Scheduling for Prosumer Microgrid with Considering Price Based Demand Response

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Abstract. Unit commitment (UC) is the scheduling of power unit operating outages to meet electricity needs at a certain time with the aim of obtaining a total economical generating cost. Differences in the characteristics of each generating unit and limitations result in different scheduling combinations based on equations, and for this research, the renewable energy penetration will also be considered. Firefly Algorithm (FA) is a method to determine load requests and complete renewable energy scheduling power by using unit commitment. FA is a simple but reliable algorithm that solves optimization problems. Firefly Algorithm (FA) method obtained maximum generating power of 81,329 MW with the total cost of 827,556 $ and network losses of 3.6696 Coefficient of operating costs.

1. Introduction

The problems facing the energy system are the depletion of fossil fuels, rising energy prices and greenhouse gas (GHG) emissions that greatly affect the comfort and affordability of large-scale energy for commercial customers. This problem can be mitigated by the optimal scheduling of distributed generators (DGs) and demand response policies (DR) in distribution systems[1][2].

Air pollution, falling prices of solar components and government profits from renewable energy adoption incentives, have resulted in prosumers with rooftop solar panels[3]. With a game theory model for real-time P2P energy trading for prosumer-based micro-grid communities. Prosumer involved in P2P trading is the seller or buyer, where the interaction between the seller and the buyer is modeled as a Stackelberg game, with the seller They are leaders and buyers are followers[4].

Electricity demand and supply should be constant and balanced, as electricity demand has a typical weekly and seasonal pattern so power plants need to be carefully scheduled to meet this volatile demand. This scheduling optimization is known as the commitment unit[5]. The problem of unit commitment in deciding which generating units to run at each period to predict Varying electricity demand. Commitment units allow unbroken power to be played to consumers at a minimum cost, using the priority list method. Generators are turned on and off based on priority to minimize the total operating costs of the generating unit[6][7]. Model (MINLP) to optimize the operation of multiple buildings in a microgrid to minimize the total cost energy imported from the main network at the interconnection point and manage power demand and building generation, but for operational constraints of the power grid are guaranteed[8]. With the incentive-based demand response optimization (IDRO) model it is proposed to schedule efficient use of household appliances during peak hours. The method used is a multi-object optimization technique based on the Nonlinear Auto-Regressive Neural Network (NAR-NN) taking into account the energy provided by the user and the roof attached photovoltaic system (PV)[9].

Fully energy management methods to consider Distributed energy uncertainties such as household photovoltaics and electric vehicles [10][11][12].
With the hybrid firefly algorithm-ant colony optimization (hybrid FA-ACO) method to solve the problem of traveling salesman problem (TSP). In improving solutions and accelerating convergence time, combined methods are used that include solution search with FA and global search with ACO. The results of the hybrid FA-ACO compared to the FA and ACO suggest that the proposed method could find a better solution[13][14].

Optimization of power flow in the power grid taking into account associated flow and operating constraints in the context of demand response that maximizes management utility in the distribution network, where customer demand must be subject to voltage operating constraints and transmission power capacity[15].

In this research, the main goal is to conduct a scheduling for prosumer microgrid by considering price-based demand response and considering a penetration of a renewable energy distributed generator within the system. The scheduling simulation will be done by using Firefly Algorithm in MATLAB and the results for the scheduling will be discussed with comprehensive analysis.

2. Literature Works
This section will cover the basic theory of scheduling, including unit commitments, optimal power flow, the firefly algorithm, and the generation of distributed renewable energy itself.

2.1. Renewable Energy Distributed Generator
The world's population and industry today are rapidly depleting energy and chemical sources—such as petroleum, natural gas, coal, and other non-renewable resources on earth. With the condition of the world's population and industry, as well as the rapid growth of the human population, the demand for energy is increasing more than ever in history.

Many renewable resources are available—such as wind power, sunlight, moving water, biomass—and various technologies to utilize these resources effectively and efficiently. However, to develop a transition technology from non-renewable to renewable energy systems is a difficult and very complex challenge.

For each example of renewable energy distributed generator, such as photovoltaic, wind turbine, and hybrid of photovoltaic and wind turbine in the joint DC bus before the inverter that will be used in this research.

2.1.1. Photovoltaic.
The large amount of energy produced from solar irradiance makes solar cells or a photovoltaic a very promising alternative energy source in the future. Solar cells also have the advantage of being a practical energy source considering that they do not require transmission because they can be installed modularly in any location where they are needed. Solar cells do not have as much noise as wind power plants and can be installed in almost any area because almost every location in this part of the world receives irradiance.

