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Abstract. Renewable energy sources like solar and wind face an insurmountable obstacle in the form of environmental change-induced discontinuity and instability. Since hydropower is quick to respond and doesn't cost much to alter, it was a common choice for electric energy system correction. A cascade hydropower (CHP) station compensates the hydro power-solar-wind energy system that we present in this study, which considers several long-term goals. Among the model's objectives is the optimization of the power system's annual total power generation while simultaneously minimizing power output variations. As a prerequisite for optimizing hydropower, this model first determines the total Photovoltaic (PV) and wind power, and then feeds those numbers into the power grid. In order to obtain a set of solutions for the model that has been proposed, we suggest an enhanced non-dominated sorting whale optimization algorithm (NSWOA). According to the findings, decision-makers have access to a plethora of options for optimal selection through the revised NSWOA, and hydropower's superior modifying capabilities more than compensate for the PV and wind power's deficiencies.

Keywords. Photovoltaic, NSWOA, Hydro Power Generation, Wind Power, Optimization, Cascade Hydro Power.

1. Introduction

Energy consumption is on the rise due to the expanding economy. Cut backs in fossil fuel use are critical for environmental protection. More and more individuals are thinking about renewable energy these days [1]. Renewable energy sources like solar and wind are gaining popularity. An admirable use of these energies is photovoltaic (PV) and wind power generating. Solar and wind power are intermittent and unpredictable to satisfy grid needs, it is critical to discover a means to increase the quantity and quality of electricity delivery [2]. If this doesn't happen, the electrical grid will be weakened by the erratic and unpredictable electricity [3]. The rapidity and cheap cost of hydropower's adjustment and response make it an attractive complementary energy source that could help reduce the volatility of other
energy sources [4]. Therefore, many methods for running hybrid power generation systems were proposed to fix the problem with PV and wind power that was discussed earlier. Authors [5] proposed a scheduling method for hybrid generation and created a model for lowest-cost optimization with the aim of making hybrid systems more dependable and adaptable. For economic dispatch using hydrothermal wind, authors [6] suggested a strategy. In the end, they settled on a technique for delayed constraint generation based on semi-definite programming (SDP) that was functionally identical. Authors [7] proposed a control method based on the many situations methodology to enhance the operating efficacy of the micro grid. Micro grids that combine energy storage with small hydro-PV power might benefit greatly from this approach. The computational cost of this optimization problem is minimal, making evolutionary algorithms (EAs) a good fit [8]. Some well-known EAs include differential evolution (DE), particle swarm optimization (PSO), and genetic algorithms (GA) [9]. To determine the best solution for the dispatch model of wind-PV-hydro-thermal power systems, authors [10] developed a novel approach known as compound differential evolution (CDE). In practice, there are a number of goals that are considered concurrently with total power generation maximization. When faced with MOPs, one prevalent approach is to employ multi objective evolutionary algorithms (MOEAs) [11, 12]. Authors [13] using an elitist multi-objective non-dominated sorting genetic algorithm (NSGA-Ⅲ). The supplemental role of hydropower is investigated in this programme with the aim of enhancing power generation and reducing output variability. In their work on PV-wind-pumped storage hybrid power systems, researchers [14, 15] utilized the NSGA-Ⅲ to address the scheduling challenge of integrated operation optimization. A multi-objective model considering the maximization of economic gain while limiting power production fluctuation, minimizing economic risk while maximizing financial return, and so on has been established in numerous previous researches on the hybrid power system [16, 17]. While many studies have looked at small-scale systems, they tend to focus on their short-term operations and neglect to analyze their long-term operational potential [18, 19]. Considering the smoothness of the output variance and the potential annual power generation, this work builds a multi-objective model for a long-term hydro-PV wind hybrid power system. This model calculates the output of PV and wind electricity on an hourly basis. As a starting point for the hydropower optimization, we use their average monthly power output. The hybrid system's compensatory electricity comes from cascading hydropower stations. Our proposed method, enhanced NSWOA is a modification of the non-dominated sorting whale optimization algorithm that aims to obtain the best possible results for this model. In order to enhance the distributivity of the non-dominated solutions discovered, the modified NSWOA, which is constructed on the NSGA-Ⅲ framework, utilizes the externally store technique from the strength Pareto evolutionary algorithm (SPEA) [20, 21]. In order to increase genetic variety in the population, population updates are performed using an improved form of the whale optimizing algorithm (WOA) with the help of polynomial mutation [22].

