Environmental Health Engineering and Management Journal 2016, 3(2), 99–106
doi 10.15171/EHEM.2016.07
http://ehemj.com
Environmental Health Engineering and Management Journal

Original Article

Open Access Publish Free

Optimization of cascade hydropower system operation by genetic algorithm to maximize clean energy output

Aida Tayebiyan[1*], Thamer Ahmad Mohammad[2]

[1]PhD, Environmental Health Engineering Research Center, Kerman University of Medical Sciences, Kerman, Iran
[2]Professor, Faculty of Engineering, Department of Civil Engineering, Universiti Putra Malaysia, 43300 Serdang, Malaysia

Abstract
Background: Several reservoir systems have been constructed for hydropower generation around the world. Hydropower offers an economical source of electricity with reduce carbon emissions. Therefore, it is such a clean and renewable source of energy. Reservoirs that generate hydropower are typically operated with the goal of maximizing energy revenue. Yet, reservoir systems are inefficiently operated and manage according to policies determined at the construction time. It is worth noting that with little enhancement in operation of reservoir system, there could be an increase in efficiency of the scheme for many consumers.
Methods: This research develops simulation-optimization models that reflect discrete hedging policy (DHP) to manage and operate hydropower reservoir system and analyse it in both single and multi-reservoir system. Accordingly, three operational models (2 single reservoir systems and 1 multi-reservoir system) were constructed and optimized by genetic algorithm (GA). Maximizing the total power generation in horizontal time is chosen as an objective function in order to improve the functional efficiency in hydropower production with consideration to operational and physical limitations. The constructed models, which is a cascade hydropower reservoirs system have been tested and evaluated in the Cameron Highland and Batang Padang in Malaysia.
Results: According to the given results, usage of DHP for hydropower reservoir system operation could increase the power generation output to nearly 13% in the studied reservoir system compared to present operating policy (TNB operation). This substantial increase in power production will enhance economic development. Moreover, the given results of single and multi-reservoir systems affirmed that hedging policy could manage the single system much better than operation of the multi-reservoir system.
Conclusion: It can be summarized that DHP is an efficient and feasible policy, which could be used for the operation of existing or new hydropower reservoir system.
Keywords: Optimization, Hedging policy, Reservoir operating rule, Genetic algorithm, Hydropower reservoir system, Clean energy.
Citation: Tayebiyan A, Mohammad TA. Optimization of cascade hydropower system operation by genetic algorithm to maximize clean energy output. Environmental Health Engineering and Management Journal 2016; 3(2): 99–106. doi: 10.15171/EHEM.2016.07.

Article History:
Received: 3 May 2016
Accepted: 5 June 2016
ePublished: 18 June 2016

***Correspondence to:**
Aida Tayebiyan
Email: ida_tayebiyan@yahoo.com

Introduction

The unavoidable growth of worldwide energy consumption and the adverse environmental impacts of burning fossil fuels pave way for extensive prospects to exploit renewable energies such as hydropower (1). Meanwhile, several reservoirs have been constructed for the generation of hydropower in the world as a result of the constraint on fuel usage, the pollution produced by fossil fuel and the benefits of using clean and renewable hydro energy. So, hydropower being a clean energy source will play an important role in the future. From economic point of view, reservoirs and power plants operation should be examined over a representative hydrologic period when designing and operating hydroelectric system in order to yield its maximum beneficiation in industry (2). But, the operation of reservoir system is complicated because of the uncertainties of inflow and increasing energy demand due to development and population growth. For the above-mentioned reasons, different operational policies have been used and tested to improve the reservoir system operation such as the New York City rule (NYC rule) (3), the space rule (4), the pack rule (5), standard operation policy (6), and hedging policy (7). The operational policies usually focus on the time and amount of water that would be released in horizontal time steps.

Meanwhile, hedging policies have gained substantial attention by researchers as a result of increase in water demand, uncertainty in water sources and occurrence of more droughts compared to the past. Hedging policies are generally applied to conserve some amount of water in the dry periods by reducing the water supply in some period in order to ease its intense deficiency. The main benefits of using hedging rules are to distribute the predictable water deficiency uniformly to reduce intense shortage in the future (8,9). Therefore, hedging policy are mostly used for the operation of reservoir system with the purpose of irrigation, urban and industrial water, and drinking water to prevent the severe shortage in drought periods and seldom used for operation of hydropower systems. Since the output of hydropower production depends on water release and water head, the concept of hedging and rationing can be used in operation of hydropower reservoir in order to preserve the water storage and elevate the water level in a reservoir. It means that the output of power generation not only depend on water release but also on water head which is an important key factor, hence hedging policy cover both factors by keeping the water in the reservoir. In other words, when available water in the reservoir increases, the available head increases too and by smaller discharge the required power can be produced. In addition, it seems that the application of hedging policy for reservoir operation has been mostly presented in terms of optimal hedging. Consequently, the optimization-simulation technique has been used to develop the various types of hedging rules to find the decision variables in each form of hedging and specify optimum hedging policies such as (9-12).

