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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

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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 synthesize 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 0.3-0.7ºC 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.

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**PENGOPTIMUMAN SISTEM TAKUNGAN HIDROKUASA MENGGUNAKAN GENETIK ALGORITMA UNTUK PELBAGAI SENARIO CUACA**

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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 (CHBPHS) di Cameron Highland, Malaysia. CHBPHS 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

pengoptimum. Oleh itu, untuk meningkatkan keberkesanan fungsi dalam penjanaan hidrokuasa, memaksimumkan jumlah penjanaan kuasa dalam tempoh operasi telah dipilih sebagai fungsi objektif, manakala had fizikal dan operasi dipenuhi. Keputusan menunjukkan bahawa dengan penggunaan polisi catuan teroptimum, hasil penjanaan kuasa dalam sistem takungan yang dikaji boleh ditingkatkan sehingga 13% berbanding dengan polisi operasi sedia ada (operasi TNB). Peningkatan ketara dalam penjanaan kuasa ini akan menyumbang dalam pembangunan ekonomi. Tambahan lagi, perbezaan hasil penjanaan kuasa purata bulanan di antara bulan tertinggi dan bulan terendah dengan menggunakan polisi catuan adalah lebih kurang 10% di takungan Ringlet dan 26% di takungan Jor, manakala perbezaan penjanaan kuasa dengan menggunakan undang-undang operasi TNB adalah masing-masing lebih kurang 30% dan 49%. Memandangkan polisi catuan selalunya digunakan untuk pengagihan bekalan air, bekalan kuasa juga berselerak dalam tempoh simulasi. Ini adalah disebabkan pengagihan air memberi kesan kepada penghasilan kuasa. Sebagai kesimpulan, polisi-polisi ini meningkatkan kestabilan sistem. Skop utama tahap kedua ialah ramalan penghasilan kuasa di masa hadapan dengan menggunakan data cuaca terjana. Dengan itu, aspek pertama yang perlu ditunjukkan ialah penghasilan parameter cuaca di masa hadapan. Pertamanya, model Long Ashton Research Station-Weather Generator (LARS-WG) telah digunakan, yang mana ia telah dikalibrasi dan disahkan menggunakan data jam pancaran matahari, hujan, dan data suhu minimum dan maksimum yang diperhatikan. Kemudian, nilai minimum dan maksimum suhu dan rekod hujan, disintesis oleh fail senario untuk meramalkan parameter cuaca di masa hadapan (taburan hujan, suhu minumum dan maksimum) di bawah senario yang munasabah. Kesemua senario menunjukkan bahawa perubahan cuaca meningkatkan suhu di lokasi sistem takungan lebih kurang 0.3-0.7ºC. Peningkatan suhu boleh mempengaruhi masa dan magnitud hujan dengan menganjakkan musim panas dan musim hujan. Tambahan lagi, hasil keputusan menunjukkan pengurangan hujan bulanan. Keputusan dari LARS-WG digunakan sebagai input kepada Rangkaian Neural Buatan (ANN). ANN seterusnya digunakan sebagai model taburan hujan-air larian untuk meramal aliran sungai yang masuk ke dalam sistem takungan di masa hadapan. Untuk lebih penerangan, pemodelan ANN mempunyai dua tahap. Tahap pertama ANN di kalibrasi dan disahkan dengan menggunakan evapotranspirasi harian, hujan dan aliran sungai yang diperhatikan (2003–2012). Untuk menganggarkan evapotranspirasi harian, suhu minimum dan maksimum harian yang diperhatikan digunakan dalam penganggaran berdasarkan persamaan Hargreaves-Samani. Dengan menggunakan data harian yang diperhatikan, ANN boleh memetakan hubungan di antara hujan-air larian. Keputusan menunjukkan model ANN memiliki kebolehan yang baik untuk mencerap data masukan/keluaran tak-linear dalam kedua-dua set latihan dan set ujian. Dalam tahap kedua, hujan masa hadapan (hasil dari LARS-WG) dan evapotranspirasi masa hadapan (tukar suhu minimum dan maksimum masa hadapan yang dihasilkan LARS-WG kepada evapotranspirasi masa hadapan menggunakan formula Hargreaves-Samani) diekspot ke ANN untuk meramal aliran sungai di masa hadapan di bawah senario yang munasabah. Selepas penghasilan parameter cuaca di masa hadapan, aliran sungai yang diramalkan oleh ANN dan anggaran penyejatan masa hadapan (tukar suhu minimum dan maksimum masa hadapan yang dihasilkan oleh LARS-WG kepada penyejatan masa hadapan mengunakan 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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This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
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| | |
|---|---|
| CHBPHS | Cameron Highland and Batang Padang Hydro Scheme |
| RCM | Regional Climate Model |
| AOGCM | Atmosphere-Ocean Global Circulation Model |
| SDSM | Statistical Down Scaling Model |
| SWGs | Stochastic Weather Generators |
| WGs | 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 |
| $ET_0$ | Evapotranspiration |
| E | Nash-Sutcliffe Coefficient |
| r | Pearson Correlation of Coefficient |
| RMSE | Root Mean Square Error |
| MBE | Mean Bias Error |

