Optimal Hydropower Production for Xin’anjiang hydropower Station using Future Scenarios

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Abstract**—**This study integrated a mathematical model with particle swarm optimization technique to study the climate change impact on hydropower generation and to get maximum benefits. Change factor downscaling method and Arc SWAT hydrological model have been used to downscale future scenarios and for the simulation of past and future stream flows, respectively. Moreover, Particle Swarm Optimization (PSO) technique has been applied to the past and future water flows to get the maximum hydropower production. The results revealed that the future hydropower generation is more than the past generation. Results depicted that with the allocation of water optimally, hydropower generation increased in the future with the application of the proposed model.

Keywords**—** PSO, Future Scenarios, Water allocation, Hydropower Station.

I. INTRODUCTION

Due to climate change, water resources optimal use is becoming important now a day. water is the vital component for all living things and becoming limited source that is necessary for agricultural, hydropower generation, industrial use, and economic development of a nation. Runoff on the surface of the earth is one of the key source of water for domestic, industrial, and agricultural use. Though, its allocation and optimal use is quite important and became mathematical based due to complication and the importance of optimal allocation of water [1-3]. During the 19th century, many programming approaches, linear to non-linear, were used for the reservoir operation [4-9]. Many water researchers and scientist applied these methods for finding the solution of different problems [10-12]. One of the utmost problematic parts faced in real engineering optimization design is management of constraints [13-15]. Real-life limitation normally presents several nontrivial and nonlinear constraints for the solution of engineering design problems [16]. These Constraints frequently limit the possible solutions**.** Due to the difficulty and randomness of constraints, a deterministic solution of the problems is quite tough to find. In recent decades, numerous approaches have been suggested for the treatment of constraints and more than a few evolutionary procedures have been planned for these engineering optimization problems. Lately a new evolutionary technique, named particle swarm optimization (PSO), proposed by Kennedy and Eberhart, has been utilized worldwide [17-24].

Moreover, GCMs scenarios are widely used around the globe for the future prediction of the streamflows.

Xin’anjaing hydropower station Optimization is a complicated problem. This paper focused on the optimal electricity generation using two different waters available scenarios (1970-2010 and 2010-2040). 2010-2040 flow is obtained after, calibration and validation of SWAT model, and downscaling of future data. This paper discusses how we could get the maximum benefit in the future by using optimal water resources.

II. MATHEMATICAL MODEL

The mathematical model comprises of the objective function and constraints and take water levels as decision variables and maximizations of the hydropower as objective function. The objective function is:

$$G=Max= \sum_{n=1}^{I}\sum_{j=1}^{M} A_j q_{jt} H_{jt} \Delta \qquad (1)$$

The constraints are given as below

Water balance equation

$$V_{j,t+1} = V_{jt} + \left(Q_{\gamma jt} - Q_{jt}\right)\Delta t \qquad (2)$$

Reservoirs discharge limits

$$Q_{jt.min} \leq Q_{jt} \leq Q_{jt.} \qquad (3)$$

Reservoir storage volume limits

$$V_{jt.min} \leq V_{jt} \leq V_{jt.max} \qquad (4)$$

Hydropower station power generation limits

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$$N_{jt.min} \le N_{jt} \le N_{jt.max} \quad (5)$$

T total period count within a year, T=12
M total number of reservoirs
A_j Power generation coefficient
G maximum power generation output from hydropower
Q_{vjt}Inflow of reservoir j for period t, m^3/s
H_{jt}Average head of reservoirs j for period t, m
$V_{j,t+1}$Volume of reservoir j at the end for period t
$Qj_{t.min}, Q_{jt.max}$Minimum and maximum water discharge of reservoir j for period t, m^3/s
$V_{jt.min}, V_{jt.max}$Minimum and maximum volume of reservoir j at time t
$N_{jt.min}$Minimum hydropower generation constraint of reservoir j for period t
$N_{jt.max}$Installed plant capacity kW

III. PARTICLE SWARM OPTIMIZATION

Particle swarm optimization, developed by Keneddy and Eberhart (1995), has divided into two phases and its working algorithm is shown in figure 1. In initial phase particles are distributed randomly in the search space and during evolutionary phase particles change and adjust their position in search of optima until termination by following the best particles. Suppose particles are distributed in a Z dimensional space with v velocity with position $k_x = k_{x1}, k_{x2}, k_{x3}, \ldots k_{xz}$) with velocity $V_x = (V_{x1}, V_{x2}, \ldots\ldots V_{xz})$. And the velocity and position after t+1 time is given as:

$$V_x^{t+1} = w * V_x^t + c_1 rand_1(pbest_x - k_x^t) + c_2 rand_2(gbest_x - k_x^t) \quad (6)$$

$$k_x^{t+1} = k_j^t + V_x^{t+1} \quad (7)$$

where $k^{min} < k_x^{t+1} < k^{max}$

where x= (1,2…….population size/swarm),i=number of reproduction steps, V_x^t::the speed vector of particle x in the xth reproduction step; w=inertial weight, c_1, c_2:learning rates, , $rand_1, rand_2$: independent random variables from (0,1) uniformly distributed, $pbest_x$best solution reached by particle x, $gbest_x$:the best solution reached by the swarm.

