan, penambahbaikan dalam undang-undang operasi walaupun kecil boleh meningkatkan keberkesanan sistem hidrokuasa. Oleh itu pelbagai polisi operasi telah dibangunkan dan dinilai dalam kajian ini. Secara umumnya, kajian ini dibahagi kepada dua peringkat. Peringkat pertama ialah untuk memaksimumkan hasil penjanaan kuasa dengan menggunakan data sejarah (2003-2012). Oleh itu, pelbagai bentuk polisi seperti Polisi Satu Titik Catuan (1PHP), Polisi Dua Titik Catuan (2PHP), Polisi Tiga Titik Catuan (3PHP), Polisi Catuan Terputus (DHP), Polisi Catuan Piawai untuk Penjanaan Hidrokuasa (SHPHP), Polisi Operasi Binari Piawai untuk Penjanaan Hidrokuasa (BSOPHP), dan Polisi Operasi Piawai untuk Penjanaan Hidrokuasa (SOPHP) telah diformulasi dan dibangunkan menggunakan simulasi Matlab. Model yang dibangunkan telah digunakan ke atas Skim hidrokuasa Cameron Highland dan Batang Padang (CHBPSh) di Cameron Highland, Malaysia. CHBPSh merupakan sistem takungan hidrokuasa lata, di mana terdapat dua takungan (Ringlet dan Jor) dan dua stesyen janakuasa. Untuk meningkatkan keberkesanan sistem dan memaksimumkan penjanaan kuasa, model operasi yang dibina dioptimumkan. Untuk menentukan penyelesaian optimum setiap polisi, algoritma genetik terkod sebenar digunakan sebagai teknik
masa hadapan yang dihasilkan oleh LARS-WG kepada penyejatan masa
hadapan menggunakan formula Penman) diekspot ke model yang dibina untuk
meramal penghasilan kuasa di masa hadapan. Keputusan menunjukkan
penghasilan kuasa di kedua-kedua takungan di masa hadapan akan
berkurangan di bawah semua kemungkinan senario cuaca. Merujuk kepada
keputusan yang diberi, penggunaan 3PHP untuk takungan Ringlet dan polisi
SHPHP untuk takungan Jor, boleh memberikan jumlah kuasa yang tertinggi
yang boleh dihasilkan di masa hadapan dan boleh digunakan untuk
mengurangkan kesan negatif dalam perubahan cuaca.

**Kata Kunci:** Pengoptimuman, Operasi takungan hidrokuasa, Polisi catuan,
Algoritma genetik, Perubahan cuaca, LARS-WG, Pemodelan hujan-air larian,
Rangkaian neural buatan.
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I certify that a Thesis Examination Committee has met on 9/10/2015 to conduct the final examination of Aida Tayebiyan on her thesis entitled "Optimization of Hydropower Reservoir System Using Genetic Algorithm for Various Climatic Scenarios" in accordance with the Universiti Putra Malaysia. The committee recommends that the student be awarded the Doctor of Philosophy.

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TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>ABSTRACT</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRAK</td>
<td>iv</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>vii</td>
</tr>
<tr>
<td>APPROVAL</td>
<td>x</td>
</tr>
<tr>
<td>DECLARATION</td>
<td>xi</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>xv</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>xviii</td>
</tr>
<tr>
<td>LIST OF ABBREVIATIONS</td>
<td>xx</td>
</tr>
<tr>
<td>LIST OF NOTATIONS</td>
<td>xxiii</td>
</tr>
</tbody>
</table>

