Binary Particles Swarm Optimization for Power Plant Schedule by Considering “Take or Pay” Contract

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Abstract. This study discuss 24-hours load scheduling to get the minimum generation cost. Fuel cost in load scheduling need to be considered, because fuel and power suppliers are bound by take or pay schedule. In addition load scheduling considering heat rate, start-up cost, minimum up time and minimum down time. Load scheduling calculate by priority list method that is completed using artificial intelligence, Binary Particle Swarm Optimization (BPSO). The data used in this study is IEEE 30 bus and Java-Bali 500 kV.

1. Introduction
PT PLN (Persero) is the largest electricity producer in Indonesia. PT PLN cooperates with private electricity producers, and is bound by a power purchase contract. In the power purchase contract, PT PLN bears a significant risk because it is bound by Take or Pay. The Take or Pay contract requires PLN to absorb electricity from private producers in a minimum amount of the total capacity of the power plant. For example, the capacity of 150 MW, 80% availability factor, the PLN must buy a minimum of 120 MW. If PLN is unable to absorb 120 MW, PLN must pay a Take or Pay penalty to the private electricity producer. In this case, it is necessary to schedule a generator in order to meet the load requirements and not be subject to a Take or Pay penalty.

Generator scheduling aims to obtain economical costs by considering various constraints such as rotating reserves, heat rates, minimum up / down time, and minimum operational costs. Generating scheduling is more complex when compared to economic dispatch so a method is needed to solve this problem if the system is used on a large scale. Based on the function of generating scheduling costs are divided into non-convex and convex costs. To schedule a generator can be solved mathematically or with artificial intelligence. The priority list and Lagrange can only complete the convex cost function [1]. Artificial intelligence or heuristic approach methods can solve non-convex cost functions and can solve in large systems[2]

Load scheduling can be mathematically solved by the Quadratic Programming and Unit Decommission (QPUD) method, this method can schedule generating units precisely and convergently and is able to complete scheduling by considering minimum up / down time, backup operations, and load balances [3]. Conventional methods such as the priority list are compared to the lagrange method [4]. With proper initialization, the lagrange method gets an economical scheduling value. However, when compared to the priority list method, the lagrange method has the disadvantage of having a limited state so that it can only schedule generators on small systems. To complete the scheduling of more complex plants and systems used on a large scale, the artificial intelligence method is one of the...
recommended methods such as the Artificial Bee Colony Algorithm (ABC) [5]. Load scheduling in addition to considering minimum up / down time, backup operations, and load balance, can also consider contingencies [6] Binary Particle Swarm Optimization (BPSO) [7]. Artificial intelligence is one of the methods most developed by researchers today. Artificial intelligence is divided into three namely neural networks, fuzzy systems, and evolutionary computing [8].

In this research, artificial intelligence used is Binary Particle Swarm Optimization (BPSO). In scheduling the generator using the priority list method and finished with BPSO. Load scheduling for 24 hours by considering take or pay as well as minimum up / down time limits, backup operations, and load balance. The system used is the Java-Bali 500 kV system. Figure 1 shows the workflow scheduling diagram using BPSO. Meanwhile, to determine Take or Pay using the gamma search method shown in Figure 2 [9].

The cost function in general generator scheduling can be written in the following equation:

\[
F_H = \sum_{h=1}^{H} \sum_{n=1}^{N} \left[ F_{nh}(P_{nh}) + STC_{nh}(1 - U_{n(h-1)}) \right] U_{nh} + DC_{nh}(u_n(h - 1)^0)
\]

with

\[
F_{nh}(P_{nh}) = a_n(P_{nh})^2 + a_n(P_{nh}) + c_n \left| e_n \sin(f_n x(P_{nh} - P_n)) \right|
\]

\[STC_{nh} \text{ is} \]

\[HSC_n \text{ if } MDT_n \leq T_n^{off} \leq MDT_n + CSH_n\]

\[CSC_n \text{ if } T_n^{off} > MDT_n + CSH_n\]

with

\[
\sum_{n=1}^{N} P_{nh} = D_h
\]

\[
\sum_{n=1}^{N} P_{nh}(max) \geq D_h + R_h = D_h
\]

\[U_{nh}P_n(max) \geq P_n \geq U_{nh}P_n(min)\]

\[T_n^{off} \geq MDT_n\]

\[T_n^{on} \geq MUT_n\]

Where:

- \(F_H\) Operation cost every h
- \(N\) Number of each generating unit
- \(H\) Hourly number for each scheduling period
- \(n\) Generator index per unit
- \(h\) Hourly number
- \(STC_{nh}\) Start Up Cost unit n every hour h
- \(HSC_n\) Hot Start Up Cost unit n
- \(CSC_n\) Cold Start Up Cost unit n
- \(U_{nh}\) ON / OFF each unit n at h
- \(DC_{nh}\) Shut Down Cost unit n
- \(a_n, b_n, c_n, e_n, f_n\) Cost function of each unit n
- \(P_{nh}\) Generating each unit n at h hours
- \(P_n(max)\) Maximum generation each unit n
- \(P_n(min)\) Minimum pembangkit each unit n
- \(D_h\) Peak Load at h
\( R_h \)  
**Spinning reserve at h**

\( T_{on}/T_{off} \)  
**On or Off time**

\( MUT_n \)  
**Minimum Up Time each unit n**

\( MDT_n \)  
**Minimum Down Time each unit n**

BPSO is the development of Particle Swarm Optimization (PSO) [10], the difference of the two methods is the update and position speed. Following of the BPSO steps are:

1. **Population Initialization**
   
The parameters used for initialisation consist of, the number of particles represented as the number of generators, the number of iterations, constant variables and manipulation variables. Generating initial initial population in binary form. To determine the initial initialization can be written as follows [10]

   Initial Position \( X_i = (x_{i1}, x_{i2}, ..., x_{iD}) \) \((10)\)

   for \( i = 1,2,3 ..., m \) and velocity \( V_i \) for \( i = 1,2, ..., m \) with all particles randomly set.

2. **Update speed and position**
   
   For each article \( i \), with dimension \( d \),

   \[ V_{id}(t) = w * V_{id}(t-1) + c_1 * r_1 * (\|pbest\|_i - x_{id}(t-1)) + c_2 * r_2 * (\|gbest\|_d - x_{d}(t-1)) \] \((11)\)

   \[ X_{id}(t) = 1, \text{if } r_2 < \frac{1}{1 + \exp(-vid(t-1))} \] \((12)\)

   Where \( w \) is the weighting of inertia, \( c_1 \) and \( c_2 \) are constant speeds, \( r_1 \) and \( r_2 \) are generated randomly with a range \([0,1]\)

3. **Fitness function evaluation.**
   
   Evaluate the fitness function using equation (1). If it violates the limitation of the fitness function value, a penalty factor will be imposed so that the particle candidate will not be selected as a good solution candidate. After evaluating the fitness function, update the particle position:

   if \( f(x_i) > f(\|pbest\|_i) \) then update \( \|pbest\|_i = x_i \), for \( k \) is the area of \( x_i \) if \( f(x_k) > f(\|gbest\|_i) \), so the value \( \|gbest\|_i = x_k \), where \( f() \) is an evaluation of the fitness function

4. **Termination of iteration**
   
   Repeat steps 2 and 3, until you find the position and speed that has been determined by the fitness function evaluation
Read the data (Load, Particle, variable, maximum iteration)

Start

Initial population

Calculate Economic Dispatch and Take or Pay with Gamma Search

Evaluate Fitness Function

Value of G best and P best

Maximum Iteration

Scheduling Generator

Finish

Figure 1. Flow Chart of Load Scheduling Using BPSO

Determine the value of y randomly

For interval j with Load = Pload j, evaluate economic dispatch with:

\[ \frac{\partial G_j}{\partial P_j} = \lambda_j, j = 1 \ldots N \]

\[ \frac{\partial G_j}{\partial P_j} = \lambda_j \]

\[ \varepsilon = \sum_{j=1}^{J_{max}} \eta_j q_{T_j} - q_{TOT} \]

\[ \varepsilon \leq \text{Tolerance}? \]

Yes

Finish

Figure 2. Take or Pay Calculation Flow Chart with Gamma Search.

2. Results And Discussion

Table 1. 500 kV Java-Bali generator data

| Unit     | Generator Cost Coefficient (Rp/hour) | P min (MW) | P max (MW) | Fuel Cost (Rp/MBtu) |
|----------|-------------------------------------|------------|------------|---------------------|
|          | a   | b                                      | c          |                      |                     |
| Suralaya | -0.0015 | 34.2155                                | 275.1741   | 1600               | 3400               | 0.41               |
| Muaratawar | -0.0512 | 178.862                                | 624.9346   | 600                | 1400               | 1.25               |
| Tanjung Jati | -0.0019 | 27.2541                                | 348.5491   | 1200               | 2100               | 0.85               |
| Gresik   | -0.0003 | 52.8313                                | 538.3751   | 900                | 2100               | 0.26               |
| Paiton   | -0.0083 | 151.780                                | -212.5033  | 1800               | 4300               | 1.74               |
| Grati    | -0.0061 | 45.6393                                | -119.3939  | 290                | 800                | 0.38               |