2.1.2. Wind Turbine.
In utilizing wind energy to be converted into electrical energy, using a wind turbine as a component that converts wind energy into mechanical energy and then distributes it for the generation of electrical energy. Wind turbines produce electrical energy by utilizing the pressure from wind energy to rotate the turbine then this turbine rotation is used to rotate the turbine rotor which is connected to the generator rotor which will then be processed to be converted into electrical energy. There are 2 types of wind turbines, namely horizontal axis wind turbines and vertical axis wind turbines. Horizontal axis wind turbines are a common model of wind turbines which are often found with a waterwheel-like design and must be pointed in the direction the wind is blowing. Meanwhile, vertical axis windmills in capturing wind energy do not need to be directed towards the wind so that they are more effective, and do not require high wind speeds because they receive a combination of wind supplies from various cardinal directions so that they can be placed in lower areas or locations close to the settlement.
2.1.3. Hybrid Type of Photovoltaic and Wind Turbine.
In the research, there will be a scheme by using photovoltaic and wind turbine in a single connected grid, by using two renewable resources in an different intermittency resource availability, it is expected to give more stabilized power output for the grid.

3. Optimal Power Flow Implementation Method
In this section, there will be discussed about optimal power flow implementation on system scheduling generation, as well as firefly algorithm and the renewable energy consideration in this research.

3.1. Optimal Power Flow Initialization
This paper proposes IEEE 30 bus system with six units of generator. As shown table 1.

Table 1. Data Limitations of IEEE 30 Bus System Generator Units.

| Unit | Pmax (mW) | Pmin (mW) | Up time (hour) | Down time (hour) |
|------|-----------|-----------|----------------|------------------|
| 1    | 200       | 50        | 4              | 4                |
| 2    | 80        | 20        | 3              | 3                |
| 3    | 40        | 12        | 2              | 2                |
| 4    | 50        | 15        | 2              | 2                |
| 5    | 30        | 10        | 2              | 2                |
| 6    | 55        | 10        | 2              | 2                |

Table 2. Data on operating costs of the IEEE 30 bus system

| Unit | Coefficient of operating costs | Startup Costs | Extinguished Charges |
|------|--------------------------------|---------------|----------------------|
|      | a     | b  | c  | $               | $             | $               |
| 1    | 0.00375 | 2.00 | 0  | 70 | 176 | 50 |
| 2    | 0.01750 | 1.75 | 0  | 74 | 187 | 60 |
| 3    | 0.02500 | 3.00 | 0  | 40 | 113 | 30 |
| 4    | 0.06250 | 1.00 | 0  | 110| 113 | 30 |
| 5    | 0.02500 | 2.50 | 0  | 72 | 180 | 52 |
| 6    | 0.00834 | 3.00 | 0  | 50 | 267 | 85 |

Figure 1. Hourly Demand for 24 hours.
Particles are sets of variables, and variables are parameters that will be optimized in this paper. Objective functions are to find the cheapest generation costs with the limitations outlined in the unit commitment.

All State and Feasibility State Drafting Procedures is stated as with priority list, (1) Calculate the FLAC to determine the order of the plant with the cheapest to most expensive operating costs (2) Making the All-State Priority List and the feasibility state on all load hours. Load Sharing Burden is stated as before the influx of renewable energy (Figure 1) and for the Net Load (Load after being reduced by energy generated by renewable energy).

### 3.2. Calculation of Objective Functions and Constraints of Units Commitment Using OPF

As an objective function is the total generating cost of all existing generating units over a certain time frame and calculated using OPF. In detail can be described as next:

- **Objective function**: Cost function of generating unit

  Expressed in the form of equations:

  \[ F_i(P_i) = a_i(P_i)^2 + b_i P_i + c_i \]

  \( P_i \) is the output power of the unit to \( i \) and \( a_i, b_i \) and \( c_i \) be cost coefficient unit generator – \( i \) then:

  Minimize \( F \sum_{i=1}^{N} F_i(P_k) \)

  (2)

- **Problem variable**, to optimize in this commitment unit is the generation of active power \( (P) \).