CHAPTER

1 INTRODUCTION 1

1.1 Background 1

1.2 Problem statement 1

1.3 Objectives of study 3

1.4 Scope and limitation of the study 4

1.5 Significance of study 5

1.6 Thesis organization 6

2 LITERATURE REVIEW 8

2.1 General 8

2.2 Operational strategies for reservoir systems operation 9

2.3 Application of optimization techniques in reservoir system operation 12

2.4 Downscaling techniques of global climate data 16

2.5 Rainfall-Runoff modelling 19

2.6 Summary of literature review 20

2.6.1 Summary of operational policies 20

2.6.2 Summary of optimization techniques 21

2.6.3 Summary of weather generator 22

2.6.4 Summary of rainfall-runoff modelling 24

3 METHODOLOGY 26

3.1 Overall stages of present research 26

3.2 Data Collection 27

3.2.1 Case study; Cameron Highland and Batang Padang Hydro Scheme 31

3.2.2 Description of Cameron Highland Hydro Scheme (CHHS) 33

3.2.3 Description of Batang Padang Hydro Scheme (BPHS) 36

3.3 Construction and optimization of reservoir system operation by using historical data 37
3.3.1 Water release based on the one-point hedging policy (1PHP)
3.3.2 Water release based on the two-point hedging policy (2PHP)
3.3.3 Water release based on the three-point hedging policy (3PHP)
3.3.4 Water release based on discrete hedging policies (DHP)
3.3.5 Modified standard operating policy for hydropower generation (SOPHP)
3.3.6 Binary standard operating policy for hydropower generation (BSOPHP)
3.3.7 Modified standard hedging policy for hydropower generation (SHPHP)
3.3.8 Objective function and constraints
3.3.9 Characteristics of hydropower generation
3.4 Optimization technique; Real Coded Genetic Algorithm (RCGA)
3.5 Procedure of Downscaling by LARS-WG Model
3.6 Procedure of Downscaling by LARS-WG Model
  3.6.1 Model calibration
  3.6.2 Model validation
  3.6.3 Generation of synthetic weather data
  3.6.4 Generation of Climate Scenarios
3.7 Using an Artificial Neural Network approaches as Rainfall-Runoff model
  3.7.1 ANN Learning Process
  3.7.2 ANN Training Procedure
  3.7.3 Model Development
  3.7.4 Model Evaluation
3.8 Evapotranspiration Estimation Method
  3.8.1 Extra-terrestrial radiation (Ra)
3.9 Prediction of future power generation under possible scenarios
  3.9.1 Estimate Evaporation (Penman Method)

4 RESULTS AND DISCUSSIONS
4.1 Model implementation and determination of optimized hedging for operation of Ringlet reservoir
4.2 Analysing the impacts of possible future scenarios at Ringlet reservoir by LARS-WG
  4.2.1 Evaluation of LARS-WG performance for prediction of climate variables at Ringlet reservoir
  4.2.2 Change in temperature
  4.2.3 Change in future rainfall
4.3 Analysis of rainfall-runoff modelling by Artificial Neural Networks
  4.3.1 Training ANN algorithm for projection of future Bertam stream flow
4.3.2 Prediction of Bertam stream flow for possible future scenarios
4.4 Assess the effect of climate change on future hydropower generation in Cameron Highland Hydro scheme
4.5 Analysis result of power generation under possible climate scenarios at Ringlet
4.6 Results of optimal hedging policy Models for operation of Jor reservoir
4.7 Analysing the impacts of possible future scenarios at Jor reservoir by LARS-WG
4.7.1 Evaluation of LARS-WG performance for prediction of climate variables at Jor reservoir
4.7.2 Change in temperature
4.7.3 Change in rainfall
4.8 Training ANN algorithm for projections of future Batang Padang stream flow
4.8.1 Prediction of Batang Padang stream flow for future possible scenarios
4.9 Assess the effect of climate change on future hydropower generation in Batang Padang Hydro scheme
4.10 Analysis result of power generation under possible climate scenarios at Jor
4.11 Model implementation and determination of optimized hedging policies for operation of multi-reservoir hydropower system

