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A Review on Applications of Evolutionary Algorithms to Reservoir Operation for Hydropower Production

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Abstract**—**Evolutionary Algorithms (EAs) have been used widely through evolution theory to discover acceptable solutions that corresponds to challenges such as natural resources management. EAs are also used to solve varied problems in the real world. EAs have been rapidly identified for its ease in handling multiple objective problems. Reservoir operations is a vital and researchable area which has been studied in the last few decades due to the limited nature of water resources that is found mostly in the semi-arid regions of the world. The state of some developing economy that depends on electricity for overall development through hydropower production, a renewable form of energy, is appalling due to water scarcity. This paper presents a review of the applications of evolutionary algorithms to reservoir operation for hydropower production. This review includes the discussion on areas such as genetic algorithm, differential evolution, and reservoir operation. It also identified the research gaps discovered in these areas. The results of this study will be an eye opener for researchers and decision makers to think deeply of the adverse effect of water scarcity and drought towards economic development of a nation. Hence, it becomes imperative to identify evolutionary algorithms that can address this issue which can hamper effective hydropower generation.

Keywords**—**Evolutionary algorithms, genetic algorithm, hydropower, multi-objective, reservoir operations.

I. Introduction

DUE to the rapid development in some nation economies coupled with the surge in demand for energy, energy shortages are now becoming a challenge to the world. Energy security is important for every country since it promotes economic development. As a result of growth in population, socioeconomic development, industrial and agricultural development in most developing nations, a tremendous increase in energy demand is seen in the past decade. Hydropower is a clean and renewable source of energy that is used to generate electricity. Finding ways to attain a safe, secure and sustainable form of energy has attracted the society and governments attention. However, all kinds of demand for water resources must be considered (domestic, industrial, irrigation and hydropower generation) before optimizing the reservoir operation for hydropower production [1]. Conceivably, growth in electricity usage shows that electricity is one of the most multipurpose energy carrier in today's modern global economy [2]. The spiral electric power utilisation from residential and industrial sectors of a country, along with costs associated with provision of energy to the sectors and the knowledge of fossil fuel reserve limits, have stimulated the necessity for this study on review of application of evolutionary algorithms on hydropower production, an aspect of reservoir operation. The maximum power generated by hydropower station is largely dependent on the annual runoff and reservoir operations management [3]. Various studies has taken cognizance of uncertainties in multi objective problems of reservoir operations [4], optimal operation policy in reservoir [5] and efficiency of evolutionary algorithms in achieving better Pareto optimal solution when applied in reservoirs [6]. However, reservoir operation is not devoid of flood, drought, environmental consequences, water supply, navigation and hydropower thereby making it a complex multi objective problem. Description of the reservoir operation is always attributed to uncertainties such as future inflow, future demand, unforeseen climate conditions, seasonal and economic effects. These factors are bound to change the state of any reservoir system. Nevertheless, hydropower production is basically known for its dynamic complex nature. Such as, generating more electricity in a period of low water level will result to having less water in the reservoir for future production [7]. Previous studies have shown that many optimization algorithms have been used to solve reservoir operation problem. Hydropower management system is a function with many constraint and objectives. In solving this problem, several techniques have been presented in recent years such as linear programming (LP), nonlinear programming (NLP), progressive optimality algorithm and dynamic program (DP). But, all these methods suffer from dimensionality and slow convergence. Hence evolutionary algorithms (EA) were developed, such as differential evolution (DE) [8], cultural algorithm (CA), particle swarm optimization (PSO) [9], genetic algorithm (GA) [10] and artificial neural network (ANN) [11]. These algorithms have been used widely to solve multi objective problems due to their powerful global search abilities [12] and achievement of high quality solutions in an adequate computational time [3]. Evolutionary algorithms ascertain optimal solution from a population rather from single point thereby placing it above other optimization techniques for solving real world issues [13]. Recently, differential evolution (DE) due to its popularity and characteristics in handling multi objective

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optimization problems, has been applied to solve daily optimal hydro generation scheduling problem [7]. Also, genetic algorithm has been applied by [14] to solve hydropower generation expansion planning problem.

This paper is organized as follows. Section II gives a brief outline of multi objective optimization. Section III describes hydropower generation. Section IV briefly explains evolutionary algorithms, differential evolution and genetic algorithm. Section V gives an overview of literature studies conducted on hydropower generation. Section VI outlines the conclusions.

