Optimal Energy Scheduling of Renewable Energy Sources in Smart Grid using Cuckoo Optimization Algorithm with Enhanced Local Search

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Abstract. The emerging trend of micro grid enabled technologies with renewable energy sources are used to satisfy the high demand of energy requirement and are preferred over conventional energy sources. However, it has disadvantages like uncertainty in energy on hand with renewable energy sources and unpredictable demand. Optimal scheduling of power generation among the available renewable energy sources is necessary to achieve minimum cost of energy generation with consideration of power loss. In this work, we have used Cuckoo search optimization algorithm with enhanced local search using Tabu search for optimal energy scheduling. This approach is compared with other evolutionary algorithm and existing approaches and results show that our proposed approach performs well.

1. Introduction

Renewable energy resources are now a days more important in order to meet the energy requirement. To deal with the growing demand for electricity, various researches have been reported. Most of the approaches pay attention to improve the efficiency of conventional power generation and distributions. But this is restricted due to the existing infrastructure of power station. Hence this work is focused on micro grid optimization which also efficiently satisfies the growing demand of electricity. Power producer offered electrical energy at different rates and optimal power scheduling is necessary to meet the demand with minimum generation cost and could handle the complexity of power system [1].

In this work, Energy scheduling management is proposed which optimizes the generated power scheduling to balance between the generated and received energies. The numbers of renewable energy resources (RER) is selected to satisfy the requirement. RER sometimes may fail to generate the power to meet the load due to the stochastic nature of RER. In this case, RER uses the power from the storage systems and virtual power plants. Energy scheduling management should also handle this issue. But in our work we considered that the energy generated by RER is higher than the requested power and also considers that the power loss may occur in RER. In previous literature optimization of power scheduling is rarely investigated. Hence, cuckoo based optimization procedure is proposed for optimal sharing of power generation of RER to the requested power.

Evolutionary algorithms are effective in energy scheduling problem as the nature of energy scheduling is nonlinear and complex. Cuckoo search is used for engineering optimization problems since it can handle continuous problems and NP-hard problems well [2]. Cuckoo search often falls in local minima if the diversity of the solution is not met over the generations. So in this work, the local search is further enhanced in cuckoo optimization with the Tabu search. Smart grid with three wind plants (WP), two photo voltaic plants (PV), and one CHP plant is simulated to calculate the effectiveness of the proposed approach and energy scheduling optimization based on cuckoo with enhanced local search is applied and evaluated.

The remaining paper is organized as follows. Section 2 summarizes the related work. Section 3 explains the proposed work on energy scheduling algorithm. Section 4 discuss about the experimental results and section 5 concludes the paper.
2. Related works
The author in [3] used Memory based genetic algorithm (MGA) for optimal energy scheduling among RER in the micro grid. MGA was used to increase the local exploration ability of Genetic Algorithm (GA) by strengthening the local and global searches. Particle swarm optimization algorithm (PSO), Genetic algorithm and some variations of PSO are used for comparison. But this work does not consider the load uncertainties and power loss of renewable energy resources. Fuel cost is minimized in the micro grid [4] by optimal scheduling of the communication to aid distributed generations.

Hybrid evolutionary algorithms were also employed in optimization of maintenance scheduling in terms of both economic and reliability [5]. Authors in [6] used additive increase and multiplicative decrease algorithm for optimal RER management. Economic dispatch problem was handled in the micro grid with multi objectives in [7] by pareto concavity removal in both the grid associated and isolate modes and the results were compared with non-dominated sorting GA and PSO.

Authors in [8], considered micro grid with RER and storage devices for power scheduling. Aggregator was used to allocate the energy among the charging station and drop based controller was used in energy management of batteries. Charging stations were responsible for allocating energy among the individual batteries using droop participation factor. Multi objective with environmental, reliable and minimum cost were considered in [9], and PSO was used for optimal scheduling of power among the renewable energy resources.

3. Proposed Method

3.1. Energy Scheduling Management
Micro grid contains loads and generation units of combined heat and power, photovoltaic, and wind plants etc. Loads are supplied using generation units in microgrid and are changeable. Power availability of generation units also variable at time varies. There are so many approaches to share the produced power among renewable energy resources to meet up the requested power. Cost minimization is a powerful objective function for energy scheduling. The cost minimization objective function in microgrid is formulated [9], [10] as follows:

\[
\text{cost minimization} = \sum_{i=1}^{n_r} c_i p_i = \sum_{i=1}^{n_r} [\alpha_i \times p_i + \beta_i \times p_i + \gamma_i]
\]

Subject to

\[
\sum_{i=1}^{n_r} p_i = p_l
\]

where \( i \) denotes each available RER. \( c_i \) is the cost in hourly basis, \( p_i \) is the generated energy of \( i^{th} \) unit. \( \alpha_i, \beta_i, \) and \( \gamma_i \) are the function coefficients fixed numbers and assigned based on the nature of renewable energy such as fuel cost, efficiency, etc. \( p_l \) is the requested load. \( n_r \) is the number of renewable energy resources. The load should be less than or equal to the generated power and the cost of generation must be equal to the sum of cost of each RER power generation. Energy scheduling management should share the requested power optimally with the renewable energy resources available as well as minimize the cost at each hour.