Accordingly, the capability of hedging policy in operation of hydropower reservoir system in both single and multi-reservoir systems is investigated in this research. In order to survey both cases, the Cameron Highland and Batang Padang in Malaysia, which comprises of two cascade reservoirs system (Ringlet and Jor reservoir system) was selected as study area. At first, each of the reservoir system was constructed separately and then the two cascade reservoirs system was constructed in Matlab. Each model comprises of physical and operational constraints such as hydroplant discharge limits, water balance equation, reservoir storage volume, and hydro plant power limits based on the characteristics of specific system. Afterwards, the genetic algorithm (GA) is linked to each of the constructed models in order to maximize the total power generation output in horizontal period. The given results of optimal hedging policy in both single and cascade hydropower reservoir system are evaluated and compared.

Methods

Water release based on discrete hedging policies

In the present research, hedging policy is used as an operational policy. One of the prominent forms of hedging policy is called discrete hedging policies (DHPs) since water rationing applies in discrete steps (13). The overall scheme of DHP is presented in Figure 1. For each time step in this policy, if available storage (WA_t) is greater than D_t, target demand can be fulfilled without any rationing. If WA_t is greater than V3 but less than D_t, then the stage-I of rationing will be occurring for the coming time step and only the fraction HF1 of target demand will be provided. If WA_t is greater than V2 but less than V3, then the stage-II

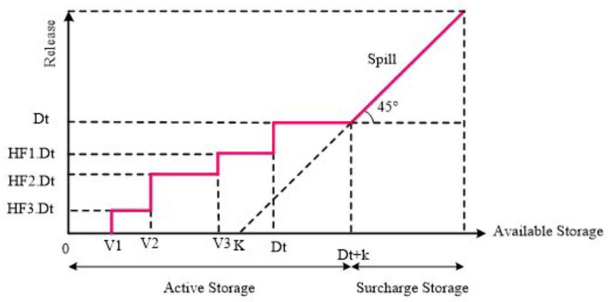

Figure 1. Overall scheme of discrete hedging policy (DHP).

of rationing will be initiated. In this case, the demand will be decreased to only HF2 times of target demand. If WA_t is greater than V1 but less than V2, then the stage-III of rationing will be occurring and the fraction HF3 of target demand will be discharged (14). In this water release policy, it is assumed that the minimum trigger-volume will always be sustained in a reservoir. The trigger-volumes are determined according to the hydrology of inflows and amount of demand reduction due to water savings. The formulations of water release based on DHP are as follows:

$R_t=D_t$	$SP_t=WA_t - D_t - K$	$WA_t \geq D_t+K$	(1)
$R_t=D_t$	$SP_t=0$	$Dt \leq WA_t < D_t+K$	(2)
$R_t=HF1*D_t$	$SP_t=0$	$V_3 \leq WA_t < D_t$	(3)
$R_t=HF2*D_t$	$SP_t=0$	$V_2 \leq WA_t < V_3$	(4)
$R_t=HF3*D_t$	$SP_t=0$	$V_1 \leq WA_t < V_2$	(5)
$R_t=0$	$SP_t=0$	$WA_t < V_1$	(6)

Where HF1, HF2, and HF3 represent the fraction of target demand at stage-I, stage-II, and stage-III respectively. V1, V2, and V3 represent hedging trigger-volumes at stage-I, stage-II, and stage-III respectively. R_t denotes Release at time period t, D_t denotes Target demand at time period t, SP_t represents Spill at time period t, WA_t represents Water available (available storage) at time period t, and K is the active storage.

After determination of operational policy, physical and operational constraints such as hydro plant discharge limits, water balance equation, reservoir storage volume, and hydro plant power limits should be considered for the construction of models (15).