II. Multi-Objective Optimization

A class of real world problem represent multi objective optimization problems which involves trade-offs, benefits, and constraints. For example, some multipurpose reservoir serve the purposes of hydropower generation and municipality water supplies, but the operator of the reservoir may decide to maximize hydropower generation benefit and releases little amount of water for municipal supplies. Ideally, it is known that these objectives conflict with each other. The profit desired to be made on power generation would decrease water supply releases since the decision on both is taken and acted on simultaneously. Hence, the operator would need to consider possible trade-off solutions prior to choosing the best alternative. The Pareto front describes the optimal trade-off solution amongst the goals. In this, an objective function is attained at the expense of another alternative performance [6]. Through the use of optimization, dominated solutions are discarded, and the non-dominated solutions are appraised for trade-offs, thereby giving the decision maker an avenue to choose from a smaller set of preferred options [15]. Varied techniques such as heuristic algorithms like EAs exist in solving multi objective problems especially in reservoir operations. Some of these EAs are discussed below;

A. Evolutionary Algorithms

Motivated by various mechanisms of biological theory, evolutionary algorithms (EAs) are the best established system theoretic class of metaheuristics that are appropriate to solving water resources problems and challenges [16]. Inspired by diverse mechanisms of biological growth (e.g. mutation, crossover, selection and reproduction) [16], EAs discover acceptable solutions which corresponds to challenges such as natural resources management and varied problems in the real world through the use of evolution theory. EAs have been identified rapidly for its ease in handling multiple objective problems. Evolutionary algorithms allow the discovery of a whole set of Pareto-optimal solutions in a single run of the algorithm. Several types of evolutionary algorithms exist including genetic algorithms (GAs), evolution strategies, learning classifier systems, evolutionary programming and genetic programming (GP). GAs have been promising and widely accepted as the dominant optimization methods [17]-[19]. Though all the above EAs are stimulated by the same natural evolution but each of them constitutes different approach. EAs procedure includes initialization, mutation, crossover and selection [12].

Evolutionary algorithms have the characteristic of displaying an adaptive behaviour. This allows (EAs) to handle high dimensional non-linear problems without precise knowledge of the problem structure. EAs are very robust to time-varying behaviour but can show low speed of convergence. EAs have the benefits of conceptual simplicity, can be broadly applied to problems, outperforms classic approaches on real problems, are likely to utilise knowledge, can crossbreed with other methods, has parallelism in search method, strong to dynamic changes- used in adapting solution to varying circumstance, proficiency for self-optimization and can solve problems with no identifiable solutions [20]. EAs also have the ability to simultaneously optimize contradictory objective functions [21]. Some disadvantages of evolutionary algorithms include high computational demand, difficult adjustment of parameters and heuristic principle [22].

Many researchers have studied reservoir operations using single and multi-objective techniques [19], [23]-[29]. In all these studies, reservoir problems were solved using varied optimization techniques. Particularly, genetic algorithm and differential evolution algorithm are widely used in optimizing reservoir operations. Genetic algorithms (GAs) have been demonstrated to be superior to most traditional methods like linear, non-linear and dynamic programming. For the purpose of this study, genetic algorithm (GA) and differential evolution (DE) will be discussed.

B. Genetic Algorithm (GA)

Genetic algorithm was defined by [30] as exploration algorithms which are based on natural selection mechanics. GA represents solution with chromosomes or strings of variables that show the genetic formation of an individual. It uses some problem dependent knowledge known as fitness function to direct its search to favourable areas [31]. The genetic operators used are selection, mutation and crossover. Perturbation occurs according to random quantity. Binary encoding of the solution parameters was the basis on which GAs was developed. Application of the penalty function approach will reduce the chromosomes fitness so as to reduce the constraints [32]. The importance of GA to the study of reservoir operation includes:- GA exploits historical data to speculate on new offspring with improved performance. A coding parameter set of the GA allows it to differ from most of the usual optimization and search procedures. GA works concurrently with multiple points and conducts search using stochastic operators to produce new solutions. When used as an optimization technique, the search space may not be continuous so GA has minimal chance of getting stuck at a local optimum. To appraise the fitness or suitability of the derived solutions, GA needs only a suitable objective function that allows it to map from chromosomal to solution spaces [31]. The basic principle of GA is the natural selection or survival of the fittest disposition. GA has the disadvantages of slow repetitions to reach global optimal solution, getting stuck at a local optimum and slow convergence. Examples of improved genetic algorithm include chaos genetic algorithm (CGA) [33], non-dominated sorting genetic algorithm (NSGA) [34] and non-dominated sorting genetic algorithm II (NSGA-II) [35].