  If \( n \) is the number of generators, so the size of the matrix \( x \) is \([n:1]\) then the variable to be optimized can be written with the following 3 equations.

  \[ x = \begin{bmatrix} P_1 \\ \vdots \\ P_n \end{bmatrix} \]

  (3)

- **Constraints**

  As for the maximum-minimum limit of generator generation, voltage, active power, and reactive are group as equality constraints and inequality constraints

  **Equality constraint** based on the equation:

  \[ P_i^t = P_{gi}^t - P_{di}^t = \sum_{j=1}^{n} V_j^t V_j^t (G_{ij} \cos \theta_{ij} + B_{ij} \sin \theta_{ij}) \]

  (4)

  \[ Q_i^t = Q_{gi}^t - Q_{di}^t = \sum_{j=1}^{n} V_j^t V_j^t (G_{ij} \sin \theta_{ij} - B_{ij} \cos \theta_{ij}) \]

  (5)

  **Inequality constraints** based on the equation:

  \[ P_{gi \min} \leq P_{gi}^t \leq P_{gi \max} \]

  (6)

  \[ Q_{gi \min} \leq Q_{gi}^t \leq Q_{gi \max} \]

  (7)

  \[ V_i^t \geq V_{i,mint} \leq V_{i,max} \]

  (8)

  \[ |P_{ij}^t| \leq P_{ij} \max \]

  (9)

### 3.3. Firefly Algorithm and Renewable Energy Distributed Generator Penetration

From the optimal power flow analysis, it is obtained the best scenario for each hour by determining which power source to load power demand. After the results are obtained, the firefly algorithm will be simulated by using data from IEEE 30-bus system, and renewable energy generator penetration will take generator 3 and 5 (maximum possible power generated from a windmill and solar farm hybrid system) as the modification for the IEEE 30-bus system.
4. Simulation Results and Analysis
Here is an all-state priority list table, there are 6 plant combinations arranged based on FLAC, each combination has its generation capacity so that each combination can later be used to encode in the most important load conditions or usually called feasibility state.

**Table 3. All-state priority list table.**

| State | Generator Unit | P Limit |
|-------|----------------|---------|
|       | 1   | 2   | 3   | 4   | 5   | 6   | Max | Min |
| 1     | 1   | 0   | 0   | 0   | 0   | 0   | 200 | 50  |
| 2     | 1   | 1   | 0   | 0   | 0   | 0   | 280 | 70  |
| 3     | 1   | 1   | 0   | 1   | 0   | 0   | 315 | 85  |
| 4     | 1   | 1   | 0   | 1   | 1   | 0   | 345 | 95  |
| 5     | 1   | 1   | 0   | 1   | 1   | 1   | 385 | 105 |
| 6     | 1   | 1   | 1   | 1   | 1   | 1   | 435 | 117 |

Feasibility state pada table 4 below is a combination state that allows to handle loads that vary every hour for 24 hours. Feasibility state determined based on a feasible state to handle the load in every hour with a value of P max total load every hour.

**Table 4. Feasibility State**

| Hour | Load (MW) | State Number |
|------|-----------|--------------|
|      |           | 1 | 2 | 3 | 4 | 5 | 6 |
| 1    | 166       | 1 | 1 | 1 | 1 | 1 | 1 |
| 2    | 196       | 1 | 1 | 1 | 1 | 1 | 1 |
| 3    | 229       | 0 | 1 | 1 | 1 | 1 | 1 |
| 4    | 267       | 0 | 1 | 1 | 1 | 1 | 1 |
| 5    | 283       | 0 | 1 | 1 | 1 | 1 | 1 |
| 6    | 272       | 0 | 1 | 1 | 1 | 1 | 1 |
| 7    | 246       | 0 | 1 | 1 | 1 | 1 | 1 |
| 8    | 213       | 0 | 1 | 1 | 1 | 1 | 1 |
| 9    | 192       | 1 | 1 | 1 | 1 | 1 | 1 |
| 10   | 161       | 1 | 1 | 1 | 1 | 1 | 1 |
| 11   | 147       | 1 | 1 | 1 | 1 | 1 | 1 |
| 12   | 160       | 1 | 1 | 1 | 1 | 1 | 1 |
| 13   | 170       | 1 | 1 | 1 | 1 | 1 | 1 |
| 14   | 185       | 1 | 1 | 1 | 1 | 1 | 1 |
| 15   | 208       | 0 | 1 | 1 | 1 | 1 | 1 |
| 16   | 232       | 0 | 1 | 1 | 1 | 1 | 1 |
| 17   | 246       | 0 | 1 | 1 | 1 | 1 | 1 |
| 18   | 241       | 0 | 1 | 1 | 1 | 1 | 1 |
| 19   | 236       | 0 | 1 | 1 | 1 | 1 | 1 |
| 20   | 225       | 0 | 1 | 1 | 1 | 1 | 1 |
| 21   | 204       | 0 | 1 | 1 | 1 | 1 | 1 |
| 22   | 182       | 1 | 1 | 1 | 1 | 1 | 1 |
| 23   | 161       | 1 | 1 | 1 | 1 | 1 | 1 |
| 24   | 131       | 1 | 1 | 1 | 1 | 1 | 1 |