IV. CHANGE FACTOR DOWNSCALING METHOD (C.F)

The change factor method [25, 26] is a bias correction method that is used to reduce bias among observed data and model outputs. The main purpose of the CF is to modify the daily variables in the data series of the precipitation and the temperature of the future periods by adding monthly mean changes to the output of the GCM. The modified daily maximum and minimum temperatures (Tmax and Tmin) of the future data series can be obtained by adding monthly changes between the base years and the future years of the GCM, while future precipitation can be obtained by multiplying the ratio of the future to the reference year monthly data series with the daily precipitation of the base year.

The temperature and precipitation equations to be used are given below:

$$P_{adj;fut;d} = P_{obs;d} \times \sum_{i=1}^{k} p_i \left(\frac{\overline{P}_{GCM,fut,m}}{\overline{P}_{GCM,ref,m}} \right) \quad (1)$$

$$T_{adj;fut;d} = T_{obs;d} + \sum_{i=1}^{k} p_i (\overline{T}_{GCM,fut,m} - \overline{T}_{GCM,ref,m}) \quad (2)$$

where $P_{adj;fut;d}$ and $T_{adj;fut;d}$ are the future adjusted daily precipitation and temperature series, whereas $P_{obs;d}$ and $T_{obs;d}$ are observed daily precipitation and temperature, $\overline{P}_{GCM,futr\ m}$ and $\overline{T}_{GCM,futr\ m}$ are future and base year mean monthly temperature and $\overline{P}_{GCM,refr\ m}$ $\overline{T}_{GCM,refr\ m}$ are future and base years mean monthly precipitation data series of GCM, respectively. p_i is the grid weight of each grid cell, and k is the total number of cells

V. FUTURE SCENARIOS

The General Circulation Models (GCMs) have been downscaled using Change factor downscaling technique as given above. The RCP4.5 of CCSM4 GCMs has been downscaled to local scale and climatic variables obtained after downscaling are incorporated into Arc SWAT hydrological model for runoff simulation.

A. *ArcSWAT data Inputs*

ArcSWAT hydrological model requires spatial and temporal data requires for the simulation of the streamflows. The data sets obtained and used in this study are described below.

Spatial datasets

The spatial database includes the topography of the area, land use and soil type. Moreover, the Digital Elevation Model (DEM) for land use and soil are the inputs of the Arc SWAT model. The DEM data of 90 m spatial resolution were retrieved from http://www.cgiar-csi.org/data/srtm-90m-digital-elevation-database-v4-1 which was processed to delineate the watershed and other topographic parameters. Finally, a watershed area of about 11675.710 km^2 was attained with 17 sub-basins. Land use and its change is another important data needed and this data was extracted from the USGS Land Cover Institute data portal (http://landcover.usgs.gov/). The soil map of the study area was obtained from the United Nations Food and Agriculture Organization (http://data.fao.org/map?entryId=446ed430-8383-11db-b9b2-000d939bc5d8). The HRUs were defined, finally, by overlying the soil and land use data.

Temporal data

Time series data of precipitation and temperature are compulsory to run Arc SWAT simulations as flows change due to these two climatic variables. These temperature and precipitation data was obtained from the China metrological department for the past years for the calibration of hydrological model while the data for the future precipitation and temperature was downloaded from CMIP5 website. The other climatic data requirement for SWAT hydrological model include wind speed, relative humidity and solar radiation but these data are optional because Arc SWAT has a weather generation function to generate these data itself.

The other important temporal data used in Arc SWAT is hydrological data of the watershed including surface runoffs, which is mandatory for the calibration and validation of the model. This data was collected from the Hydrology Bureau of Zhejiang province for a period of 1979-2005. Data from 1979-1993 were used for the model calibration, while data from 1994-2005 were used for the validation of the model.

Furthermore, ArcSWAT-CUP tool was used for the calibration and validation of the model.