5 CONCLUSIONS AND RECOMMENDATIONS
5.1 Conclusion
5.2 Recommendations for future work
5.3 Contribution of study

REFERENCES
APPENDICES
BIODATA OF STUDENT
LIST OF PUBLICATIONS
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>Overall flowchart of present research</td>
<td>27</td>
</tr>
<tr>
<td>3.2</td>
<td>Study area and location of Ringlet and Jor reservoirs</td>
<td>28</td>
</tr>
<tr>
<td>3.3</td>
<td>Diagrammatic sketch of Cameron Highland and Batang Padang hydropower reservoir system (Reference: TNB)</td>
<td>31</td>
</tr>
<tr>
<td>3.4</td>
<td>Schematic diagram of cascade hydropower reservoir system</td>
<td>32</td>
</tr>
<tr>
<td>3.5</td>
<td>Monthly mean inflow coming into Ringlet reservoir (Reference: TNB)</td>
<td>33</td>
</tr>
<tr>
<td>3.6</td>
<td>Total catchment area of Cameron Highland, Malaysia</td>
<td>34</td>
</tr>
<tr>
<td>3.7</td>
<td>Monthly mean stream flow of Jor River and side stream Rivers</td>
<td>37</td>
</tr>
<tr>
<td>3.8</td>
<td>Overall flowchart of reservoir system operation models by using available historical data</td>
<td>39</td>
</tr>
<tr>
<td>3.9</td>
<td>Overall scheme of standard operating policy</td>
<td>41</td>
</tr>
<tr>
<td>3.10</td>
<td>Overall scheme of the one-point hedging policy (1PHP)</td>
<td>43</td>
</tr>
<tr>
<td>3.11</td>
<td>Overall scheme of the two-point hedging policy (2PHP)</td>
<td>44</td>
</tr>
<tr>
<td>3.12</td>
<td>Overall scheme of the three-point hedging policy (3PHP)</td>
<td>45</td>
</tr>
<tr>
<td>3.13</td>
<td>Overall scheme of Discrete Hedging Policy (DHP)</td>
<td>46</td>
</tr>
<tr>
<td>3.14</td>
<td>Scheme of Standard Operating Policy for Hydropower Generation</td>
<td>47</td>
</tr>
<tr>
<td>3.15</td>
<td>Overall scheme of Binary Standard Operating Policy for Hydropower Generation</td>
<td>48</td>
</tr>
<tr>
<td>3.16</td>
<td>Scheme of Standard Hedging Policy for Hydropower Generation</td>
<td>50</td>
</tr>
<tr>
<td>3.17</td>
<td>Flowchart of real coded genetic algorithm</td>
<td>54</td>
</tr>
<tr>
<td>3.18</td>
<td>(a), (b), (c) illustrate the integrated model of LARS-WG and ANN in order to predict the future climate parameters</td>
<td>56</td>
</tr>
<tr>
<td>3.19</td>
<td>Process of Calibration and Validation of LARS-WG</td>
<td>59</td>
</tr>
<tr>
<td>3.20</td>
<td>Process of generating future climate parameters by LARS-WG</td>
<td>60</td>
</tr>
<tr>
<td>3.21</td>
<td>Architecture of Back Propagation ANN Model</td>
<td>61</td>
</tr>
<tr>
<td>3.22</td>
<td>Process of prediction of future power generation based on various operating policies under possible emission scenarios</td>
<td>67</td>
</tr>
</tbody>
</table>
4.1 Flow diagram of reservoir system operation based on physical and operational constraints 71
4.2 Box plot of Ringlet reservoir elevation for different form of operational policies 76
4.3 Impacts on mean monthly live storage (as a fraction of maximum) at Ringlet reservoir by using optimized operational policies 78
4.4 Impacts on mean monthly power generation at Ringlet reservoir by using optimized operational policies. 79
4.5 Compare monthly mean of observed and simulated rainfall, 84
4.6 Compare monthly standard deviation of observed and simulated rainfall, 1984-2012 at Ringlet 85
4.7 Compare monthly mean of observed and simulated maximum temperature, 1984-2012 at Ringlet 85
4.8 Compare monthly mean of observed and simulated minimum temperature, 1984-2012 at Ringlet 86
4.9 Compare monthly mean of observed and simulated Max temperature in the future under possible scenario 87
4.10 Change in monthly mean of Max temperature in 2011-2030 87
4.11 Compare monthly mean of observed data and simulated Min temperature in the future under possible scenario 88
4.12 Change in monthly mean of Min temperature in 2011-2030 88
4.13 Compare monthly mean of observed and simulated rainfall in the future under possible scenario 89
4.14 Percentage change in monthly mean of rainfall in 2011-2030 90
4.15 Compare daily observed and simulated stream flow in one year by ANN for Bertam River 92
4.16 Compare monthly mean of observed and predicted Bertam River stream flow by possible climate scenarios in future 93
4.17 Process of applying regression analysis 94
4.18 Regression analysis between recorded and Penman evaporation at Ringlet reservoir 95
4.19 Compare monthly mean of present and future power generation (as a fraction of maximum) at Ringlet reservoir using optimized operation policies.

4.20 Flowchart of mathematical model for operation of Jor reservoir.

4.21 Compare monthly mean of power generation by optimized operational policies with TNB operation at Jor reservoir.

4.22 Compare monthly mean of observed and simulated rainfall, 1984-2012 at Jor.

4.23 Compare monthly standard deviation of observed and simulated rainfall, 1984-2012 at Jor.

4.24 Compare monthly mean of observed and simulated maximum temperature, 1984-2012 at Jor.

4.25 Compare monthly mean of observed and simulated minimum temperature, 1984-2012 at Jor.

4.26 Compare monthly Min temperature between present data and simulated data by A1B, A2, and B1 at Jor.

4.27 Change in monthly mean of Min temperature at Jor.

4.28 Compare monthly Max temperature between present data and simulated data by A1B, A2, and B1 at Jor.

4.29 Change in monthly mean of Max temperature at Jor.

4.30 Percentage change in monthly mean of rainfall at Jor.

4.31 Compare daily observed and simulated stream flow by ANN for Batang Padang River.

4.32 Compare monthly mean inflow of Batang Padang River in present and future.

4.33 Regression analysis between recorded and Penman evaporation for Jor reservoir.

4.34 Compare monthly mean of present and future power generation (as a fraction of maximum) at Jor reservoir using optimized operation policies.