C. Differential Evolution

Differential evolution algorithm was introduced by Storn and Price in 1995 [8]. DE was proposed to achieve faster convergence and robustness in optimization problems. It is different from other EAs at the recombination and mutation stages. DE uses weighted difference approach amongst solution vectors to perturb the population distinct from the GAs where perturbation happens in accordance with a random quantity. Two operators used for DEs technique include the mutation and crossover methods. The perturbation are usually made in any randomly chosen vector (rand) or in the best vector of the previous generation (best). The basic principle of DE algorithm is survival of the fittest [8].

According to [17], DE technique has proven to be numerical, robust and faster for numerical optimization problems and is able to optimize all discrete and continuous variables, integers and can handle all nonlinear objective functions with nontrivial solutions. DE has the advantages of handling difficult problems with interdependencies amongst input parameters and this can be solved by carefully rotating the coordinate system of the given function, it is also devoid of computational cost and operational complexities. DE also retains correlated self-adaptive mutation step sizes so as to make quick progress in optimization. An example of an improved version of DE is multi objective differential evolution (MODE), proposed by [17].

DE disregards the use of some probability functions to present variations to the population but instead uses alteration between randomly selected individuals as the source of random variations for a third vector known as the target vector. This is the reason why the trial solutions that will contest among the parent solutions are produced by adding the weighted difference vectors to the target vector [36].

D. Reservoir Operation

Reservoirs are facilities used to store away water for prospective use. Reservoir purposes ranges from recreation, flood control, irrigations, hydropower purposes, domestic and industrial water supplies. It is constructed mostly to provide flood protection for downstream areas and also for low flow regulation especially during dry seasons. Reservoirs which are composed of varied physical components such as pipelines, irrigation area and hydropower plants have a heightened need for information on hydropower production and how it is handled. [37]. To determine the reservoir size before a dam construction, an optimization modelling is needed before the plan takes place. Irregular inflow of water and other uncertainties must be catered for through set guidelines on reservoir management planning [37].

Several studies have reported the use of evolutionary algorithms in reservoir operation. A study by [26], involves proposing the design of a fuzzy linear programming reservoir process technique and applying this approach to Jayakwadi reservoir stage-II, Maharashtra state, India with the aim of maximizing the hydropower and irrigation releases using three different models. The primary model involves fuzzy resources, second model considers fuzzy technological factors and third model reflects both one and two models. The outcomes revealed that the recommended method provides a useful instrument for reservoir operation.

Li, Wei [38] developed a parallel dynamic programming algorithm to optimize a multi-reservoir system joint operation. The parallelization is based on the message passing interface (MPI) protocol and the distributed memory architecture. The results show that the good performance in parallel efficiency was exhibited by the parallel DP algorithm and was also applied to five-reservoir system in China. In another study, Zhang, Jiang [39] presented the improved adaptive particle swarm optimization (IAPSO) to resolve the problem of reservoir operation optimization (ROO) that involves a lot of conflicting objectives and constraints. The results of this method show that IAPSO gives a good result in terms of power generation benefit and convergence performance with much robustness and effectiveness when compared with other methods.

Reference [19] applied a multi-objective evolutionary algorithm, the non-dominated sorting genetic algorithm (NSGA-II), to observe a Taiwan multi-reservoir system operation. The study was applied to the Feitsui and Shihmen reservoirs in Northern Taiwan. Realization of optimal joint operating strategies by NSGA-II was the objective of the model. This was to minimize the shortage indices (SI) value. A day to day operational simulation model to reduce the shortage indices (SI) values of both reservoirs for a long term simulation period was developed. The results showed that a promising approach is provided by NSGA-II by providing enhanced operational strategies which would lessen the SI for both reservoirs using a 49-year data set.

Reference [23] presents a multi-objective evolutionary algorithm (MOEA) to develop a set of optimal operation plans for a multipurpose reservoir system. A population based search evolutionary algorithm named multi-objective genetic algorithm (MOGA) to create a Pareto optimal set was employed and applied to Bhadra reservoir system, in India. The outcomes specified that the evolutionary algorithm proposed was able to suggest many alternate plans for the reservoir operator thereby allowing flexibility in choosing the best, hence proving that MOGA was capable of solving multi-objective optimization issues.

