Indonesian Journal of Electrical Engineering and Computer Science
Vol. 8, No. 1, October 2017, pp. 129 ~ 136
DOI: 10.11591/ijeecs.v8.i1.pp129-136

Ant Lion Optimizer for Solving Unit Commitment Problem in Smart Grid System

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Abstract

This paper proposed the integration of solar energy resources into the conventional unit commitment. The growing concern about the depletion of fossil fuels increased the awareness on the importance of renewable energy resources, as an alternative energy resources in unit commitment operation. However, the present renewable energy resources are intermitted due to unpredicted photovoltaic output. Therefore, Ant Lion Optimizer (ALO) is proposed to solve unit commitment problem in smart grid system with consideration of uncertainties .ALO is inspired by the hunting appliance of ant lions in natural surroundings. A 10-unit system with the constraints, such as power balance, spinning reserve, generation limit, minimum up and down time constraints are considered to prove the effectiveness of the proposed method. The performance of proposed algorithm are compared with the performance of Dynamic Programming (DP). The results show that the integration of solar energy resources in unit commitment scheduling can improve the total operating cost significantly.

Keywords*: Unit Commitment, Dynamic Programming, Ant Lion Optimizer, Smart Grid*

1. Introduction

Smart grid is an electrical power organization that generates intelligent decisions about the state of the electrical power system to preserve a stable environment. Smart grid can be defined as the integration of numerous enabling power system automatic, protection, communication and technology control that tolerate real-time connection between end-users and energy sources, to enhance utilization efficiency in decision-making, based on resource accessibility and economics [1]. One of the goals of smart grid is to use distributed generation instead of bulk power generating units.

Due to exponential increase in population, economic growth and rise in industrial sector the generation capacity needs to be increased [2]. The depletion of fossil fuels becomes a global climate issue. With increasing concern over the change of global climate, policy makers are enhancing the application of renewable energy resources as a means of meeting emission reduction goals. The alarming rate at which global energy reserves are depleting are the world's major concern at economic, environmental, industrial, and community levels [3]. This condition has motivated the practice and improvement of alternative, sustainable and clean energy resources. Solar energy is continuous and considered as one of the most favorable renewable resources of bulk power generation. In 2014, large capacity of PV power generation was installed in Germany (38.24 GW), China (28.05), Italy (18.31 GW), Japan (23.3 GW), U.S.A. (18.28 GW), and Spain (5.39 GW) [4]. PV power generation has presented significant economic and environmental interests to the public social awareness, such as minimizing emissions of CO_2. PV power is reaching higher and higher penetration level in the smart grid system [5].

Unit commitment (UC) plays a significant element in scheduling operation of power system. One of the major concerns of power system planner is the problem of optimum cost of generation [6]. UC problem refers to the optimization issue in determining the start-up and shut-down time of generating units, in order to minimize the whole production cost and sustain the system constrains [7]. UC consists of two linked-optimization decision made, which is UC itself and economic dispatch (ED). UC determines the status of generating units, ON/OFF

Received June 24, 2017; Revised August 25, 2017; Accepted September 11, 2017

over the horizontal period of the scheduling time. To find the optimal amount of generated power of the committed units, ED is implemented [8].

UC may be characterized as the determination of units that essential to be committed in order to fulfill load demand. UC scheduling is important to fulfill load demand in a cost efficient method. It is impossible for supplying power towards end-user without any disturbances, due to the continuous and increasing of load demand from day to day, and also the depletion issue of the fossil fuels. Even though nowadays, there is enough stress laid on the application of renewable energy, it seems like it is not helpful in facing power deficit. The increasing load demand and unpredictable renewable resources becomes a great challenge for the operation schedule to satisfy the load demand at the most cost efficient manner. In order to meet the load demand and avoid power wastage, the optimal generation of electricity must be optimized effectively [9].

Determination of the optimal unit commitment scheduling with the integration of smart grid system will require a unique technique. In this paper, we are considering the use of solar generation as part of smart grid element in the unit commitment system. Ant lion optimizer is used solve the unit commitment problem is smart grid system. The results are compared with conventional method of Dynamic Programming in terms of cost saving and computational time.

2. Problem Formulation

2.1. Objective Function

The main objective on solving unit commitment problem is to minimize the total operating cost, TOC. TOC consists of fuel cost, start-up cost, and shut down cost. However, in most of the cases, shut down cost is usually ignored, assumed to be zero. The equation of TOC is illustrated as below:

$$TOC = \sum_{i=1}^{N} \sum_{i=1}^{T} U_{i,t} [FC_i(P_{i,t}) + ST_i(1 - U_{i,t-1})] \tag{1}$$

2.2. Fuel cost

Fuel cost refers to the running cost of generating unit. It represents the function power output of each particular generating unit. The equation is shown as below:

$$FC_i = \alpha_i P_{i,t}{}^2 + \beta_i P_{i,t} + \gamma_i \tag{2}$$

2.3. Start-up cost

Start-up cost, ST_i consists of hot start-up cost, HST_i and cost start-up, CST_i cost are calculated based on equation below:

$$ST_i = \begin{cases} HST_i\,;\; if\; T_{i,t}^{off} \leq MDT_i + T_{cold,i} \\ CST_i\,;\; if\; T_{i,t}^{off} > MDT_i + T_{cold,i} \end{cases} \tag{3}$$

2.4. Power Balance Constraint

In order to determine the optimal unit commitment, the power in the system need to be balanced as shown in equation (4):

$$\sum_{i-1}^{N} P_{i,t} U_{i,t} = P_{demand,t} \tag{4}$$

2.5. System Reserve Capacity

The overall unit commitment operation has to preserve a certain megawatt capacity as spinning reserve for a reliable performance. In this paper, the spinning reserve is set to be 10% of total load demand at the corresponding hour.