4.35 Flowchart of mathematical model for operation of multi-reservoir hydropower system.
LIST OF TABLES

Table                                                                                                            Page
3.1 Details of rainfall and temperature stations 29
3.2 Characteristics of Sultan Abu Bakar dam and Ringlet 35
3.3 Characteristics of Sultan Yusuf Power Station (Reference: TNB) 36
3.4 Characteristics of Jor dam and Jor reservoir (Ref: TNB) 36
4.1 Finding the optimal decision variables for each type of release policy 74
4.2 System’s firm, mean, and total power generation of Ringlet reservoir 75
4.3 Monthly mean power generation (KWh) based on different operational policies for Ringlet reservoir 82
4.4 Weather data used at Ringlet site 82
4.5 Statistical results of comparing the equality of observed and simulated data generated 83
4.6 Statistical evaluation measurements of Ringlet reservoir 92
4.7 Compare the output of power generation in the present & future period at Ringlet Reservoir 98
4.8 Optimization of decision variables in operational release policies of Jor reservoir 101
4.9 System’s Firm, mean, and total power generation of Jor reservoir 103
4.10 Monthly mean of power generation (KWh) based on different operational policies at Jor reservoir 105
4.11 Weather data used at Jor site 106
4.12 Statistical results of comparing the equality of observed and simulated data generated 106
4.13 Statistical evaluation measurements of Jor reservoir 114
4.14 Compare the output of power generation in the present & future period at Jor Reservoir 119
4.15 Optimized decision variables of operational policies in cascade hydropower reservoir system 123

xviii
4.16 Compare the number of non-power release in single and multi-reservoir systems  

4.17 Compare system’s total power generation (GWh) in single and multi-reservoir systems
LIST OF ABBREVIATIONS

CHBPHS  Cameron Highland and Batang Padang Hydro Scheme
RCM      Regional Climate Model
AOGCM    Atmosphere-Ocean Global Circulation Model
SDSM     Statistical Down Scaling Model
SWG      Stochastic Weather Generators
WG       Weather Generators
SWM      Stanford Watershed Model
ISO      Implicit Stochastic Optimization
ESO      Explicit Stochastic Optimization
LP       Linear Programming
NLP      Nonlinear Programming
SQP      Successive Quadratic Programming
DP       Dynamic Programming
DDP      Deterministic DP
IDP      Incremental DP
DDDP     Discrete Differential DP
DPSA     DP with Successive Approximation
FDP      Folded DP
SDP      Stochastic DP
CI       Computational Intelligence
EC       Evolutionary Computation
EA       Evolutionary Algorithms
GAs      Genetic Algorithms
ACO      Ant Colony Optimization
PSO      Particle Swarm Optimization
SA       Simulated Annealing
TS       Tabu Search
GA       Genetic Algorithm
CHHS     Cameron Highlands Hydroelectric Scheme
SYPS     Sultan Yusuf Power Station
BPHS     Batang Padang Hydro Scheme
SIPS  Sultan Idris II Power Station
TNBR  Tenga Nasional Berhad Research
SOP   Standard Operating Policy
1PHP  One Point Hedging Policy
2PHP  Two Point Hedging Policy
3PHP  Three Point Hedging Policy
DHP   Discrete Hedging Policy
SOPHP Standard Operation Policy for Hydropower Generation
BSOPHP Binary Standard Operation Policy for Hydropower Generation
SHPHP Standard Hedging Policy for Hydropower Generation
RCGA  Real Coded Genetic Algorithm
BCGA  Binary Coded Genetic Algorithm
LARS-WG Long Ashton Research Station Weather Generator
IPCC  Intergovernmental Panel on Climate Change
GCMs  General Circulation Models
CPDs  Cumulative Probability Distributions
SED   Semi Empirical Distribution
CPF   Cumulative Probability Distribution’s Function
HadCM3 Hadley GCM3
SRES  Special Report On Emissions Scenarios
GHG   Greenhouse Gas
KS    Kolmogorov–Smirnov test
t     Student’s t distribution
F     F-distribution
Tmin  Minimum Temperature
Tmax  Maximum Temperature
W/D   Seasonal Distributions of Wet and Dry Series
D/Tmax Distributions of Maximum Temperature
D/Tmin Distributions of Minimum Temperature
D/Rain Distributions of Daily Rainfall
M/Tmax Monthly Mean of Maximum Temperature
M/Tmin Monthly Mean of Minimum Temperature
M/Rain Monthly Mean Rainfall
MV/Rain  Monthly Variances of Rainfall
R-R  Rainfall-Runoff
ANNs  Artificial Neural Networks
HS  Hargreaves-Samani
ET₀  Evapotranspiration
E  Nash-Sutcliffe Coefficient
r  Pearson Correlation of Coefficient
RMSE  Root Mean Square Error
MBE  Mean Bias Error
## LIST OF NOTATIONS