Objective function and constraints

The principal scope of this research is to discover how the hydropower reservoirs system could produce more power generation as a clean energy. Therefore, maximizing the total power generation throughout the horizontal time (2003-2012) was taken as an objective when ever different physical and operational limits are considered. Hence, the objective function can be affirmed as a nonlinear optimization problem, which is accompany with constrained (16).

$$\text{Max } G_t = \sum_{t=1}^{T} \eta_0 \, \gamma \, r_t H_t \, t \quad (7)$$

Where, G_t: energy production in time t (KWh), η_0: hydropower plants efficiency, γ: water specific weight (9.81 kN/

m^3), r_t: the discharge in time interval (m^3/s), H_t: mean net head in time interval (in a daily scale), and t represents the length of time for release (hours).

It is worth noting that R_t, in other formula can be specified by multiplying r_t and t.

The earlier mentioned objective function should be optimum while the following limits are provided (17).

Hydro plant discharge constraints

After specifying the release in time interval, the quantity of releases (R_t) must be checked to be in a permissible limits.

$$R_{min} \le R_t \le R_{max} \quad (8)$$

R_{min} shows the minimum allowable release and maximum allowable release (R_{max}) is determined based on full capacity of turbines and tunnel capacity, which divert the water from the source into a reservoirs system.

Water balance equation

After specifying release, storage at the beginning of the next time could be determined by using water balance equation (18).

$$S_t = S_{t-1} + I_t - E_t - R_t - SP_t \quad (9)$$

Where, S_t: storage at time t, S_{t-1}: storage at time t-1, I_t: inflow at time t, E_t: evaporation at time t, R_t: release at time t, SP_t: spill at time t.

Reservoir storage capacity

The reservoir storage capacity or water available in time interval must be located in permissible limits.

$$S_{min} \le S_t \le S_{max} \quad (10)$$

Where, S_{min}: reservoir storage at minimum water level, and S_{max}: reservoir storage at maximum operating level.

Hydro plants power constraints

The power generation in time interval must be located in acceptable limits (19).

$$G_{min} \le G_t \le G_{max} \quad (11)$$

Where, G_{min}: minimum energy generation (KWh), and G_{max}: maximum power generation (KWh). The above-mentioned parameters are specified according to turbines capacity.

After constructing the reservoir system operation, the optimization technique is linked to each of the constructed model in order to determine the optimized decision variables in each operation system. In this research, GA is applied to optimize the problems. The procedure of this algorithm will be explained in the next section.

Optimization technique; genetic algorithm

Many optimization techniques have been successfully performed in reservoir operation studies. Meanwhile, GA is extensively used and reported by researchers as a powerful technique for optimization of the water resources (16). GA is inspired by the mechanisms of natural selection and genetic of populations.GA is a stochastic search method and use randomized operators such as selection, crossover, and mutation (20). The initial process of this algorithm is creating the first population; which comprise of individuals. An individual represents a candidate for optimum solution that is called a chromosome. Chromosome is made with a certain length string which is coded subsequently to be represented numerically. Afterwards, the fitness value is appointed to every population of chromosomes.

Fitness value is a parameter used in evaluating and deciding if the chromosomes can survive in a subsequent population or not. Selecting the best chromosome among the population, which can be transmitted to the subsequent generation, is determined by genetic operators such as selection, crossover, and mutation. According to the fitness value, the best candidates are selected as parents. Therefore, the next population carry the best genetic characteristics. In an overall, the cyclic of GAs consist of 5 major steps namely fitness evaluation, selection, cross over, mutation, and creation of a new population. For more details refer to (7,21-23).

In this research, GA is developed to optimize both single and cascade hydropower reservoir system namely Cameron Highland and Batang Padang Hydro Scheme (BPHS) in Malaysia. The objective of optimization is to specify the DHP in order to maximize the total power generation in time horizon (2003-2012).

Study area; Cameron Highland and Batang Padang hydropower scheme

The Sultan Abu Bakar dam was constructed on the Bertam River in the Cameron Highlands, Malaysia. The lake, which was created as a consequence of the dam construction is called Ringlet reservoir. It forms an integral part of the Cameron Highlands Hydroelectric Scheme (CHHS) of the National Electricity Board. The dam preserves the waters of Bertam and Telom Rivers and their tributaries and transmits through the Telom tunnel into the Bertam catchment. From Ringlet reservoir, the water discharges through the Bertam tunnel and divert towards the Sultan Yusuf Power Station (SYPS), which has a total installed capacity of 100 MW.