2. An Assessment of the Output of a Hydropower-Photovoltaic-Wind Energy Production System
2.1 Assessment of PV Energy Production

PV power devices consider the greatest energy point of incident rays in this investigation. This means that the sun's rays are being exploited to their full potential. Equation (1) can be used to determine the PV power output [23].

\[ P_{pv}(t) = \eta_{pv} Y S(t) \]  

Whereas\n\[ \eta_{pv} = \text{Coefficient of power convert} = 0.9 \]
\[ Y = \text{Rated power output} = 265 \text{ Wp} \]
\[ P_{pv} = \text{Actual power output} \]
\[ S = \text{Available sunny radiation.} \]

2.2 Evaluation of Wind Power Generation

A wind turbine is an apparatus that uses the force of the wind to generate mechanical energy. Linking the wind turbine to the electric generation system transforms mechanical energy into electrical energy. Power output is proportional to wind speed. Using Equation (2) one can determine the amount of electrical power produced by wind energy.

\[
P_w(t) = \begin{cases} 
0 & V_f(t) \leq V_{fmin} \\
\frac{V_f(t) - V_{fmin}}{V_R - V_{fmin}} P_R & V_{fmin} < V_f(t) < V_R \\
P_R & V_R \leq V_f(t) \leq V_{fmax} \\
0 & V_f(t) > V_{fmax}
\end{cases} \]  

Whereas\n\[ P_R = \text{Rated power output} = 2.5 \text{ MW} \]
\[ P_w(t) = \text{Real power output (t)} \]
\[ V_f(t) = \text{Real (t)} \]
\[ \text{Wind speed} \]
\[ V_{fmin} = \text{Cut-in} = 11 \text{ m/s} \]
\[ V_{fmax} = \text{Cut-out} = 30 \text{ m/s} \]
\[ V_R = \text{Rated} = 3 \text{ m/s.} \]

2.3. Evaluation of Hydropower Generation

A hydropower plant uses the difference in potential energy between water levels in a reservoir at various elevations to produce electricity. In order to meet the electrical grid's demands, reservoirs need to control the timing and location of natural runoff. In terms of water dispatch ability, cascade reservoirs outperform single reservoirs. Equation (3) determines the output power of cascade hydropower stations [24].

\[ P_{hc}(t) = \sum_{i=1}^{n} K_i Q_i(t) H_i(t) \]  

Whereas\n\[ Q_i(t) = \text{Discharge flow of reservoir ‘i’ with respect to time ‘t’} \]
\[ n = \text{No of reservoirs in the CHP system} \]
\[ P_{hc}(t) = \text{Power output of CHP stations with respect to time ‘t’} \]
\[ K_i = \text{Energy production coefficient of reservoir ‘i’} \]
\[ H_i(t) = \text{Reservoir water head ‘i’ with respect to duration ‘t’} \]

The water level head \[ H_i(t) \] is evaluated by Equation (4).
\[ H_i(t) = \frac{(Z_{i,\text{up}}(t) - Z_{i,\text{up}}(t+1))}{2} - Z_{i,\text{down}}(t) - \Delta H_i \]  

Whereas

- \( Z_{i,\text{up}}(t) \) = Water level of upstream of reservoir ‘i’ with respect to time ‘t’
- \( \Delta H_i \) = ‘i’ the loss of synthetical water head at the hydro station
- \( Z_{i,\text{down}}(t) \) = Water level of downstream of reservoir ‘i’ with respect to time ‘t’.

### 3. Hybridized Model for Power Generation

#### 3.1 Purposes

Equations (5) and (6) display a multi-objective model that considers the amount of electric energy production as well as the smoothness of the output variation of the hybrid power system [25].

\[
\begin{align*}
\text{max} f_1 &= \text{max} E = \text{max} \sum_{t=1}^{T} P_{\text{total}}(t) \Delta t = \text{max} \sum_{t=1}^{T} (P_{hc}(t) + P_{pv}(t) + P_w(t)) \Delta t \\
\text{min} f_2 &= \text{min} \delta = \text{min} \sqrt{\frac{1}{T} \sum_{t=1}^{T} (P_{\text{total}}(t) - \bar{P}_{\text{total}})^2}
\end{align*}
\]  

Whereas

- \( P_{\text{total}}(t) \) = Output power per month of system with respect to ‘t’
- \( E \) = Overall produced system energy
- \( P_{\text{total}}(t) \) = Average output power of system with respect to ‘t’
- \( \delta \) = Standard deviation of output power per month.

### 3.2 Constrained Variables and Decision-Making

At each phase, the model’s variables are the upstream water levels of the cascade reservoirs. An equation (7-11) shows the model’s constraints.