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>WA&lt;sub&gt;t&lt;/sub&gt;</td>
<td>Water Availability at time t (m³)</td>
</tr>
<tr>
<td>S&lt;sub&gt;t&lt;/sub&gt;</td>
<td>Water stored in the reservoir at the beginning of time t (m³)</td>
</tr>
<tr>
<td>I&lt;sub&gt;t&lt;/sub&gt;</td>
<td>Reservoir inflow at time t (m³)</td>
</tr>
<tr>
<td>E&lt;sub&gt;t&lt;/sub&gt;</td>
<td>Evaporation loss at time t (m³)</td>
</tr>
<tr>
<td>R&lt;sub&gt;t&lt;/sub&gt;</td>
<td>Release at time t (m³)</td>
</tr>
<tr>
<td>D&lt;sub&gt;t&lt;/sub&gt;</td>
<td>Target demand in time t (m³)</td>
</tr>
<tr>
<td>SP&lt;sub&gt;t&lt;/sub&gt;</td>
<td>Spill at time t (m³)</td>
</tr>
<tr>
<td>K</td>
<td>Active storage (m³)</td>
</tr>
<tr>
<td>S&lt;sub&gt;a1.k&lt;/sub&gt;</td>
<td>Reservoir storage at the point of one-point hedging policy (1PHP)</td>
</tr>
<tr>
<td>S&lt;sub&gt;b1.k&lt;/sub&gt;, S&lt;sub&gt;b21.k&lt;/sub&gt;</td>
<td>Reservoir storage at first and second point of two-point hedging policy (2PHP) respectively.</td>
</tr>
<tr>
<td>S&lt;sub&gt;c1.k&lt;/sub&gt;, S&lt;sub&gt;c2.k&lt;/sub&gt;, and S&lt;sub&gt;c3.k&lt;/sub&gt;</td>
<td>Reservoir storage at first, second and third point of three-point hedging policy (3PHP) respectively</td>
</tr>
<tr>
<td>HF&lt;sub&gt;1&lt;/sub&gt;, HF&lt;sub&gt;2&lt;/sub&gt;, and HF&lt;sub&gt;3&lt;/sub&gt;</td>
<td>Fraction of target demand at stage-I, stage-II, and stage-III respectively</td>
</tr>
<tr>
<td>V&lt;sub&gt;1&lt;/sub&gt;, V&lt;sub&gt;2&lt;/sub&gt;, and V&lt;sub&gt;3&lt;/sub&gt;</td>
<td>Hedging trigger-volumes at stage-I, stage-II, and stage-III respectively</td>
</tr>
<tr>
<td>TP</td>
<td>Target power (MW)</td>
</tr>
<tr>
<td>α</td>
<td>Fraction of available water</td>
</tr>
<tr>
<td>F(h)</td>
<td>Function of release and head</td>
</tr>
<tr>
<td>R&lt;sub&gt;f&lt;/sub&gt;</td>
<td>Release at time t based on maximum net head</td>
</tr>
<tr>
<td>CT</td>
<td>Full capacity of turbines</td>
</tr>
<tr>
<td>h</td>
<td>Net head</td>
</tr>
<tr>
<td>h&lt;sub&gt;max&lt;/sub&gt;</td>
<td>Maximum net head</td>
</tr>
<tr>
<td>F</td>
<td>Release is function of full capacity and net head</td>
</tr>
<tr>
<td>P</td>
<td>Probability of occurrence</td>
</tr>
<tr>
<td>v</td>
<td>Climate variable</td>
</tr>
<tr>
<td>v&lt;sub&gt;obs&lt;/sub&gt;</td>
<td>Observed variable</td>
</tr>
<tr>
<td>X&lt;sub&gt;model,I&lt;/sub&gt;</td>
<td>Simulated values</td>
</tr>
<tr>
<td>X&lt;sub&gt;obs,i&lt;/sub&gt;</td>
<td>Observed values</td>
</tr>
<tr>
<td>X&lt;sub&gt;obs,d&lt;/sub&gt;</td>
<td>Mean value of observed data</td>
</tr>
<tr>
<td>n</td>
<td>Number of samples</td>
</tr>
<tr>
<td>Xi</td>
<td>Input value of ANN</td>
</tr>
<tr>
<td>Yi</td>
<td>Output value of ANN</td>
</tr>
<tr>
<td>X&lt;sub&gt;mi&lt;/sub&gt;</td>
<td>Mean values of input data</td>
</tr>
<tr>
<td>Y&lt;sub&gt;oi&lt;/sub&gt;</td>
<td>Mean values of output data</td>
</tr>
<tr>
<td>K&lt;sub&gt;Rs&lt;/sub&gt;</td>
<td>The adjustment coefficient of radiation</td>
</tr>
<tr>
<td>T&lt;sub&gt;min&lt;/sub&gt;</td>
<td>Daily minimum temperature</td>
</tr>
<tr>
<td>T&lt;sub&gt;max&lt;/sub&gt;</td>
<td>Daily maximum temperature</td>
</tr>
<tr>
<td>T&lt;sub&gt;a&lt;/sub&gt;</td>
<td>Daily average temperature</td>
</tr>
</tbody>
</table>
The extra-terrestrial radiation