After leaving the SYPS, the water is carried through a tailrace tunnel into the Jor reservoir of the BPHS (BPHS). From there, it is conveyed by the tunnel to generate further energy in the underground Sultan Idris II Power Station (SIPS) 3 at Kuala Woh. The static head on these turbines are 420.6 m, which is among the highest heads in the world for this type of turbines, which hasa total installed capacity of 150 MW. Thus the headwaters of the Bertam and Telom rivers, which formerly reached the sea on the East Coast Peninsular of Malaysia has now been diverted through the main range of hills to the Batang Padang River, which flows out to the West Coast. Diagrammatic sketch of Cameron Highland and BPHS is shown in Figure 2.

The amount of monthly mean inflow coming to Ringlet and Jor reservoirs is presented in Figure 3a and 3b respectively. In addition, the characteristic of the reservoirs and power stations in Cameron Highland and Batang Padang hydropower scheme is shown in Table 1 in details.

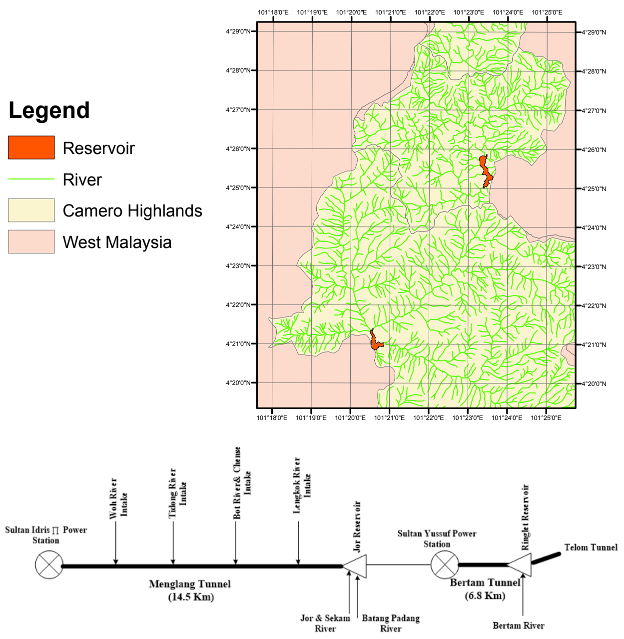

Figure 2. Study area, location, and schematic diagram of Cameron Highland and BPHS.

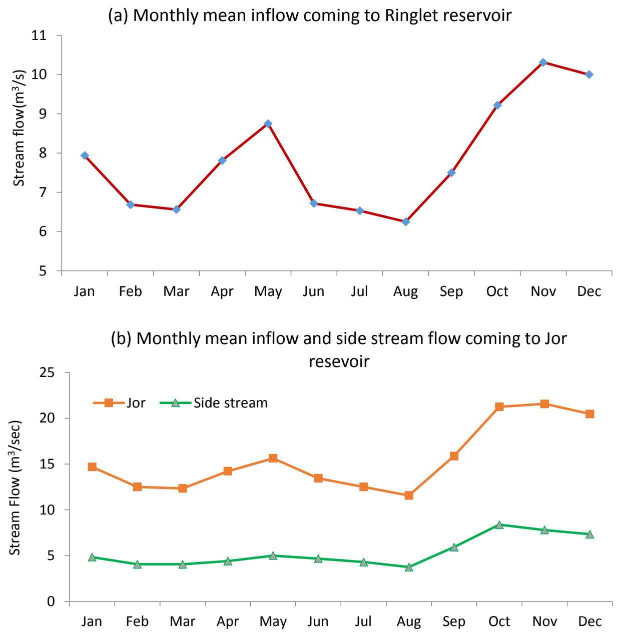

Figure 3. (a) Monthly mean inflow coming to Ringlet reservoir, (b) Monthly mean inflow and side stream flow coming into Jor reservoir.

Results and Discussion

This section presents a survey of DHP's performance in operation of single and multi-reservoir hydropower system. Both single and multi-reservoir hydropower system operation were constructed in MATLAB simulation. In this research, Cameron Highland and BPHS is selected as a case study. A flowchart of multi-reservoir hydropower system model which can be divided into two systems is illustrated in details in Figure 4.The first system include Ringlet reservoir and SYPS (left side of Figure 4) and the second system comprises of Jor reservoir and SIPS (right side of Figure 4). Three models were separately constructed in MATLAB simulation based on the characteristics of specific system including;

Model I: Ringlet reservoir and SYPS

Model II: Jor reservoir and SIPS

Model III: Combine system of Ringlet reservoir, SYPS, Jor reservoir, SIPS.

