Optimal Operation Management in A Micro-Grid System
Using Particle Swarm Optimization

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Abstract. Due to increase, the electricity demands and the cost of energy generation to cover the living requirement of modern societies, micro-grid (MG) has been established and played an important role to solve the problems of intermittent. This study focused on implementing the analytical algorithm for calculating the difference between generated units and consumed units under the control of the State of Charge (SOC) value and applied the Particle Swarm Optimization (ANALYTIC-PSO) algorithm to optimize the value resulting from the difference between generated units and consumed units. The simulation was performed using the python environment and the PSO algorithm converges to final state approximately after the 10th iterations. The results showed that the proposed approach is efficient compared to Grey Wolf Optimization (GWO) algorithm.

1. Introduction
In the last few years in modern societies, there has been an ever-increasing demand for electricity to meet the living requirements, and dispatch of power from the renewable energy source is not stable based on the current weather conditions and the shortage of fuel supply. These factors have become real issues to fulfill electricity demands. To overcome these problems, the combination of energy resources and storage units system must be taken into consideration to guarantee the system stability. The micro-grid (MG) system is being considered as one of the best solutions for the lack of electricity, especially in rural areas where people cannot access to the utility grid. Recently, multi-micro grid systems (MMS) were introduced and some systems are more reliable and economic [1, 2]. Currently, MG is drawing more attention in some developed countries to overcome the problems of dependency on fossil fuel and to provide clean energy based on the renewable energy source (RES) and distributed grid resources (DER). In addition, the MG system is implemented rapidly because is considered as a promising solution to solve the issue of the energy supply.

The U.S Department of energy defined the micro-grid system (MGS) as a group of interconnected loads and distributed energy resources (DER) within clearly defined electrical boundaries, which are considered as a single controllable entity from the main grid point of view [3]. Due to the instability and uncertainty of the output power of the wind turbine system (WTS), photovoltaic system (PVS) and battery energy storage (BES), are less effective when considered as individual sources. The aim is to
optimize the generator resource, which provides reliable power, high quality and efficiently diversified power services that keep the balance between the generation and the demands [4, 5]. More swarm intelligence or evolutionary computation algorithms are applied to solve and optimize different problems by evaluating the current and after update positions among individual movements of the particle until some stopping conditions happen. The main reason of applying some swarm intelligence algorithms, such as particle swarm optimization algorithm, neural networks, genetic algorithms, ant colony optimization, artificial immune systems, and fuzzy optimization, is effective in an optimization [6, 7]. Moreover, different swarm intelligence algorithms have been proposed to solve real-life problems. Recently, PSO has been used to implement a chaos particle swarm optimization by combining it with different machine learning algorithms, such as neural network and fuzzy logic in order to optimize the result.

This study organized in four sections as follows: the first section was about the configuration of the system, the second section to describe the optimization model and algorithm, the third section to discuss the results and finally to sum up the conclusions and future work.

2. The configuration of the MG and modeling

As mentioned in the definition by The U.S Department of energy, MG contains the distributed generator (DGR) connected with battery energy system (BESS). The DG along with the photovoltaic power (PV) (4160kw), battery energy (BES) (2000Ah) and utility grid (GR) are normally connected to adjustable load box. The system operates and stores the surplus energy from the PV in the batteries for future use. The system could work in two typical modes namely, isolated mode when the load is supplied based on the BES and PV and grid-connected mode when the load is fed on the purchasing power from the GR and PV. The condition of the two modes is determined to depend on the state of the charge (SOC) value.

The system operation gets electricity from the public grid when the price is cheap, the optimum operation strategy as shown in Figure 1. In this project, according to Changzhou price market, from 9 pm to 2 pm, the price is very expensive, and this could mainly depend on battery storage.

Figure 1. Optimum operation strategy.
2.1 Photovoltaic power generation model

The output power of PV modules is changeable and uncertain, is mostly affected by environmental factors, such as the location of the project, the solar radiation, and the temperature [8, 9]. The experiment is carried out on the roof of Hohai University, China, with an output power of 16*260W modules in two strings. The first string has a power of 260W*8 and the tilt angle of 27°, and the second one has a power of 260W*8 and tilt angle of 16°. Figure 2, 3 shows power output from the PV array and load power.

2.2 Battery Energy Storage Generation Model

Generally, the purpose of the battery energy bank is used to be as a tank to store the surplus energy from generation units, and supply it when is needed, especially during peak shaving and load level in a short period of time [10]. This advantage makes the batteries to apply in a different application to increase the system stability. The SOC is a key to control and monitor the charge and discharge process in order to extend the lifespan of the battery. SOC at the time (t) of the battery bank is given by the following equations in two modes.

\[ SOC(t) = SOC(t-1)(1 - \sigma) + (E_{pv}(t) + E_{g}(t) - \frac{E_{load}}{\beta_{inv}}) \times \eta_{b} \]  

\[ SOC(t) = SOC(t-1)(1 - \sigma) + \left(\frac{E_{load}}{\beta_{inv}} - E_{pv}(t) - E_{g}(t)\right) \]  

where \( SOC(t) \) and \( SOC(t-1) \) are state of charge of battery bank (Wh) at time (t) and (t-1), respectively, \( \sigma \) is hourly self-discharge rate, \( E_{pv} \) and \( E_{g} \) are PV array power and grid utility generators power (KW), \( E_{load} \) is load demand at time (t) (KW) \( \eta_{b} \) and \( \beta_{inv} \) are the charge efficiency of battery bank and the efficiency of inverter, respectively. The battery discharge power and discharge power are presented in Figure 4, 5 respectively.
As mentioned above, the SOC is an important factor to protect the battery from overcharge (over 80%) and over discharge (below 20%). The constraint is formulated by comparing the minimum charge and maximum discharge SOC periodically. States of the battery charge are demonstrated in Figure 6.

\[ \text{SOC}_{\text{min}} \leq \text{SOC}(t) \leq \text{SOC}_{\text{max}} \]  

3. Materials and methods

3.1 Particle Swarm Optimization (PSO)

PSO is inspired by the behavior of the movement of the flock bird, or a school of fishes by optimizing the path of searching for food or immigration. This is considered as a population-based stochastic and a random optimization technique. PSO was invented and developed by Dr. Kennedy and Dr. Eberhart in 1995 [11, 12]. An optimization technique is starting with randomly initialized population and moving in a random direction through the search space. The particles communicate with each other to get a good position and all particles update the velocity and position derived from the best position of all particles.