Solar constant \((0.0820 \text{ MJ m}^{-2} \text{ min}^{-1})\)

Inverse relative distance Earth-Sun

Sunset hour angle (rad)

Latitude (rad)

Solar declination (rad).

The number of day in year (from 1st of January to 31st December)

Evaporation rate (mm/day)

Mean temperature

Elevation (m)

Latitude (degrees)

Mean dew-point

Mean daily range of temperature

The difference between mean temperatures of the hottest and coldest months

Hydropower generation in time \(t\)

Efficiency of the hydropower plants

The specific weight of water \((9.81 \text{ kg/m}^3)\)

Defined as the difference between the level of the reservoir and the tail water in time interval \(t\)

Release at time \(t\) \((\text{m}^3/\text{sec})\)

The duration of release (hrs)

Storage volume at normal water level

Storage volume at minimum water level

Storage at time \(t-1\)

Maximum capacity of hydro plants

Minimum capacity of hydro plants

Maximum permissible release

Minimum permissible release

Time-based reliability index

The number of time intervals that reservoir can fully meet the target demands

The total number of intervals in simulation time horizon

Resilience index

The number of separate continuous sequences of failure periods

Total failure duration

Vulnerability index

Maximum shortfall in each of failure trails

Dimensionless vulnerability

Target demand during the failure
CHAPTER 1

INTRODUCTION

1.1 Background

Dams and reservoirs have been constructed since 5000 years ago to serve humankind by retaining water in times of surplus and releasing it in times of deficiency. Nowadays, there are more than 45,000 dams in all over the world, which must be operated efficiently to manage the water shortage, suppress floods, and mitigate the large catastrophic droughts. The main duty of reservoir systems is to regulate the natural runoff to meet all demands. While, the operation of reservoirs are so complex because of the seasonal variations and disarray of climate. Reservoir systems are mostly operated as a multipurpose function such as meeting water for agriculture, power production, urban and industrial water supply, tourist attraction, recreation, fisheries and aquaculture, and can improve environmental conditions.

Meanwhile, many reservoir systems around the world have been constructed for hydropower generation. Hydro power provides a cheap source of electricity with few carbon emissions. So, it is such a clean and renewable source of energy where power is derived from the energy of water moving from higher to lower elevations. It is a proven, mature, predictable and price-competitive technology. Hydropower has among the best conversion efficiencies of all known energy sources (about 90% efficiency, water to wire). It requires relatively high initial investment, but has a long lifespan with very low operation and maintenance costs. Reservoirs that generate hydropower are typically operated with the goal of maximizing energy revenue. Yet, reservoirs are not operated sustainably and still operate based on experience, rules of thumb or static rules appointed at the time of construction. It is noticeable that even small ameliorations in the way of operation can increase efficiency of system for many consumers.