VI. CASE STUDY

The study area, which is the Xin’anjiang watershed, lies between 117^{o}38’15’’-119^{o}31’56’’ longitude and 29^{o}11’9.9’’-30^{o}13’49” latitude, as shown in Figure 2. The watershed has an area of about 11675.710 km^{2}. In this watershed are located the Xin’anjiang (29^{o}28’38.16 Latitude and 119^{o}13’31’’ Longitude) hydropower stations. The Xin’anjinag hydropower station is located at the Xin’an River in china with 9 powers generating turbine having an 845,000-kW installed capacity.

Change factor downscaling technique has been employed at the future CMIP5 RCP4.5 data to downscale climatic variables to local scale. To simulate future streamflows and to calibrate and validate of the hydrological model, ArcSWAT hydrological model and SWAT-CUP have been used. After that, A Mathematical model has been developed for monthly inflow data of past (1970-2010) and future (2010-2040), which is obtained from RCP4.5 scenario of CCSM4 model of CMIP5 future data and downscaled using change factor downscaling technique, and calculate the annual energy. Results are shown in figure 3, 4 and given in table 1. Results revealed that in the future more water will be available as shown in figure 4 a and b and we can get more electricity if we will use this water optimally. In managing our discharge as given in figure 3 and 4, we can get maximum benefits from this hydropower station in future.

As shown in figures and given in table 1, we can generate more electricity amount using optimization technique than conventional method. Results revealed that rainy year can generate more electricity amount than dry and average rainfall years because of water availability in rainy year is more than dry and average rainfall years. it can also be seen that in future flow will be increase than past flow in the area. Only 3.2*10^{8} kWh of electricity amount can be generated if we use conventional methods to generate electricity for the rainy year stream flows. Similarly, about 2.8*10^{8} and 2.4*10^{8} kWh electricity amount could be generated using conventual methods for average and dry years flows. Contrary to the conventual methods, we could generate upto 7.02*10^{8}kWh electricity amount using the same past flow by the application of mathematical model and particle swarm optimization technique.

Results revealed more electricity generation by using future streamflows than past streamflows. For future streamflows, results revealed that we can generate upto 10.2 * 10^{8} kWh of and only 7.2*10^{8}kWh electricity using future and past streamflows, respectively in the rainy years (years with maximum rainfall) as given in the table 1 and presented in the figure 3 and 4. Similarly, average and dry years electricity generation for the future streamflows is more than the past years streamflows as presented in the table 1. Similarly, an electricity amount of 9.8*10^{8} and 8.2*10^{8} kWh could be generated for the average and dry years as given in the table 1 for future streamflows. Similarly, the electricity generation for the past years flows during average and dry years are 6.02*10^{8} and 5.01*10^{8} , that is quite low than the average and dry years electricity generation for the future flows.