PSO is well suited to solve different types of problems, such as the non-linear, non-convex, continuous, and discrete and integer variable problems. Below is the equation for the movement of the particle in solution space.

Particle velocity

\[ V_{k+1}^i = W_k V_k^i + C_1 r_1 (P_k^i - X_k^i) + C_2 r_2 (g_k^i - X_k^i) \]  

Particle position

\[ X_{k+1}^i = X_k^i + V_{k+1}^i \]
where $X^k_i$ is particle position, $V^k_i$ is particle velocity, $P^k_i$ is the best individual particle position, $g^k_i$ is the best swarm position, $W_k$ is constant inertia weight, $C_1, C_2, C_3 (0.8, 1.5, 2)$ respectively and $r_1, r_2$ are cognitive, social parameters and random numbers between $(0, 1)$, respectively. While $K$ refers to the current iteration and $k+1$ implies the next iteration. Particles number = 50, iteration = 100.

3.2 Proposed method

The algorithm is based on combining the PSO method and the analytic algorithm. The analytic algorithm runs with some constraints of evaluating the system ability by calculating the difference between the generation units, such as PV-battery energy storage, utility grid, and the demand. The system modes are determined based on the SOC to ensure that is in the connected or isolated mode.

The following steps summarize the analytic algorithm:

Step 1, initialize the parameters: PV, PG, PL, PBESS

Step 2, determine the total load connected with the system. $PL(t) = \sum_{i=1}^{N} PL(t)$

Step 3, determine the total power generation from different forms (PV, PG, and PBESS). $PG(t) = \sum_{i=1}^{N} P_{PV}(t) + \sum_{i=1}^{N} P_{BESS}(t) + \sum_{i=1}^{N} P_G(t)$

Step 4, from the two previous steps (step 2 and 3), we can calculate the difference between generation and consumption. $PD(t) = PG(t) - PL(t)$

Step 5, set the difference equals the power in battery storage.

Step 6, read or check the state of the charge condition of the battery (SOC). If the percentage is below 20%, can purchase from the utility grid (charge state), if the percentage of SOC is more than 80%, can discharge the battery (discharge state).

Steps 7, feed the load and read the (SOC) states again.

Step 8, Action is taking based on the (SOC) states

Step 9, end.

In this study, after applying the previous steps, the PSO is applied with the constructed constraint based on the SOC percentage to guarantee the system stability by optimizing the power difference between the generation and consumption units.

4. Results and discussions

In this paper, the analysis of the micro-grid system is based on the photovoltaic, battery bank storage and the utility grid. The principle of the operation is explained in the previous section. To reduce the replacement cost of the battery energy storage system (BESS), we consider the amount of the energy that can be charged and discharged per time by controlling and monitoring the value of SOC that could help to improve the stability of the micro-grid system. The proposed approach optimized the value of the difference between the generation and consumption power under the percentage of SOC to avoid the overcharge and over-discharge using the combination algorithm (ANALYTIC-PSO). Moreover, the data were collected in a period of five and half months for the PV power (W), load demand (W), grid power (W), battery discharge (KWh), battery charge (KWh), state of charge (%) and time (H). The analytic algorithm plays an important role in guiding the evolution, while the PSO algorithm works as an assistant. The PSO algorithm is converged to a final state after the ten iterations. The proposed methods obtain a powerful result as compare to Vaiju Kalkhambkar [13] that demonstrated GWO has offered best the fitness value compared to PSO. In this study, we did not consider the cost-effectiveness of the system, but the researchers can refer to [14], [15] for more details.
As presented in Figure 7, we can indicate that the results obtained from the proposed approach based on PSO algorithms achieve the best fitness value compared to GWO algorithm. This improvement is due to combining the PSO algorithm with the proposed analytic algorithm.

5. Conclusion
In conclusion, we proposed an algorithm to optimize the difference of power between the generation units and consumption units using the combination algorithm (ANALYTIC-PSO). The battery energy storage (BES) is considered as the heart of the system and it has less lifespan compared to the other components of the micro-grid system. SOC is a key factor to optimize the battery capacity and to protect it from overcharge and over discharge. The analytic algorithm plays a significant role in guiding the evolution, while the PSO algorithm works as an assistant in the python environment of the parameters in order to optimize the power difference. The PSO algorithm converged to the final state and achieved the $G_{best}$ after the ten iterations and less error accrued for the proposed algorithm (0.07) as compared with (GWO) (0.33). The proposed algorithm in terms of best fitness with slower convergence value demonstrated a better performance of PSO algorithm and a lesser number of iteration compared to the result of GWO. The economic dispatch is needed for the further study.

Acknowledgement
This work was supported by the National Natural Science Foundation of China, No.51777059; Key Research Project of Jiangsu Province, China (Industry Foresight & Universality Key Technology) No. BE2017063; the Fundamental Research Funds for the Central Universities No.2018B22714 and the National Key Research and Development Program of China (2018YFB1500600).

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