1.2 Problem statement

Hydropower is a major resource of electrical energy. The advantages of using hydropower are restriction in use of fuels, the pollutions caused by fossil fuels, and the benefits of using clean and renewable source of energy. The operation of a reservoir system is complicated because of the uncertainties of inflow and rising in demand due to development and population growth. One of the most striking problem is how hydroelectric systems including reservoirs and power plant should be operated over a representative hydrologic period to give the maximum beneficiation in industry (Afzali et al. 2008). One of the significant problem that effects on the hydropower reservoir system output in Malaysia is operating rules. Present managers (TNB) still used the standard operating policy to open gates at a time of flooding, which is not efficient. Another factors
that contribute to rapidly rise water level than usual are deforestation, increasingly intensive agricultural activities and in some cases poorly managed agricultural practices in the dam’s catchment area. This is coupled with poor land use practices and the encroachment of urban development into the flood plain below the dam. More parameters that decrease the efficiency of hydropower systems are loss of live storage due to the high volume of rubbish, sand, geology, drainage density, ground slopes, and silt sediment on the lake floor. Losing the water storage volume increase the risk of flooding downstream, which directly influence on the safety of human population and properties. In addition, loss of live storage cause an economic losses not only in revenue for power generation but also large capital and maintenance cost for reservoir dredging and restoration works. Changes in sediment load in reservoirs due to extreme events such as higher rainfall intensity cause erosion. Sediment has a significant effect on the performance of hydropower reservoirs in some ways such as; it could increase turbine abrasions and decrease its efficiency, it could reduce the lifespan of reservoir capacity by filling up reservoirs faster, it also leads to decrease the water quality. The foregoing factors are occurring due to lack of suitable and efficient management in whole catchment area. Although numbers of factors effects on the output of hydropower systems, only the reservoir operating policies will be discussed and investigated in this research.

1. Hydropower reservoir system are not operated efficiently and still operate based on experience, rules of thumb or static rules appointed at the time of construction. While, it is necessary to modify and improve the way of operation by considering the current system situation and using more efficient release policies for operating and managing the reservoir system. It is remarkable to say that even small improvement in the way of operation could enhance efficiency of system and increase the output of power generation. According to fill up the gap of inefficient operating policy in Malaysia, this research is done to test and evaluate different forms of operational policies in order to adapt the hydropower reservoir system operation in the face of changing hydrological balance and climate change.

Another aspect in a survey of hydropower reservoir system is although the renewable energy such as hydropower has obvious advantages, it still faces in significant drawbacks. One of the significant problem is that hydropower resources are so vulnerable to seasonal variation and climate change. According to World Commission on Dams (WCD, 2000), climate change has the potential to make an effect on global hydropower installations in different ways.
2. Changes in seasonal and annual local climate parameters, especially in temperature and rainfall could influence on river stream flow feeding the studied reservoirs. To explain more, changes in time, magnitude, length of the wet season flows especially delayed on rainy season, affecting dam operations as well as release patterns. In addition, increase in temperature effects on water surface evaporation at reservoirs and decrease the available storage. Changes in temperature and rainfall could influence on the runoff volume and consequently output of power generation.

Meanwhile, another issue raise from the statement that is absence of available toolbox to predict the future power output.

3. There is no integrated model or package available for prediction and analysis of power generation in the future. To overcome the mentioned problem, an integrated model were constructed to predict the future power output and analyse the output of different operating policies in order to mitigate the negative effects of climate change on hydropower reservoir systems.

1.3 Objectives of study

The principal objective of this study is to derive the best policy in order to increase the output of hydropower generation and mitigate the effects of climate change on power output. Accordingly, the specific objectives are summarized as following

1. To construct and optimize different forms of release policies in order to increase the system efficiency and maximize the power generation.

2. To apply an efficient model that could predict the effects of climate change on weather parameters in regional-scale.

3. To construct an integrated model in order to predict the future power generation using predicted climate parameters.
1.4 Scope and limitation of the study

The scope and limitation of this research is summarized based on each of specific objective.

Objective 1: Construct efficient operating policies

Scope 1: Various type of release policies namely, One Point Hedging Policy (1PHP), Two Point Hedging Policy (2PHP), Three Point Hedging Policy (3PHP), Discrete Hedging Policy (DHP), Standard Hedging Policy for Hydropower Generation (SHPHP), Binary Standard Operating Policy for Hydropower Generation (BSOPHP), and Standard Operating Policy for Hydropower Generation (SOPHP) are formulated and constructed in Mat lab simulation. In order to determine the optimum solution in each policy, real coded genetic algorithm is used as an optimization technique while maximizing the total power generation over the operational periods is chosen as an objective function.