In a study carried out by Chang [40], a recommendation on a reservoir flood control optimization model with linguistic description of existing and required procedures for coherent operating decisions was proposed. A genetic algorithm (GA) was used to represent a search instrument and formulated reservoir flood process as an optimization issue. The GA was used to examine a global optimum of a combination of mathematical and non-mathematical inventions. The recommended methodology was applied to the Shihmen reservoir in North Taiwan. Hence, it was discovered that a penalty-type genetic algorithm can conveniently offer balanced hydrographs especially when some constraints are violated due to its huge number and the proposed model can help in guiding the GA search process.

Reference [41] applied differential evolution (DE) for the best operation of multipurpose reservoir with an interest to exploit the hydropower production. The algorithm application was undertaken through Jayakwadi project stage-1, Maharashtra state, India. The outcomes of GA and ten DE strategies show that both results can be compared.

Chang, Chang [25] proposed a procedure which includes the constrained genetic algorithm (CGA) whereby the natural base flow necessities are taken into consideration as limitations to reservoir operation water flow when optimizing the 10-day reservoir storage. A lot of penalty functions aimed for diverse types of limitations were integrated into the operational goals of the Shih-Men Reservoir to form the fitness function. The shih-Men Reservoir and its downstream were used as a case study. Hence, it was concluded that to optimize reservoir operations for numerous users and enhance the effectiveness and efficiency of water supply ability to natural base flow requirements and human needs, CGA approach is the best option to use.

Karamouz, Ahmadi [42] presented a procedure to improve operating plans for a reservoir release with satisfactory quality and quantity. A model that takes account of a genetic algorithm (GA) optimization model associated with a reservoir quality simulation model was recommended. To reduce the run time of the GA-based optimization model, the key optimization model was divided into a stochastic and deterministic one. The independent role of the optimization model was based on the Nash bargaining theory so as to take full advantage of the reliability of attaining to the demands of the downstream chain with suitable water quality, prevention of the reservoir degradation and maintaining a steady balance of reservoir storage level. The proposed method was applied to the Satarkhan reservoir in the north-western part of Iran. The results show that the recommended model can be utilised in reservoir operation as an operational tool.

Reference [43] designed the water distribution network (WDN), a novel multiobjective optimization system to advance the efficacy of a typically difficult water resource problem using decomposition techniques. A propagation method was proposed to evolve Pareto fronts of different sub-networks towards the full network Pareto front. The results from the proposed approach show that it is able to find better fronts than conventional complete search algorithms with better efficiency.

Reference [44] presented a stochastic methodology that depends on real coded genetic algorithms for enhancing the process of reservoirs in an on-demand irrigation system. The procedure shows the appropriateness of the difference between supply and demand accounting for the storage volume of the reservoirs. A weighted objective function was also proposed, containing damages of the permissible reservoir water levels. The study was tested on the Sinistra Ofanto irrigation scheme, (Foggia, Italy). The results show that the model was robust and efficient.

Chen, Mcphee [45] developed and applied a novel multiobjective optimization known as macro-evolutionary multi-objective genetic algorithm (MMGA) to reservoir operation. MMGA was applied to rule-curve optimization of a multipurpose reservoir scheme. This issue involves a nonlinear problem with mixed integer variables and a non-convex Pareto frontier. Decisions can be made by the operators with respect to hydropower generation and water supply release from the operating rule curves by defining long term targets release and storage level. Implementing the algorithm is easy and it yields enhanced range of solutions than NSGA-II. The results show that MMGA discovered an adequate solution spread on the Pareto front with a low diversity metric.

Practically, due to growing trend of competitiveness in industries and nations, with the urge to achieve competitive advantage, the demand for energy supply has also increased when compared with water resource demand. To remain competitive, costs must be reduced and that is the reason why developing and developed countries opted for renewable energy through hydropower production which is a clean and cheaper form of generating electricity without adverse effect on the environment. Hydropower production is a multi-objective problem with many objectives and constraints.

III. Hydropower Production

In comparison with the usual traditional fossil fuel, hydropower is a clean and renewable form of energy with remarkable advantages such as the use of water to generate electricity without creating pollution. Hydropower also has the ability that uniquely allows it to change its output rapidly, thereby enabling it to meet varying demands of electricity then maintain demand and supply balance Zhou, Zhang [46]. It is generated from the force of moving water.