**Hydraulic connection:**

\[ I_i(t) = Q_{i-1}(t) + q_i(t) \]  

**Equation for the water balance:**

\[ V_i(t + 1) = V_i(t) + (I_i(t) - Q_i(t)) \Delta t \]  

**Discharge flow constraint:**

\[ Q_i^{\text{min}}(t) \leq Q_i(t) \leq Q_i^{\text{max}}(t) \]  

**Upstream level constraint:**

\[ Z_i^{\text{min}}(t) \leq Z_i(t) \leq Z_i^{\text{max}}(t) \]  

**Output power constraint:**

\[ N_i^{\text{min}}(t) \leq N_i(t) \leq N_i^{\text{max}}(t) \]  

Whereas

- \( I \) = Inlet flow
- \( V \) = Water storage of reservoir i with respect to time ‘t’
- \( \Delta t \) = Time length
- \( N \) = Output power of hydro station
- \( q_i \) = Inflow between reservoir il and i

The time \( b \) is represented by the parameter \( b \) in parentheses. The top and lower bounds of each restriction are represented by the superscript max and min, respectively. The reservoir is denoted by the subscript \( i \).
4. Optimization

4.1 Specification of Improved NSWOA

NSGA-II is an appropriate optimization method for solving MOPs because of its diversity preservation strategy and provides elitism [26, 27]. Despite this, NSGA-II fails to deliver adequate results as the MOP dimension increases. Improved NSWOA is a new multi-objective optimization algorithm that draws inspiration from NSGA-II. Our model of a hybridized power generating system is to find a collection of solutions that are not dominated.

WOA developed a helix function to help people discover the best answer to problems by studying whale predation behavior [28]. Equation (12) shows the update function (12).

\[
\tilde{X}(t + 1) = \begin{cases} 
\tilde{X}^*(t) - A \cdot |C \cdot \tilde{X}^*(t) - \tilde{X}(t)| & \text{if } p < 0.5 \cup A < 1 \\
\tilde{X}_{\text{rand}}(t) - A \cdot |C \cdot \tilde{X}_{\text{rand}}(t) - \tilde{X}(t)| & \text{if } p < 0.5 \cup A \geq 1
\end{cases}
\]

Whereas
\[
\tilde{X}^* = \text{Current individual and the best global population position achieved thus far}
\]
\[
\tilde{X}_{\text{rand}} = \text{Selection at random from the present population}
\]
\[b = \text{Constant for defining the shape of the helix}
\]
\[p \text{ and } l = \text{Random number in } [0, 1]
\]
\[A \text{ and } C \text{ are evaluated by Equations (13-14).}
\]
\[A = 2a \cdot r_1 \cdot -a \quad (13)
\]
\[C = 2r_2 \quad (14)
\]

With \(r_1\) and \(r_2\) being random numbers in the interval \([0, 1]\); and is reduced to a value between 0 and 2 to facilitate exploration and exploitation, respectively, and this is determined using Equation (15).

\[a = 2 - 2 \cdot \frac{g}{g_{\text{max}}} \quad (15)
\]

Whereas
\[g_{\text{max}} = \text{maximal iteration number and } g = \text{current iteration number.}
\]

According to the research, as the optimization problem's dimension grows, the WOA will lose variety and encounter premature evolution. Polynomial mutation was used to increase population variety during evolution, which helped to address this shortcoming of WOA [29].

The impact on population diversity is analogous to switching from the population's global best position to each member's historical best position. An item's worth affects its exploratory and exploitation potential. Greater exploratory capability, as indicated by a higher value of \(a\), can lead to a more diverse population. Conversely, a lower value of \(a\) indicates less diversity in the population and worse exploration abilities. The improved NSWOA swaps out the main updated formula of an Equation (16) in order to boost variety during the late stage of evolution. Fig. 1 makes it clear that a decrease in the beginning of the evolutionary process and subsequently increases at the end, indicating that population diversity increases and the likelihood of individuals escaping the local optimal solution increases.
Fig. 1. Range of ‘a’ till the Development

\[ a = 8 \cdot \left( e^{\sqrt{1-g}-0.5} + e^{0.5-\sqrt{1-g}} - 2 \right) \]  \hspace{1cm} (16)

The non-dominated solution can be saved using the external archive approach, which improves the distributivity of the solution set [30].

4.2. Examined the Improved NSWOA’s Test Function

Fig. 2(a). Test Function Pareto Front using Improved NSWOA and NSGA-II for ZDT1
Fig. 2(b). Test Function Pareto Front using Improved NSWOA and NSGA-II for ZDT2

Fig. 2(c). Test Function Pareto Front using Improved NSWOA and NSGA-II for ZDT3
Fig. 2(d). Test Function Pareto Front using Improved NSWOA and NSGA-II for ZDT4

Fig. 2(e). Test Function Pareto Front using Improved NSWOA and NSGA-II for ZDT6
A more complex function was obtained by adding 100 to the dimensions of the test function. This set of test functions' non-dominated solutions is shown in Fig. 2(a) to Fig. 2(f). The highest number of iterations for ZDT1, ZDT2, and ZDT3 was 500, whereas for ZDT4, ZDT6, and KUR it was 1000, and a polynomial mutation occurred with a chance of 0.01. Fifty was the chosen population size. The NSGA-II has a crossover probability of 0.9 and the upgraded NSWOA has an external archive size of 50. Based on the results of ZDT1-ZDT6, improved NSWOA is better than NSGA-II in terms of distributivity and convergence. In particular, NSGA-II is unable to identify a decent set of non-dominated solutions for ZDT4. Improved NSWOA outperformed NSGA-II in terms of distributivity, however neither of these methods was able to produce a good non-dominated solution set for KUR based on the KUR result.