In this paper, micro grid is constructed with three wind plants, two photo voltaic plants, one CHP renewable energy system and the problem is formulated as follows:

\[
\sum_{i=1}^{n_r} c_i p_i = \left[ \sum_{i=1}^{n_r} [\alpha_i \times p_i + \beta_i \times p_i + \gamma_i] \right] + p_f \times \left[ p_{w1} + p_{w2} + p_{w3} + p_{pv1} + p_{pv2} + p_{CHB} \right] - p_l
\]
In this work power loss is also included in the optimization problem due to the spasmodic nature of RERs. So the equation (3) is modified as in (4),

$$\sum_{i=1}^{n_r} c_i p_i = \left[ \sum_{i=1}^{n_r} [\alpha_i \times p_i + \beta_i \times p_i + \gamma_i] \right] + p_f \times \left| p_w + p_w + p_w + p_p + p_C \right| - p_{loss}$$  \hspace{1cm} (3)

Power loss is calculated by kron’s formula as follows:

$$p_{loss} = \sum_{i=1}^{n_r} \sum_{j=1}^{n_r} a_{ij} p_j$$

where $a_{ij}$ is the power loss coefficient.

3.2. Energy Scheduling using Cuckoo Search with Tabu based Local Search
Optimal scheduling of renewable energy resources to successfully meet the energy demand is calculated using proposed cuckoo search with enhanced local search algorithm.

3.2.1. Cuckoo Search. It depends on characteristics of cuckoo birds laying its own eggs in other birds nest. Eggs in a nest represent solutions and cuckoo egg is the new solution. The goal of the algorithm is to work the fresh and possibly enhanced solutions (cuckoos) to interchange worst solutions in the nests with the following constraints:

1. Randomly each cuckoo lays one egg in a selected host bird during initialization
2. Best solutions only are agreed over to the following generation.
3. Host birds can remove the foreign egg or abandon their own nest with probability $p_a [0, 1]$, then locate a new nest.

3.2.2. Cuckoo Search with Enhanced Local Search using Tabu. Cuckoo search can converge early to sub optimal solutions if the generated solutions are not diverse. This local optima problem can be solved if it is combined with some good local search algorithm. Hence Tabu search is used for local search in cuckoo search algorithm. First, the population should be initialized. The solution (individual cuckoo) is represented as follows:

$$\text{Sol} = [\text{Powergeneration RER1, Powergeneration RER2, ...,PowergenerationRERnr}]$$

where $n_r$ is the number of RERs in smart grid. The solution contains the optimal generation of RERs in a smart grid with minimum production cost. The population is initialized with randomly generated solutions. Each RER is assigned real numbers in the range between minimum and maximum power that can be produced by that particular RER. Each solution in the population should be validated based on the objective function in (4). The user constrains are checked before starting of exploration. The
overall procedure for validating the population and returning best solution based on cuckoo with enhanced local search is depicted in Algorithm CELTES.

**Algorithm of CELTES**

**Input:** Maximum Iteration $\text{Max}_i$, Minimum power limit of particular RER, $\text{min}_p(i)$, Maximum power limit of particular RER, $\text{max}_p(i)$.

**Output:** Optimized solution

**Procedure:**

1. Generate initial population $X = \{x_1, x_2, ..., x_{\text{npop}}\}$.
   Each RER is initialized in the maximum and minimum power range in solution space.

2. While (it $<$ $\text{Max}_i$)
   3. Select randomly a solution $x_i$ from the current population and replace it with Levy flights
   4. Calculate the fitness of $x_i$ : $F(x_i)$ as in (4)
   5. Select randomly a nest $j$ among $n$ and calculate fitness function of $F(x_j)$
   6. $q = F(x_j) - F(x_i)$
   7. $T = \text{schedule}[\text{itr}]$
   8. if ($F(x_i)$ less than or equal to $F(x_j)$)
      9. Replace $x_j$ with $x_i$
   10. else if ($e^{\frac{q}{T}}$ greater than randomly generated value in between [0,1])
      11. $x_{j,\text{new}} =$ Tabu search ($x_{j,\text{old}}$)
      12. end if
   13. A portion ($p_a$) of poorest solutions are replaced with new ones using levy flights
   14. Retain the top solution
   15. Rank the solutions and calculate the best
   16. Increment the iteration