## LIST OF NOTATIONS

| | |
|---|---|
| $WA_t$ | Water Availability at time t ($m^3$) |
| $S_t$ | Water stored in the reservoir at the beginning of time t ($m^3$) |
| $I_t$ | Reservoir inflow at time t ($m^3$) |
| $E_t$ | Evaporation loss at time t ($m^3$) |
| $R_t$ | Release at time t ($m^3$) |
| $D_t$ | Target demand in time t ($m^3$) |
| $SP_t$ | Spill at time t ($m^3$) |
| K | Active storage ($m^3$) |
| $S_{a1.k}$ | Reservoir storage at the point of one-point hedging policy (1PHP) |
| $S_{b1.k}$, $S_{b21.k}$ | Reservoir storage at first and second point of two-point hedging policy (2PHP) respectively. |
| $S_{c1.k}$, $S_{c2.k}$, and $S_{c3.k}$ | Reservoir storage at first, second and third point of three-point hedging policy (3PHP) respectively |
| HF1, HF2, and HF3 | Fraction of target demand at stage-I, stage-II, and stage-III respectively. |
| V1, V2, and V3 | Hedging trigger-volumes at stage-I, stage-II, and stage-III respectively |
| TP | Target power (MW) |
| $\alpha$ | Fraction of available water |
| F(h) | Function of release and head |
| $R_f$ | Release at time t based on maximum net head |
| CT | Full capacity of turbines |
| h | Net head |
| $h_{max}$ | Maximum net head |
| F | Release is function of full capacity and net head |
| P | Probability of occurrence |
| v | Climate variable |
| $v_{obs}$ | Observed variable |
| $X_{model,I}$ | Simulated values |
| $X_{obs,i}$ | Observed values |
| $\overline{X_{obs,i}}$ | Mean value of observed data |
| n | Number of samples |
| Xi | Input value of ANN |
| Yi | Output value of ANN |
| $\overline{X_i}$ | Mean values of input data |
| $\overline{Y_i}$ | Mean values of output data |
| $K_{Rs}$ | The adjustment coefficient of radiation |
| $T_{min}$ | Daily minimum temperature |
| $T_{max}$ | Daily maximum temperature |
| $T_a$ | Daily average temperature |

| | |
|---|---|
| $R_a$ | The extra-terrestrial radiation |
| $G_{sc}$ | Solar constant (0.0820 MJ $m^{-2}$ $min^{-1}$) |
| $d_r$ | Inverse relative distance Earth-Sun |
| $\omega_s$ | Sunset hour angle (rad) |
| $\varphi$ | Latitude (rad) |
| $\delta$ | Solar declination (rad). |
| J | The number of day in year (from 1st of January to 31st December) |
| $E_0$ | Evaporation rate (mm/day) |
| T | Mean temperature |
| h | Elevation (m) |
| A | Latitude (degrees) |
| $T_d$ | Mean dew-point |
| R | Mean daily range of temperature |
| $R_{ann}$ | The difference between mean temperatures of the hottest and coldest months |
| $G_t$ | Hydropower generation in time t |
| $\eta_0$ | Efficiency of the hydropower plants |
| γ | The specific weight of water (9.81 kg/$m^3$) |
| $H_t$ | Defined as the difference between the level of the reservoir and the tail water in time interval t |
| $r_t$ | Release at time t ($m^3$/sec) |
| t | The duration of release (hrs) |
| $S_{max}$ | Storage volume at normal water level |
| $S_{min}$ | Storage volume at minimum water level |
| $S_{t-1}$ | Storage at time t-1 |
| $G_{max}$ | Maximum capacity of hydro plants |
| $G_{min}$ | Minimum capacity of hydro plants |
| $R_{max}$ | Maximum permissible release |
| $R_{min}$ | Minimum permissible release |
| Rel | Time-based reliability index |
| $N_s$ | The number of time intervals that reservoir can fully meet the target demands |
| N | The total number of intervals in simulation time horizon |
| β | Resilience index |
| $f_s$ | The number of separate continuous sequences of failure periods |
| $f_d$ | Total failure duration |
| $\eta'$ | Vulnerability index |
| $S_j$ | Maximum shortfall in each of failure trails |
| η | Dimensionless vulnerability |
| Df | 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 slops, 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 mitiagte 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

Scope1: 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.

Limitation1:

- 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.

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