5. Case study

Solar photovoltaics' and wind turbines take up the whole plan size since they are still in the development phases. Data on solar radiation and wind speeds, however, are empirical. Up to this point in time, the hydropower has been able to handle the scale. We calculate the output of PV and wind power hourly. As a starting point for optimizing the reservoir, we use their average monthly power output. The five reservoirs that make up the cascade hydroelectric system are determined on a monthly basis. Thus, this model has 60 dimensional variables. The complicated model is not compatible with the NSGA-II. In order to resolve this model, the improved NSWOA is utilized. Wet, normal, and dry year inflows are chosen to be the model inputs. A hundred people make up the population, fifty make up the external archive, ten thousand iterations is the maximum, and the likelihood of polynomial transformation is 0.01. The installation capability of the Photovoltaic power plant is 8,000 MW, the wind power station is 2500 MW, and the hydropower station is 14820 MW. Listed in table 1 are the most important features of cascade hydropower stations.
### Table 1. Key Features of Hydropower Stations in “a” Cascade

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Units</th>
<th>Station 1</th>
<th>Station 2</th>
<th>Station 3</th>
<th>Station 4</th>
<th>Station 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installing Capacity</td>
<td>(MW)</td>
<td>4305</td>
<td>1770</td>
<td>1450</td>
<td>5950</td>
<td>1850</td>
</tr>
<tr>
<td>Dead Water Level</td>
<td>(m)</td>
<td>1267</td>
<td>1012</td>
<td>892</td>
<td>865</td>
<td>691</td>
</tr>
<tr>
<td>Output of Firm Power</td>
<td>(MW)</td>
<td>1955</td>
<td>761</td>
<td>675</td>
<td>2600</td>
<td>934</td>
</tr>
<tr>
<td>Coefficient of Power Generation</td>
<td></td>
<td>9.9</td>
<td>9.5</td>
<td>9.5</td>
<td>10.1</td>
<td>10.5</td>
</tr>
<tr>
<td>Normal Water Level</td>
<td>(m)</td>
<td>1345</td>
<td>1024</td>
<td>919</td>
<td>846</td>
<td>716</td>
</tr>
</tbody>
</table>
Fig. 3. Hybrid Power Generating System's Pareto Front and Power Output Procedure during Rainy Year
Fig. 4. Typical Year Hybrid Power Generating System Pareto Front and Power Output Procedure during Rainy Year
Fig. 5. A Hybrid Power Generating System's Pareto Front and Power Output Process during a Dry Year

Fig. 3 to Fig. 5 display the derived solutions that are not dominated, as well as three examples of each inflow type. Maximum, intermediate, and minimal energy generation solutions are the three most common ones. Table 2 displays the average solution's monthly power output standard deviation (SD) and total year energy generation.
The results demonstrate that the optimization problem can be effectively solved using improved NSWOA. It is not possible to maximize overall power generation while also limiting standard deviation. Power output process smoothing leads to a decline in energy generation. Hydropower is clearly the leader in the hybrid power generation system, as seen by the monthly output process. The yearly variation in solar radiation and wind speed is rather smooth. Since there is more water available for electricity generation during rainy years, it is larger than during dry years. Furthermore, it is evident that the optimization is leaning towards maximizing the efficiency of power output with a big volume of water. Case 2, the typical solution, is a reasonable one since it considers both goals, strikes a balance between the smooth and energy quantities, and is thorough. Decision makers have the option to choose the solution scenario that best suits their needs.

### 6. Conclusions

An ideal hydro-PV-wind hybrid power generating system would maximize both the quantity and quality of its output power, which is the focus of this research. Two goals are set out by the multi-objective optimal model: lowering the SD of power production per month and maximizing the overall output power. We suggest an improved NSWOA that uses a new function for parameter a, polynomial mutation to increase population diversity, and an external archive set to improve solution set distributivity in order to solve the model more successfully. The enhanced NSWOA demonstrated strong performance as the optimization problem's dimension increased. According to the findings, hydropower is an effective complement to PV and wind generation. Both overall generation capacity and stability can be considered by the hybrid power generation system. As a point of reference for real-world operations, the proposed model can also be tokenized.

### References