Thereafter, real coded GA is linked to the constructed model as an optimization technique to discover the optimal solution of problems. The output of optimal power generation by using historical data (2003-2012) in both single (Model I and Model II) and multi-reservoir system model (Model III) are presented and discussed in this section. The values of constant parameters in construction of proposed models are as follows;

For Ringlet reservoir (m=1):$Snpl_1$ =6,700,000 m^3, Eff = 0.85, $h_{1,0}$=485.8 m, P_{max} =100 MW, t_{max} = 3652, and for Jor reservoir (m=2): $Snpl_2$ =2,818,068 m^3, Eff = 0.85, $h_{2,0}$ =76.2 m , P_{max} =150 MW, t_{max} = 3652.

Table 1. Description of Cameron Highland and Batang Padang Hydropower Scheme

	Ringlet reservoir	Jor reservoir
Gross storage	6.7 Mm^3	3.8 Mm^3
Usable storage	4.7 Mm^3	
Catchment area	183.4 km^2	275 km^2
Reservoir surface area	0.5 Km^2 at EL. 1071.1 m	0.3 km^2
Normal operating level	EL. 1068.3 m	493 m
Min operating level	EL. 1065.2 m	486.1 m
Max operating level	EL. 1070.8 m	497 m
	SYPS	**SIPS**
Number of turbine	4	3
Type of turbine	Pelton	Pelton
Turbines capacity	25 MW	50 MW
Installed capacity	100 MW	150 MW
Rated head	573 m	

Abbreviations: SYPS, Sultan Yusuf Power Station; SIPS, Sultan Idris II Power Station.

Model I & Model II: Analysis of result of optimized hedging policy model for operation of Ringlet and Jor reservoir system respectively

This research was conducted in the Cameron Highland and Batang Padang cascade hydropower system to test and evaluate the applicability of DHP in operation of both single and cascade hydropower reservoir systems. This complex system can be divided into two single reservoir system. Thus, three models comprising two single reservoir system (Ringlet, Jor) and one integrated reservoirs (cascade Ringlet and Jor reservoirs system) were constructed and optimized. The optimized results of all three models were provided and explained subsequently.

Model I: The CHHS includes Ringlet reservoir and SYPS. A flowchart of the mathematical model for the operation of the Ringlet reservoir system is presented in the left side of Figure 4. The left side of diagram was constructed based on the Ringlet reservoir system constraints such as hydro