End while

3.2.3. *Tabu Search.* Tabu search uses memory to prevent the searching from revisiting the past examined solutions and exploring the new solutions that are not examined before [11]. In this work Tabu search is invoked with the power production of renewable energy resources ($x_1, x_2, ..., x_n$) as starting point. Local optima is avoided by preventing revisit of already examined solution. Tabu search is adopted for our problem in the following way: Tabu search is started with a renewable energy configuration (Power generation RER1, Power generation RER2, ..., Power generationRERnr). Tabu list will be maintained for storing the previsited solutions using short term memory. One RER is randomly selected using $\text{Random}(1, \text{max}_{\text{nr}}(i))$ in each iteration. The solution is updated by increasing or decreasing the value of particular RER selected early. For example, if the solution is (80, 40, 20, 70) and the random value $d$ is selected in the minimum and maximum power range of the randomly selected index $i$ (assume $i=3$, $d=30$), then for even number iteration $d$ value is added and new solution is created as (80, 40, 50, 70) and for odd numbered iteration the $d$ value decremented. The selected $i$ value is included in the Tabu list. Whenever the RER type is modified the counter value incremented. If the counter value exceeds the tabu limit, then the particular RER is forbidden for further modification. The above procedure is continued for maximum number of iteration in Tabu search and returns the best solution and this will be used as a new solution in cuckoo search. The overall procedure is presented in Algorithm TabuLocalSearch.

4. *Experimental Results and Analysis*

MATLAB R2018a is used to implement the proposed approach with the micro grid containing five generation units viz., the three wind plants, two photovoltaic plants, and one CHP plant using IEEE-37-node feeder as in [3]. The maximum population is 100 and the maximum amount of iterations is 1000. The cost coefficient values such as $\alpha$, $\beta$, and $\gamma$ are calculated as in [3].

The performance is compared with the GA, MGA, PSO, and PSO with inertia weight as discussed.
Algorithm Tabu Search

**Input:** Maximum Iteration $T_{\text{Max}}$, Maximum number of renewable energy resources $\text{max}_{\text{nr}}[1, 2, \ldots, \text{nr}]$, Minimum power limit of particular RER $\text{min}_p(i)$, Maximum power limit of particular RER $\text{max}_p(i)$.

**Output:** New solution $x_{j,\text{new}}$

**Procedure:**
1. While (it $<$ $T_{\text{Max}}$)
2. Randomly select $i$ from the number of renewable energy resources required tuning.
3. if ($i$ is not in Tabu list)
4. $d = \text{Random(}\text{min}_p(i), \text{max}_p(i)\text{)}$
5. end if
6. if (iteration $\%$ 2 $=$ 0)
7. $x_i = x_i + d$
8. else
9. $x_i = x_i - d$
10. end if
11. Increment count[$i$] // count[$i$] is the counter for index $i$;
12. if (count[$i$] $>$ Tabu limit)
13. Add $i$ to Tabu list
14. end if
15. if ($f(x_i) < f(x_{j,\text{old}})$)
16. $x_{j,\text{new}} := x_i$
17. end if
18. end while
19. return $x_{j,\text{new}}$

in [3]. The power capacities of Each RER are represented in Table 1 and the hourly requested power is depicted in Figure 2. It can be seen from the Table 2, the proposed method produced lowest cost during a day compare to other existing approaches as the proposed method considers the power loss of renewable energy resources and avoiding local optima using Tabu search.

Moreover, the optimal power generated at each hour by RERs in microgrid during a day is presented in Figure 3. It can be seen from the Figure 3, that the proposed approach effectively meets the requested demand with the RERs generated power with the minimum cost.

![Figure 2 The Hourly Load](image)
Table 1 Available Power of RERs

| RER  | Maximum Power/hour |
|------|-------------------|
| WP   | 0.75 MW           |
| PV   | 0.2 MW            |
| CHP  | 1 MW              |

Table 2 Cost comparison of the proposed approach with existing approaches

| Optimization Method            | Cost per day |
|--------------------------------|--------------|
| GA                             | 1868.55      |
| PSO                            | 1273.87      |
| PSO with inertia weight        | 1259.69      |
| MGA                            | 1203.88      |
| Proposed method                | 1104.98      |

Figure 3 Optimal Power generation of proposed method

5. Conclusion
Optimal and robust energy scheduling among the renewable energy resources is required to achieve minimum generation cost. In this work cuckoo search with enhanced local search using Tabu is used to optimize the energy among the RERs. Moreover this work considers the intermittent nature of renewable energy resources. Simulation was conducted with three wind plants, two photovoltaic plants, and one CHP plant and the results proved that the proposed approach performs well compared to other evolutionary algorithm based existing power scheduling approaches in terms of cost.

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