After the process of determining the feasibility state, the next step is to describe the generation process or determination of the value of the plant with condition 1 in the feasibility state into a large value of a generation that must be generated by each plant that is worth 1 with the firefly method so that the total generation is equal to the total load. The best combination is determined based on which
state number combined the cheapest costs. For the results, the best results are to make the state number 1 is variable (on and off controlled).

The result of this procedure is in table 5 with the total cost in table 6.

**Table 5. Unit Generation**

| Hour | P Generation (MW) |
|------|-------------------|
| 1    | 187,463          |
| 2    | 187,093          |
| 3    | 187,084          |
| 4    | 186,578          |
| 5    | 186,130          |
| 6    | 186,156          |

**Table 6. Table Product and Total Cost**

| Hour | Product Cost ($/h) | Total Cost ($/h) |
|------|--------------------|------------------|
| 1    | 187,463 139,989 139,350 123,967 112,500 123,031 826,300 |
| 2    | 187,093 139,295 142,570 123,967 112,500 122,131 827,556 |
| 3    | 187,084 139,604 141,003 123,967 112,426 123,051 827,135 |
| 4    | 186,578 138,021 141,160 123,967 112,500 126,677 828,408 |
| 5    | 186,130 139,762 141,744 123,967 112,500 123,809 827,912 |
| 6    | 186,156 137,590 141,087 123,967 112,500 122,391 823,691 |
| 7    | 185,165 138,315 141,404 123,967 112,500 122,997 824,348 |
| 8    | 184,463 139,989 139,350 123,967 112,500 122,225 823,482 |
| 9    | 185,301 139,168 140,653 123,967 112,500 122,236 823,825 |

The combination of generation must be adjusted to the target load to be simulated, with the appropriate division according to the portion of each hour per hour for 24 hours, can be seen in the following figure.

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| 9    | 185,301 139,168 140,653 123,967 112,500 122,236 823,825 |
From the combinations that have been obtained for scheduling, the generation costs are obtained at any time for 24 hours and provide the lowest price for each combination that has been made with the firefly algorithm.

Table 7. Total P Loss

| Hour | Total P Loss (MW) | Hour | Total P Loss (MW) | Hour | Total P Loss (MW) |
|------|------------------|------|------------------|------|------------------|
| 1    | 3.6435           | 9    | 3.6435           | 17   | 3.6061           |
| 2    | 3.6193           | 10   | 3.6435           | 18   | 3.6236           |
| 3    | 3.6435           | 11   | 3.6193           | 19   | 3.6165           |
| 4    | 3.6193           | 12   | 3.68             | 20   | 3.6696           |
| 5    | 3.68             | 13   | 3.6608           | 21   | 3.6165           |
| 6    | 3.6244           | 14   | 3.6287           | 22   | 3.6696           |
| 7    | 3.6435           | 15   | 3.6377           | 23   | 3.6188           |
| 8    | 3.6193           | 16   | 3.6741           | 24   | 3.6139           |

The following is a graph of power losses for each combination that has been calculated with the cost of generating generators every hour for 24 hours.

Figure 2. Total Power Loss Graph

It can be concluded that using the firefly algorithm can solve the scheduling problem for generation that is tailored to the needs of the load. As shown in figure above, the power losses has increase and decrease between the 24-hours limit.

5. Conclusion
From the simulation obtained conclusions as follows:
1. Firefly algorithm can be used to optimize unit commitment to obtain the cost of the generation that is minimum but can still be meet the required load demands.
2. The initial condition of the plant affects the time the operation of the generating unit, and the cost of generation system because of the cost of the flame and dead generator unit.
3. Maximizing the operation of the generating unit affected by the operating costs of each generating unit different differences.
4. Maximum generating power of 81,329 MW with the total cost of 827,556 $ and network losses of 3.6696 Coefficient of operating costs.
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Acknowledgments

Authors wishing to thank for assistance or encouragement from colleagues, special work by technical staff from Institut Teknologi Sepuluh Nopember.