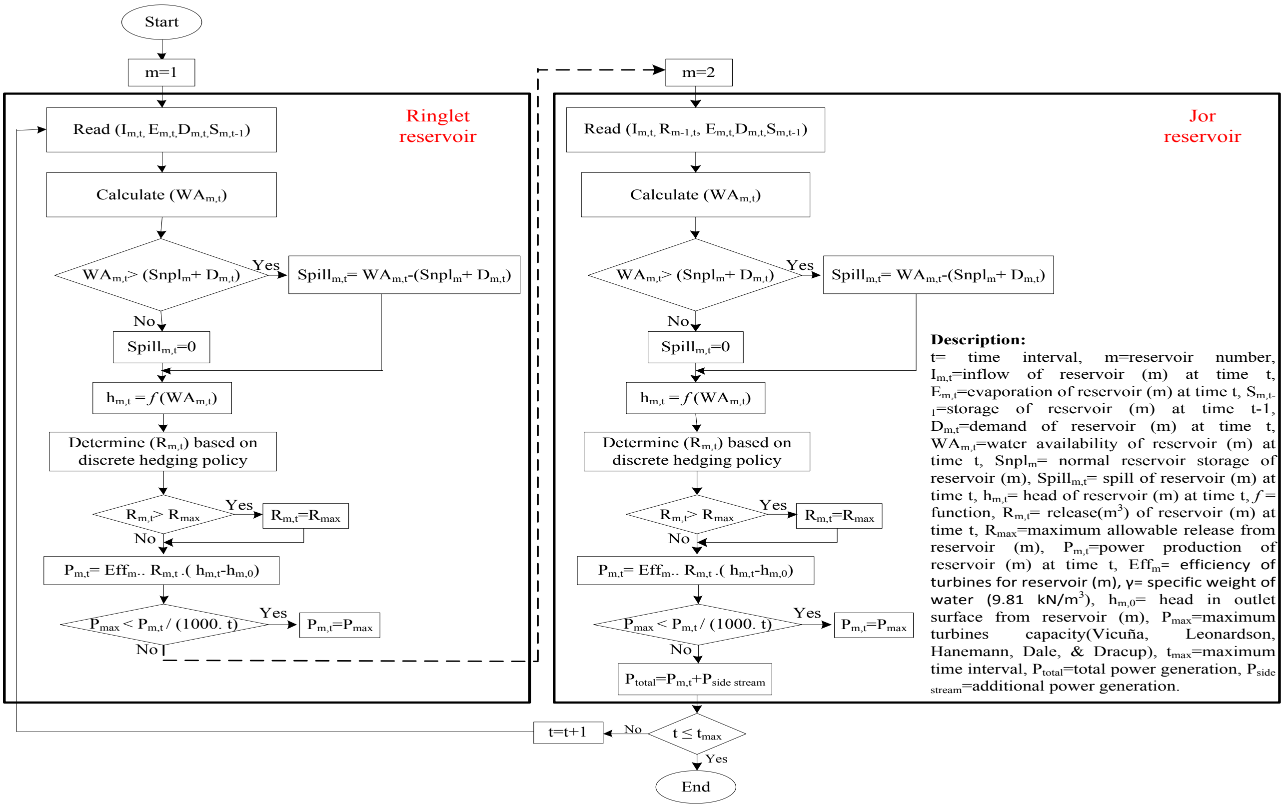

Figure 4. Flowchart of multi-reservoir hydropower system operation.

plant discharge limits, water balance equation, reservoir storage volumes, hydro plant power limits, and release constraints based on DHP.

Model II: The BPHS comprises Jor reservoir and SIPS. A flowchart of Jor reservoir system operation which was constructed based on the specific characteristics and constraints of Jor reservoir system is presented in the right side of Figure 4. BPHS system has an additional side stream, which supply more water to the Menglang tunnel (Figure 2). Although these side streams do not have any effect on Jor reservoir operation, they help in the generation of additional power in SIPS. In other words, the total power generation (P_{total}) is summation of power from Jor reservoir ($P_{m,t}$) and that from side stream ($P_{side\ stream}$).

After construction of Ringlet and Jor reservoir system operation, the models were subsequently linked to the GA in order to find the optimal decision variables of system based on the DHP. Meanwhile, maximization of total power generation as a clean energy is chosen as an objective function.

In this research, DHP was formulated as a release policy. In this policy, water rationing applies in discrete steps. The numbers of discrete steps are assumed to be three and the initial and end point of each step is the amount of available water. For example, the initial point of the first step is V1 and its second point is V2. This policy has six decision variables, which are divided into two groups, (V1, V2, and V3) and (HF1, HF2, and HF3). V1, V2, and V3 are determined as a coefficient of active storage and HF1, HF2, HF3 are defined as a coefficient of target demand (D). Results of optimal decision variables for discrete hedging in simulation period (2003-2012) at Ringlet and Jor reservoir system is presented in Table 2 respectively.

It is worth noting that one of the key factors in the construction of DHP model is the determination of target demand. No seasonal or annual demand pattern is used for hydropower reservoir system and the water demand is not constant and depends on the water head or water availability. Generally, the output of power generation (G) is determined in terms of water head (H) and water release

Table 2. Results of optimal decision variables in single Ringlet and single Jor reservoir system

		Point	Point	Optimal Parameter()	Storage (m^3)	HF
Model I	Ringlet reservoir	V1	a*K	0.213	4476394	0.531
		V2	b*K	0.275	4652413	0.975
		V3	c*K	0.430	5089372	0.981
Model II	Jor reservoir	V1	a*K	0.235	1613972	0.520
		V2	b*K	0.694	2449194	0.870
		V3	c*K	0.700	2456400	0.951

$D_{Ringlet}$: target demand (700 000 m^3), $K_{Ringlet}$: active storage (2 158 200 m^3), a,b, and c: coefficient of active storage, D_{Jor}: target demand (1 Mm^3); K_{Jor}: active storage (1 205 290 m^3).

Table 3. Comparison of system's mean and total power generation from 2003 to 2013 by using optimal DHP and current policy (TNB) at Ringlet and Jor reservoir system respectively

		Release policy	Mean power generation (KWh)	Total tower generation (GWh)
Model I	Ringlet reservoir	DHP	897321	3277.91
		TNB	792959	2895.89
Model II	Jor reservoir	DHP	1325987	4843.829
		TNB	1267158	4242.446

Abbreviations: DHP: discrete hedging policy, TNB: Tenga Nasional Berhad.