Interest in hydropower research studies has grown [47]. Kıran, Özceylan [48] proposed a novel hybrid method (HAP) to evaluate energy demand of Turkey using the Ant colony optimization (ACO) and Particle swarm optimization (PSO). The proposed energy demand model (HAPE) was the first model which incorporates the PSO and ACO techniques. The PSO is used for continuous optimization while ACO is used for discrete optimizations. Using gross domestic product (GDP), a hybrid method using both metaheuristics techniques was developed. The results obtained shows that the relative estimation error associated with the HAPE model was low and quadratic form (HAPEQ) gives a defined fit solution because of the socioeconomic indicators.

Li, Zhou [49] proposed an enhanced decomposition-coordination and discrete differential dynamic programming (IDC-DDDP) technique. To reduce generation time, the strategy adopted, assumes initial solution is randomly generated. Another proposal was undertaken which includes a relative coefficient based on maximum output capacity to generate more power. To enhance convergence speed, an adaptive bias corridor technology was proposed. This was applied to the large scale hydropower system in the Yangtze River basin. The results shows that when IDC-DDDP was compared to other techniques, it performed better in convergence speed and total power generation and can solve optimization of large-scale hydropower system (OLHS).

Yoo [50] proposed an LP technique for maximizing hydropower generation based on calculating optimal values. Hence, the opinion suggested that hydropower must continually produce electricity and will be sold with minimum and maximum market risk in the deregulated power market. A multi-objective combinatorial optimization method was used to evaluate the ecological-economic tradeoffs and to assist complex decision making with an objective of reducing loss of hydropower and increasing storage capacity [51].

Perez-Diaz, Wilhelmi [52] solved a non-linear programming (NLP) scheduling model that regulates the optimal unit commitment in terms of scheduling (start-ups and shut-downs) and hourly power output. The outcomes shows in order to maximize revenue, the model performs well through providing a feasible and optimal operation schedules by both plant station with the hourly generated power.

The ideal performance of PSO to resolve short-term hydroelectric generation scheduling of a power system through wind turbine generators in relation to computation efficiency and quality was demonstrated by Lee [53].

An immune-based algorithm with PSO that is used to optimise load distribution between cascade hydropower stations was proposed by Li, Wang [54]. The results show that through high convergence precision, a good load distribution is attained. It was also concluded that real time hydropower reservoir involves a continuous decision making process which evaluates the released volume of water and reservoir water level. This is because hydropower generation operation decision is undertaken as a strategic plan.

Zhang, Zhou [5] presented a problem of unparalleled expansion rate and scale of development of hydropower which has been modelled as a challenge to the operation of multi-reservoir system (OMRS). The OMRS aim is to discover an optimal hourly water discharge rate in each hydro station of a multi-reservoir system so as to reduce the power deficit and then share the uniformly deficit if there is any. A proposed model known as multi-elite guide particle swarm optimization (MGPSO) is introduced using archive set in the typical PSO. To provide multi-elite flying directions for particles, an external archive set that can preserve elite solutions along evolution process is employed. To handle the issue of constraints in operation of the OMRS, an effective constraint handling method was presented. The proposed model was applied to a multi-reservoir system that consists of 10 cascaded hydro plants for case study. The simulation outcomes of MGPSO was benchmarked with numerous previous techniques and it was discovered that the novel model can achieve better solutions with little energy deficit, hence proving it to be an alternative in dealing with OMRS issue.

Yuan, Zhang [7] presented the daily optimal hydro generation problem (DOHGSB) as a complicated nonlinear dynamic constrained optimization problem that plays a critical part in the economic operation of electric power systems. A novel enhanced differential evolution algorithm that can solve DOHGSB was proposed. Three simple feasibility based selection comparison models entrenched into DE were developed to lead the process toward feasible search space region, so as to handle constraints effectively. Chaos theory was also applied to the proposed technique to obtain self-adaptive parameter settings in differential evolution (DE). Four interconnected cascade hydro plants were used to test the proposed technique's feasibility for daily generation scheduling of a hydro system. A comparison of the test results with the ones obtained by the two phase neural network method and the conjugate gradient in relation to solution quality was carried out. Higher quality solutions were noticed in the proposed technique after the simulation was completed.