Java-Bali electricity generation daily load data on April 20, 2016, and made into 4 periods [11]. The Heat Rate value is obtained from the factory specifications. The Java-Bali plant's Heat Rate data is shown in Table 2. PT PLN is bound by a contract with a private power plant of 206,000 MW per day, so the load scheduling is carried out taking into account the Take or Pay contract which must fulfill the contract within a day so as not to be subject to penalties or fine. Optimal load scheduling aims to reduce fuel costs to a minimum. The results of the Java-Bali power plant scheduling simulation using Lagrange are shown in Table 3 while using BPSO are shown in Table 4. The simulation results using lagrange are obtained by generating power by meeting the needs with a total power of 228,319 MW and a total cost of Rp 379,318,526,529.78 while BPSO generates a total power of 205,860 MW and a total cost of Rp 1,192,518,224,448.21 to a difference of Rp 260,066,704,081.57, making it cheaper to
use the BPSO method compared to the lagrange method. If using a Lagrange the total power exceeds the Take or Pay contract that has been specified. While the total power using the BPSO method the total power is less than the Take or Pay contract with an error of 0.068%.

Table 2. Heat Rate of the Java-Bali generator 500 kV

| Unit        | Power Generated (MW) | Heat Rate (Btu/kWh) |
|-------------|----------------------|---------------------|
|             | 1        | 2       | 3       | 4       | 1            | 2      | 3      | 4         |
| Suralaya    | 1703    | 2221    | 2561    | 3247    | 76492.24    | 7493.38 | 73454.29 | 71796.5 |
| Muara Tawar| 666     | 826     | 993     | 1140    | 112582.8    | 112253.6| 100783.9 | 98182.3 |
| Tanjung Jati| 1227   | 1525    | 1812.8  | 1982.8  | 28800.93    | 28483.89| 28186.52 | 27978.62 |
| Gresik      | 1141    | 1382    | 1649    | 1973    | 191161.2    | 189915.8| 189237.6 | 188630.8 |
| Paiton      | 2071.5  | 2792.5  | 3358.75 | 4005    | 76161.72    | 73013.27| 70840.3  | 68897.35 |
| Grati       | 320     | 400     | 560     | 795.6   | 124583.9    | 111932.4| 108890.5 | 106665.5 |

Table 3. 500 kV Java-Bali Power Plant Scheduling Simulation Results by Using Lagrange

| Hour (MW) | Power (MW) | Suralaya | Muara tawar | Tanjung Jati | Gresik | Paiton | Grati | Cost (Rp/hour) |
|-----------|------------|----------|-------------|--------------|--------|--------|-------|----------------|
| 1         | 8350       | 8553     | 2090        | 0            | 1980   | 789    | 2928  | 0              |
| 2         | 8197       | 8263     | 2068        | 0            | 1980   | 621    | 2928  | 0              |
| 3         | 8138       | 8318     | 2063        | 0            | 1980   | 582    | 2928  | 0              |
| 4         | 8132       | 8318     | 2063        | 0            | 1980   | 582    | 2928  | 0              |
| 5         | 8304       | 8494     | 2087        | 0            | 1980   | 738    | 2928  | 0              |
| 6         | 8218       | 8405     | 2075        | 0            | 1980   | 657    | 2928  | 0              |
| 7         | 8138       | 8319     | 2063        | 0            | 1980   | 582    | 2928  | 0              |
| 8         | 9256       | 9551     | 2236        | 0            | 1980   | 945    | 2928  | 697            |
| 9         | 9237       | 9543     | 2252        | 0            | 1980   | 945    | 2928  | 673            |
| 10        | 9337       | 9475     | 2090        | 1324         | 1980   | 238    | 2928  | 150            |
| 11        | 9320       | 9459     | 2098        | 1308         | 1980   | 238    | 2928  | 150            |
| 12        | 9318       | 9457     | 2098        | 1306         | 1980   | 238    | 2928  | 150            |
| 13        | 10361      | 10508    | 2158        | 1980         | 1980   | 697    | 2928  | 0              |
| 14        | 10454      | 10609    | 2171        | 1980         | 1980   | 785    | 2928  | 0              |
| 15        | 10401      | 10552    | 2164        | 1980         | 1980   | 735    | 2928  | 0              |
| 16        | 10401      | 10552    | 2164        | 1980         | 1980   | 735    | 2928  | 0              |
| 17        | 10454      | 10609    | 2171        | 1980         | 1980   | 785    | 2928  | 0              |
| 18        | 11292      | 11526    | 2299        | 1980         | 1980   | 945    | 2928  | 629            |
| 19        | 11301      | 11536    | 2300        | 1980         | 1980   | 945    | 2928  | 638            |
| 20        | 10734      | 10912    | 2211        | 1980         | 1980   | 898    | 2928  | 150            |
| 21        | 10454      | 10609    | 2171        | 1980         | 1980   | 785    | 2928  | 0              |
| 22        | 8885       | 9142     | 2183        | 0            | 1980   | 945    | 2928  | 341            |
| 23        | 7997       | 8167     | 2044        | 0            | 1980   | 449    | 2928  | 0              |
| 24        | 7196       | 7338     | 1665        | 0            | 1980   | 0      | 2928  | 0              |