(R). In an overall, the formula can be summarized as G=*f* (R, H). So, in order to determine the mean target demand (water release), the mean output of power generation and mean water head was specified based on recorded data (2003-2012) in each reservoir system. Based on the results, the amount of target demand in simulation period was found 700 000 m^3 for Ringlet reservoir and 1 Mm^3 for Jor reservoir.

The mean and total output of power generation during the simulation period (2003-2012) by using optimal DHP compared with output of current policy (TNB) is presented in Table 3. According to the given results, mean output of power generation by using DHP could increase to about 13% of Ringlet reservoir and 5% of Jor reservoir system output respectively. In addition, by analysing the output of total power generation during the simulated period, it can be summarized that the given output is almost 13% higher than the total output of TNB in both reservoir system and this has great economical effect in the power sector and help the societies to use more clean energy.

Model I: Mean monthly power generation at Ringlet reservoir by using optimal operating policies and TNB is compared and illustrated in Figure 5. The differences in power output between highest and lowest months are 10 (70-80 MW), while a value of approximately 31 (53-84 MW) was obtained for TNB operation, which is 3 times higher, hence by applying hedging policies, it can be concluded that the stability of the system will increase. Model II: Moreover, the comparison between mean monthly power generation at Jor reservoir by using optimal operating policies and TNB is presented in Figure 5. The difference in power production between highest and lowest months is almost 26 (100-126 MW), while this difference is 49 (87-136 MW) for TNB operation. In accordance to the obtained result, it can be summarized that the operation of the reservoir by using hedging policies increases the stability of the system. Hedging policies are generally applied to distribute the water supply throughout the year in order to reduce the intense deficiency in dry periods. The highest and lowest monthly value of power generation using TNB operation occurred in Sep and Apr. While by employing hedging policies, the highest and lowest hydropower was generated in Nov and Feb respectively. This explanation verifies that by using hedging policies,

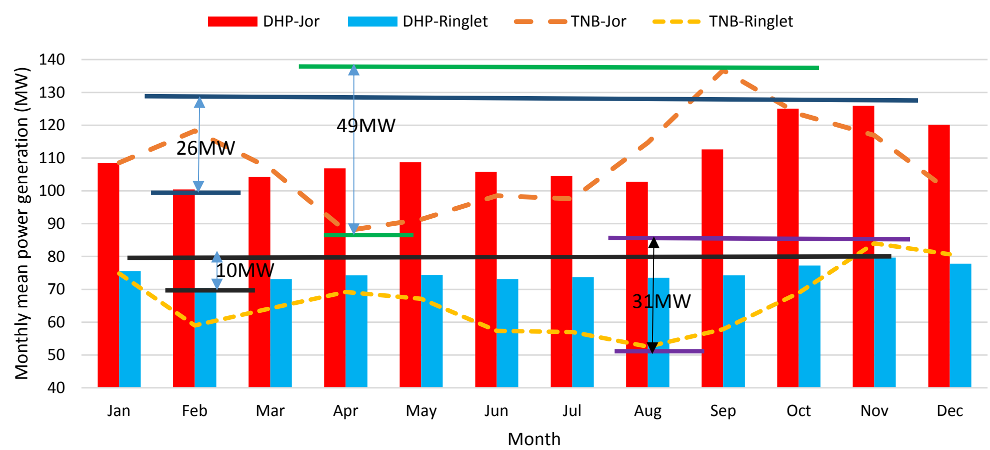

Figure 5. Compare monthly mean power generation by using DHP and TNB policy at Ringlet and Jor reservoir.

Table 4. Results of optimized decision variables of cascade hydropower reservoir system operation (Model III)

Model III	Point	Point	Optimal parameter	Storage (m^3)	HF
Ringlet Reservoir	V1	a*K	0.087	4120378	0.321
	V2	b*K	0.427	5081026	0.451
	V3	c*K	0.468	5196869	0.483
Jor Reservoir	V1	a*K	0.051	1674247	0.436
	V2	b*K	0.069	1695943	0.495
	V3	c*K	0.297	1970749	0.531

Table 5. Comparison the number of non-power release days and total power generation (GWh) in single and multi-reservoir systems