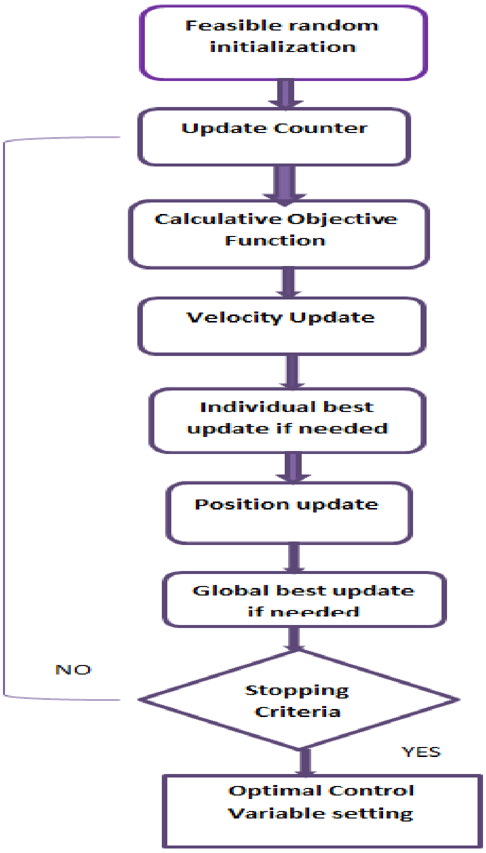

Fig. 1 Schematic diagram of particle swarm optimization algorithm

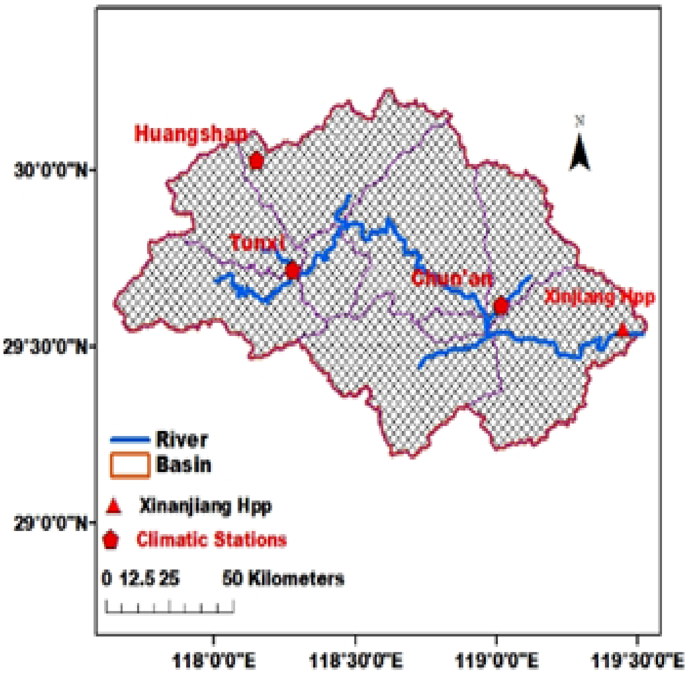

Fig. 2 Study area

Figure 3 shows that the water release pattern should be followed as given in the figure with the start of water release in the end of January with maximum water release more than 1000 cubic meter per second in the month of September for optimal electricity generation by utilizing the past years flows. Figure 3 presented that the water release for the past streamflows should decrease and then increase in the month of march and again start decreasing till the end of April. After that, water release peak increasing continuously till the month of September and then start declining till December.

Similarly, for the optimal electricity generation in the future, water release from the reservoir should follow the same pattern as shown in the figure 4b. Figure shows the release of water starts in the month of January and it starts increasing in the month of February and achieve its peak in the month of May with a release more than 1600 cubic meter per second. After that water release should decrease till June and then increase according to the flow pattern as shown in figure 4b and attain peak in September to get maximum optimal electricity generation.

Furthermore, from the table 1, it is clear that the execution time for the past flows is less than for the future flows. Execution time during the rainy year is about 2.7 second for the past streamflows whereas about 2.6 second for the future streamflows. Moreover, execution time for the average and dry years are less than the execution time for the rainy years for both past and future years streamflows as presented in the table 1.

TABLE I RESULTS OF DIFFERENT ALGORITHMS

	conventional	**PSO**			
		Past		**Future**	
Year	**Energy output (10 ^{8}kWh)**	**Execution time(s)**	**Energy output (10 ^{8}kWh)**	**Execution time(s)**	**Energy output (10 ^{8}kWh)**
Rainy year	3.2	2.7	7.02	2.641	10.2
Average year	2.8	2.5	6.02	2.45	9.8
Dry year	2.4	2.4	5.01	2.34	8.6