Doganis and Sarimveis [55] proposed a methodology to solve the issue of concurrent use of conventional and hydroelectric power units with an aim of increasing power production operations over a short term. A convex mixed integer quadratic programming (MIQP) technique was presented and it is a type of nonlinear technique that allows the global optimum to be reached in a short computational time. The application of this new technique to a realistic power production system demonstrated its efficiency.

One of the most vital problems in the world is the balancing of human and environmental flow requirements. This study uses an optimization technique for modelling reservoir operations to compare varied environmental flow requirements of river ecosystems. Four different scenarios were recognised based on environmental flow requirements and the range of variability approach (RVA) is used to determine the probable alterations of each scenario. The comparison results show that the system operation under the environmental design flow (EDF) imposes little hydrological alteration and provides adequate power production. The outcomes demonstrate that this technique will be a powerful tool for researchers to perform reservoir operations in balancing human and environmental requirements [56] .

Reference [57] proposed a parallel deterministic dynamic programming (PDDP) and a hierarchical adaptive genetic algorithm (HAGA) to solving reservoir operation optimization (ROO) problem which involves many objectives and constraints. It was discovered that multi-threads exhibit better speed up than single threads in the PDDP technique. To determine the parameter settings, an adaptive dynamic parameter control mechanism was applied in the HAGA technique and an elite individual is preserved in an archive from the first to second hierarchy. When compared with other techniques, HAGA provides better operational results due to the population diversity carved out by the archive operator. HAGA and PDDP were compared showing two contradictory objectives in the ROO issue – reliability and economy. The proposed HAGA model integrated with parallel technique is observed to be better with respect to power generation benefit and computational efficiency when compared to PDDP.

A study on the heightened concern about the reservoir ecological environment requirement was conducted by [58]. A multi-objective optimization adaptive differential evolution with chaotic neuron network (MOADE-CNN) is presented to solve the issue. To adjust the search scale with the evolution proceeds, an adaptive crossover rate is created. To avoid convergence problem, the chaotic neuron operation is integrated into the mutation operator thereby controlling the population diversity mostly when differential evolutions falls into local optima. To verify the efficiency of the proposed model, simulation on some benchmark problems was conducted with an acceptable outcome when compared to well-known multi-objective optimization problems. The proposed model (MOADE-CNN) was applied to a cascaded power operation system proving that the model can be a favourable alternative. It can also provide optimal trade-offs for multi-objective long term reservoir operation scheduling taking into account ecological environment problem.

IV. Conclusion

In reviewing the above literatures, a demonstration on the determined and useful ability of evolutionary algorithm in deciphering real world problems efficiently was shown. From this review, it can be seen that various global researchers have applied, compared and developed different evolutionary algorithms to solve reservoir operation problems, specifically hydropower. Another aspect of evolutionary algorithms which was evaluated in this study is the ability to appraise multi-objectives issues and attain optimal solutions. It becomes normal to state that Genetic algorithm (GA) has been the most prevalent EA used in solving complex nonlinear optimization problems and achieving global solutions. EAs have been proven over time to converge and attain better solution spread than non-dominated set. From this review, it is observed that most studies have critically dealt with application of EAs in hydropower in areas such as (1) efficiency in producing better Pareto front. (2) deriving optimal operation policy and (3) uncertainty in multi-objective problems. Nonetheless, the research gap identified in this review under study includes:

- The uncertainties in hydropower such as unforeseen climatic conditions, seasonal and economic effects of hydropower generation has not been critically dealt with in research studies.
- Drawbacks of reservoir operation such as drought and scarcity of water. This can adversely affect the ability of hydropower station to generate electricity thereby exerting ripple effects on the society. Fishes will die due to dwindling water levels in reservoirs, industries will shut down and the economy of a nation can be totally crippled without electricity being produced from hydropower generation.

Now, the questions observed in this review paper are:

How can the issue of low level water that is needed to generate electricity through hydropower be addressed using evolutionary algorithm techniques?

Which EA technique is applicable to specifically address issues of drought and water scarcity especially in semi-arid countries with low amount of rainfall?

Therefore, in reviewing this study, some research gaps have been identified in relation to the application of evolutionary algorithms to reservoir operation for hydropower production which is a multi-objective problem. Future research should therefore concentrate on the issues raised which will also be an eye opener to decision makers.

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