	Ringlet hydropower system		Jor hydropower system	
	Single-reservoir	Multi-reservoir	Single-reservoir	Multi-reservoir
Number of non-power release (days)	0	1519	0	0
System's total power generation (GWh)	3277.91	3341.70	4843.83	4737.24

the water-supply spread across the simulation period (24).
Model III: Analysis of result of optimized hedging policy models for operation of integrated Ringlet and Jor reservoirs system

In order to demonstrate the applicability and performance of constructed release policies in hydropower system operation, two problems are considered: single reservoir and multi- reservoir system. The objective of both problems is to maximize the total power generation in the simulation period. Meanwhile, the integrated modelling is constructed based on the characteristics of each reservoir system. These models comprise of several constraints such as hydro plant discharge limits, water balance equation, reservoir storage volumes, and hydro plant power limits. Another constraint known as the release-policy constraint is determined based on the DHP. Afterwards, the integrated model is linked to the RCGA to find the optimal solution for the decision variables of each reservoir by applying various types of hedging policies. The obtained results of cascade hydropower reservoir optimization are presented in Table 4. Based on the specific characteristics of each reservoir, the decision variables of each policy are optimized.

In order to compare the capability of constructed release policies for operation of the hydropower system in both single and multi-reservoir, two parameters are considered. These parameters are numbers of spill days and system's total power generation. The number of non-power release days in simulation time (2003-2012) in both single and multi-reservoir system operation is compared and presented in Table 5. Non-power release is the spilling water, which are not use for hydropower generation. The results affirm that in the case of single Ringlet system, DHP is capable of controlling the water supply in the reservoir in order to be utilized completely for hydropower generation without any non-power release. However in the cascade system, 1519 days of 3652 non-power days release could occur in Ringlet reservoir, which is not acceptable. The performance of Jor reservoir is much better in comparison with Ringlet reservoir performance in the multi-reservoir system. Since, both cases will not be faced the non-power release.

In addition, system's total power generation by applying all types of hedging policies in the both single and multi-reservoir system is presented in Table 5. The results indicate that the amount of total power generations at the single Ringlet system is less than the power output at Ringlet reservoir in the cascade system. However single Ringlet system perfectly manages the water supply and the spilling water is zero, while the spilling water occurred at Ringlet reservoir in the cascade system. This inconsistency can be explained by the objective function used in the optimization process. The objective of both single and multi-reservoir systems is to maximize the total power generation in the simulation period. As a result, the multi-reservoir system tries to retain the water in the higher level at first reservoir (Ringlet). At a first glance, it seems there was an increase in power generation, but the system always faces danger of spilling water. In other words, the system's safety sacrifices for producing more power generation, is not acceptable. The obtained results of Jor reservoir reveal that the total power generation in cascade system is less than that of the single Jor system (4737.24). Because in cascade hydropower system, Jor reservoir is considered as the second reservoir. As a result, it will be affected by the operation of the first reservoir system (Ringlet). Because Ringlet reservoir lost some of its water due to spilling that diverts it from the system. So, the output of Jor reservoir in cascade system is less than the output of Jor reservoir in single system. In summary, it can be concluded that the use of optimized operating policies would manage the system more efficiently in the single reservoir than in the multi-reservoir.

Conclusion

This research investigated the applicability of DHP for operation of hydropower reservoir system in both single and multi-reservoir system. Meanwhile, three models are built in Matlab and subsequently connected to GA (GA). A GA has been developed for derivation of optimal hedging policy in both cases of single and multi-reservoir hydropower reservoir system. The objectives of these models are set to maximize the total power generation in horizontal period.The constructed models have been tested and evaluated in the Cameron Highland and Batang Padang in Malaysia, which comprise of two integrated reservoirs system (Ringlet and Jor). In accordance to the optimization results, the application of DHP as an operational policy could improve the stability of the system and increase the power generation output up to 13% compared to the current policy. So, the application of this policy for existing reservoir and new hydropower system for producing more clean energy is highly recommended. The results of optimization in single and multi-reservoir system demonstrate that the use of the optimized DHP would manage the system more efficiently in the single reservoir than in the multi-reservoir.

Acknowledgements

This study is part of the doctoral research which was done in Universiti Putra Malaysia (UPM).

Ethical issues

It is certified that all data collected during the study are presented in this manuscript and no data from the study has been or will be published separately.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

All authors participated in the design of the study, performed the literature search and wrote the manuscript, data acquisition, analysis, and interpretation. All authors critically reviewed, refined, and approved the manuscript.

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