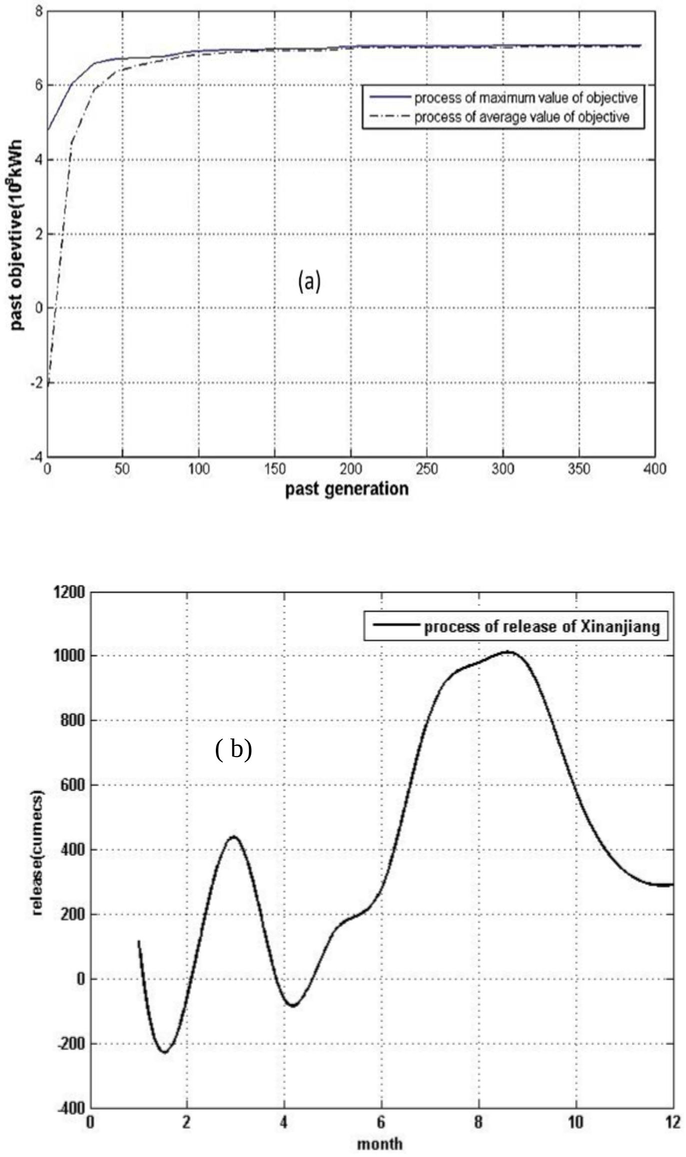

Figure 3: Results of PSO for rainy year (a) Electricity production and (b) water release for past river flows

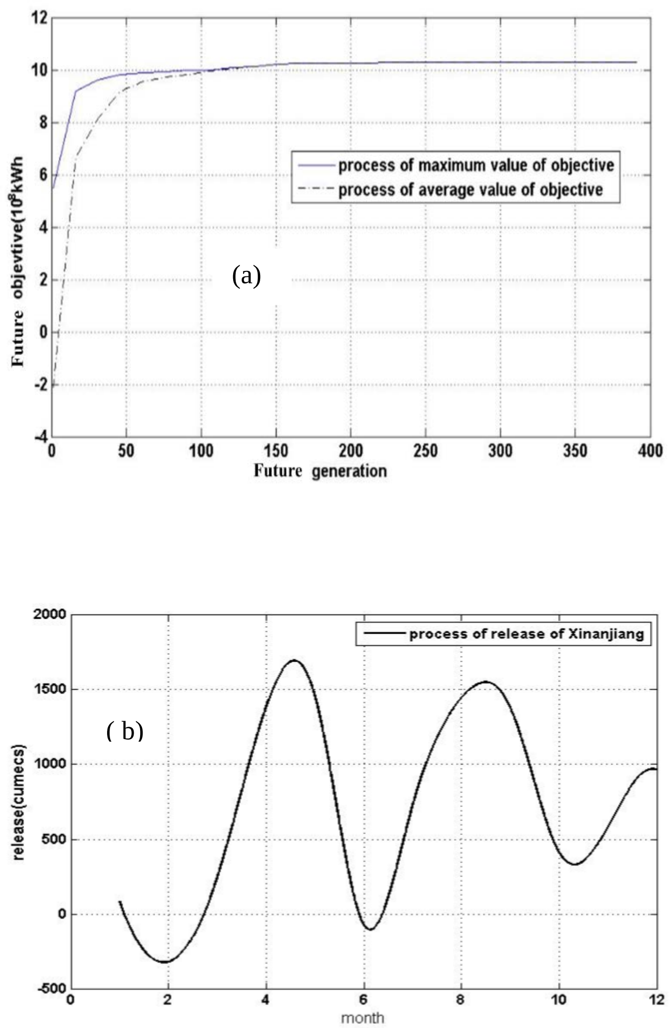

Figure 4: Results of PSO for rainy year (a) Electricity production and (b) water release for future river flows

VII. CONCLUSION

In this study, a mathematical model has been developed for the hydropower generation study in the near future till 2040. The mathematical model was integrated with particle swarm optimization technique for optimal electricity generation for the Xin’anjaing hydropower station. Climatic variables and future streamflows have been downscaled and simulated using change factor downscaling technique and SWAT hydrological model for Xin’anjiang Hydropower station.

Results revealed that future flows can produce maximum electricity generation than past river flows. Results revealed that the electricity production increases with the application of particle swarm optimization techniques at proposed mathematical model than traditional techniques. Results revealed that rainy year can generate more electricity amount than dry and average rainfall years because of water availability in rainy year is more than dry and average rainfall years. it can also be seen that in future flow will be increase than past flow in the area. We could generate upto $7.02*10^8$kWh electricity amount using the same past flow by the application of mathematical model and particle swarm optimization technique. Moreover, by managing our discharge and water level equivalent to optimal water level, we can produce maximum electricity.

More benefits can be obtained in the form of power production with the application of Particle Swarm Optimization at mathematical model for Xin’anjiang hydropower station than other traditional methods. Results showed the comparatively higher amount of electricity in the future by using future river flows optimally with maximum benefits, When the PSO technique has applied at the past and future river flows.

Results revealed that if the future water flows increased as observed here, more electricity amount could be generated which will be helpful for better future planning for the utilization of these resources optimally. This paper gives a clear picture of the past and future electricity generation using optimal electricity generation technique.

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