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| Hour | Load (MW) | Power (MW) | Suralaya | Muara Tawar | Tanjung Jati | Gresik | Paiton | Grati | Cost (Rp/hour) |
|------|-----------|------------|----------|-------------|-------------|--------|--------|------|----------------|
| 1    | 8350      | 8553       | 2095     | 0           | 1816        | 980    | 3089   | 0    | 2,334,714      |
| 2    | 8197      | 8263       | 2072     | 0           | 1972        | 986    | 3098   | 0    | 2,400,216      |
| 3    | 8138      | 8318       | 2072     | 0           | 1937        | 933    | 2468   | 0    | 2,211,709      |
| 4    | 8138      | 8318       | 2082     | 0           | 1367        | 764    | 3578   | 0    | 2,211,709      |
| 5    | 8304      | 8494       | 2090     | 0           | 1346        | 874    | 3209   | 0    | 2,186,323      |
| 6    | 8218      | 8405       | 2077     | 0           | 1904        | 846    | 3289   | 0    | 2,186,323      |
| 7    | 8138      | 8319       | 2069     | 0           | 1368        | 978    | 3227   | 0    | 2,110,332      |
| 8    | 9256      | 9551       | 2240     | 0           | 1579        | 864    | 3213   | 897  | 3,120,032      |
| 9    | 9237      | 9543       | 2261     | 0           | 1487        | 987    | 3097   | 978  | 4,128,128      |
| 10   | 9337      | 9475       | 2190     | 1355        | 1478        | 892    | 2487   | 638  | 7,110,138      |
| 11   | 9320      | 9459       | 2198     | 1209        | 1238        | 792    | 3198   | 293  | 6,139,198      |
| 12   | 9318      | 9457       | 2198     | 1431        | 1323        | 927    | 3221   | 348  | 6,019,109      |
| 13   | 10361     | 10508      | 2160     | 1978        | 1083        | 872    | 3218   | 983  | 8,135,418      |
| 14   | 10454     | 10609      | 2215     | 1967        | 1479        | 928    | 3098   | 0    | 10,193,56      |
| 15   | 10401     | 10552      | 2181     | 987         | 1585        | 627    | 3218   | 0    | 7,921,202      |
| 16   | 10401     | 10552      | 2176     | 923         | 1974        | 821    | 3127   | 0    | 9,013,202      |
| 17   | 10454     | 10609      | 2341     | 977         | 1390        | 921    | 3189   | 0    | 9,013,202      |
| 18   | 11292     | 11526      | 2344     | 1815        | 789         | 917    | 3812   | 782  | 8,019,691      |
| 19   | 11301     | 11536      | 2211     | 1753        | 987         | 934    | 2341   | 812  | 8,139,560      |
| 20   | 10734     | 10912      | 2173     | 1920        | 908         | 819    | 3109   | 267  | 9,060,50       |
| 21   | 10454     | 10609      | 2191     | 1867        | 907         | 712    | 3179   | 0    | 5,418,139      |
| 22   | 8885      | 9142       | 2051     | 0           | 1139        | 983    | 3109   | 539  | 6,920,161      |
| 23   | 7997      | 8167       | 1670     | 0           | 1940        | 791    | 3501   | 0    | 2,371,277      |
| 24   | 7196      | 7338       | 651      | 0           | 1497        | 0      | 3417   | 0    | 1,552,123      |

### 3. Conclusion

With the BPSO method the total cost of generation is more minimum compared to the lagrange method. But in the BPSO method it still has a big error when considering Take or Pay. While the lagrange method, the total power compared to Take or Pay results exceeds the specified contract. So in this case the BPSO method is better when compared with the lagrange method. For further research it is expected that the Take or Pay error is close to 0% so as not to harm the PLN.
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