Limitation 1:

- It assumes that the efficiency of turbines remains the same during present and future periods.
- It assumes that the minimum water level remains constant in present and future period due to continues dredging.
- TNB just installs one evaporation gage for CHBPHS which records monthly. So the evaporation of reservoir surface area (mm) was taken the same for a whole month and the same for both reservoirs.

Objective 2: Prediction of future climate parameters

Scope 2: An integrated model of climate change (LARS-WG) and rainfall-runoff (ANN) is constructed in order to predict the future stream flow coming to the selected reservoirs.
Limitation 2:

- Only the output of 1 form 15 sub model (GCMs) was used for prediction of climate parameter.
- The numbers of rainfall stations are available in the study area, but the data of nearest rainfall stations relative to reservoirs were taken as an input of downscaling weather generator and rainfall-runoff modelling.
- Since the deforestation and agriculture activities data is not available in this area, less number of parameters are used for construction of rainfall-runoff model.

Objective 3: Prediction of future power generation

Scope 3: The predicted stream flow are exported to the constructed operational policy models to predict the future hydropower generation output.

1.5 Significance of study

Electricity demand is increasing twice as fast as overall energy use and is likely to rise by more than two-thirds 2011 to 2035. In 2012, 42% of primary energy was converted into electricity. So, the world will need greatly increased energy supply in the next 20 years, especially cleanly-generated electricity such as hydropower, which use water supply for producing electricity. Accordingly, the number of hydropower reservoir systems have increased rapidly in developing counties such as Malaysia due to urbanization, industrialization, change in life styles and also economic growth. So, it is requisite to improve and modify the way of reservoir systems operation. Since, many of them still operate based on an experience and the rules appointed at the time of construction. However, the situation of reservoir system does not remain the same and will be vary in a face of hydrological and seasonal change. Even small amelioration could enhance the efficiency of system and increase the output of power generation. Accordingly, the main purpose of this research is to fill up the lack of inefficient operating system. So, different forms of operating policies are constructed and evaluated in this research in order to determine their capabilities in operating of system and increase electricity output. Therefore, this research focus on this question; ‘How to improve the reservoir systems operation to increase the output of power generation?’
Another problem raise up because of global warming. Recently, climate change has brought further stress on the already stressed systems and threatens the livelihood conditions of water resources. So, it is significant to analyse and predict how such changes to the earth’s climate system could effect on the temperature and amount of precipitation. Since, these variables will directly effect on water resources. Moreover, better understanding of climate parameter variation, give valuable results that could help the water resources managers to consider the climate effects for adaption of suitable operational policies and mitigation of negative effects of climate change. So, the significant of this study is to answer these questions; ‘How to adapt the operation of the water resource system in the face of changing seasonal effects and climate change?’

1.6 Thesis organization

This Chapter lays out the background, problem statement, objectives, scope and limitation, significant of study and also introduces the framework of present dissertation.

Chapter 2 review the previous studies, which have been done before. At first, the different forms of release policy for operation of water resources are reviewed and the optimization technique to find out the optimum strategy in specific water resource systems are subsequently investigated and benefits and drawbacks of methods are explained. Afterwards, the review has been done in order to achieve the second objective (generating the future climate parameters). The groups of downscaling techniques for prediction of climate variables are studied and their performances are compared. At last, the importance of understanding the transformation of precipitation into runoff in reservoir management is explained and the benefits of using artificial neural networks as a rainfall-runoff method are presented.

This research can be divided into two stages of implementation which extensively described and presented in Chapter 3. First of all, the Cameron Highland and Batang Padang Hydro Scheme (CHBPHS) with its components such as dams, reservoirs, and hydro plants and the source of gathering information for this research are explained. Afterwards, the different part of integrated modelling with their descriptions and mathematical formulations are extensively described. These Sub-models are including the mathematical models of reservoir operational policies, Long Ashton Research Station Weather Generator (LARS-WG) model, and Artificial Neural Networks algorithm.

In Chapter 4, the optimized results of various forms of release policies in both single and cascade hydropower reservoir systems are analysed and compared
to determine the best operational policy to maximize the power generation output in present time period at study area. In addition, the calibration and validation results of downscaling weather generator and rainfall-runoff modelling under different climate scenarios were investigated and future output of hydropower generation was predicted by using different release policies under possible emission scenario.

Chapter 5 sums up the research findings and recommend an outline future research directions for extension of the study presented in this dissertation.
REFERENCES