$$\sum_{i=1}^{N} P_{i,t} \max U_{i,t} \geq P_{demand,t} + R_t \tag{5}$$

2.6. Generation Limit

Each generator must operate within its generation limit. It is illustrated as the equation below:

$$\sum_{i=1}^{N} P_{i,t} \max U_{i,t} \geq P_{demand,t} + R_t \tag{6}$$

2.7. Minimum up/down time constraint

Minimum up/down time constraints refers to the period of generating unit must be on/off before it can be shut down or be brought online. Minimum up time is the shortest period for a generator working from zero output to non-zero output and from non-zero output to zero output. Minimum down time is the shortest period for a generator going from non-zero output to zero output and from zero output to non-zero output. The equations for minimum up time and minimum down time are shown in equation (7) and (8) respectively.

$$T_{i,t}^{on} \geq MUT_i \tag{7}$$

$$T_{i,t}^{off} \geq MDT \tag{8}$$

3. ALO Algorithm

In 2015, Seyedali Mirjalili has introduced a new unique nature algorithm known as Ant Lion Optimizer (ALO) [10]. The algorithm imitates the hunting behavior of antlions in natural surroundings. There are five main stages of the algorithm which include random walk of ants, constructing traps, entrapment of ants in traps built by antlions, catching ants, and re-setup the traps. Antlions belong to the Myrmeleontidae family and the Neuroptera (net-winged insect). The antlions life cycle includes two major levels of larvae and adults. They are hunting in larvae and undergoing reproduction at the adult stage. An antlion larvae digs a cone-shaped bottom in sand by moving along a circular path. After that, it will use its massive jaws to throw the sands out. Afterwards, they hides at the bottom of the cone while waiting for the insects to be trapped. When a prey in caught, it will be pulled and consumed. After that, the antlions throw the remains outside the pit and upgrade the pit for the next hunt.

3.1. Random walk of ants

Random walk is selected for demonstrating movement of ants, described as follows:

X(t) =[0, cumsum(2r(t1)-1), cumsum (2r(t2)-1) cumsum (2r(tn)-1)] (9)

Cumsum computes the cumulative sum, n refers to maximum iteration, while t indicates the phase of random walk, and r(t) is a stochastic function definite as (10):

$$r(t) = \begin{cases} 1, if\ rand > 0.5 \\ 0, if\ rand \leq 0.5 \end{cases} \tag{10}$$

The position of each ant is save in the form of matrix as shown in (11)

$$M_{ANT} = \begin{bmatrix} A_{11} & A_{12} & \cdots & A_{1d} \\ A_{21} & A_{22} & \dots & A_{2d} \\ \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots \\ A_{nd} & A_{n2} & \cdots & A_{nd} \end{bmatrix} \tag{11}$$

During optimization, matrix $\boldsymbol{M_{Ant}}$ will save the location of all ants (variables of all results). Random walk of ants are being normalized to keep them moving within the search space using the following equation:

$$X_i^t = \frac{(X_i^t - a_i) \times (d_i - c_i^t)}{(b_i^t - a_i)} + c_i \quad (12)$$

3.1. Trapping in antlion's pit

The following equations are used to represent mathematically model of antlion's pits.

$$c_i^t = Antlion_j^t + c^t \quad (13)$$

$$b_i^t = Antlion_j^t + b^t \quad (14)$$

3.2. Building trap

Antlion's hunting capability is demonstrated by roulette wheel operator for choosing antlions based on their fitness during optimization. This appliance provides great probabilities to the fitter antlions for catching preys.

3.3. Sliding ants toward antlions

Antlions are capable to construct traps proportionate to their fitness and ants are essential to move randomly. Once the ant is in the trap, antlions will throw sands outwards the center of the trap. This condition will slides down the stuck ant in the trap. Equation 15 and 16 shows the radius of random walks of ants:

$$c^t = (c^t / I) \quad (15)$$

$$d^t = (d^t / I) \quad (16)$$

3.4. Catching prey and re-building the pit

Last phase of hunt is when ant arrives the bottom of the hole and caught in the antlion's jaw. Antlions pulls the ant inside the sand and eats its body. Catching prey is assumed to happen if ants become fitter (goes inside sand) than its corresponding antlion. Antlion is necessary to modernize its location to the newest location of the hunted ant to improve its ability of catching new prey. It is represented by the following equation:

$$Antlion_j^t = Ant_i^t \text{ if } f(Ant_i^t) > f(Antlion_j^t) \quad (17)$$

3.5. Elitism

The best antlion achieved is kept as elite, the fittest antlion in each iteration. The fittest antlion should be competent to affect the movements of all ants during iterations. Every random walks of ants around a chosen antlion by the roulette wheel and the elite instantly is represented in equation (18):

$$Ant_i^t = \frac{R_A^t + R_E^t}{2} \quad (18)$$

4. Ant Lion Optimizer (ALO) for Unit Commitment Problem (UCP)

The overall algorithm of ALO for solving UC problem is shown in Figure 1. In the initialization process, a set of possible scheduling unit the amount of generation power is generated randomly based on priority list. The total operating cost is set to be the objective function of ALO based on Equation (1). The status of generating unit must comply all the system constraints such that power balance constraint, system reserve requirement, generating limit constraint, and minimum up and minimum down constraint. The stopping criterion of ALO is based on the difference value between minimum and maximum fitness which is set to be less than 10^{-7}.

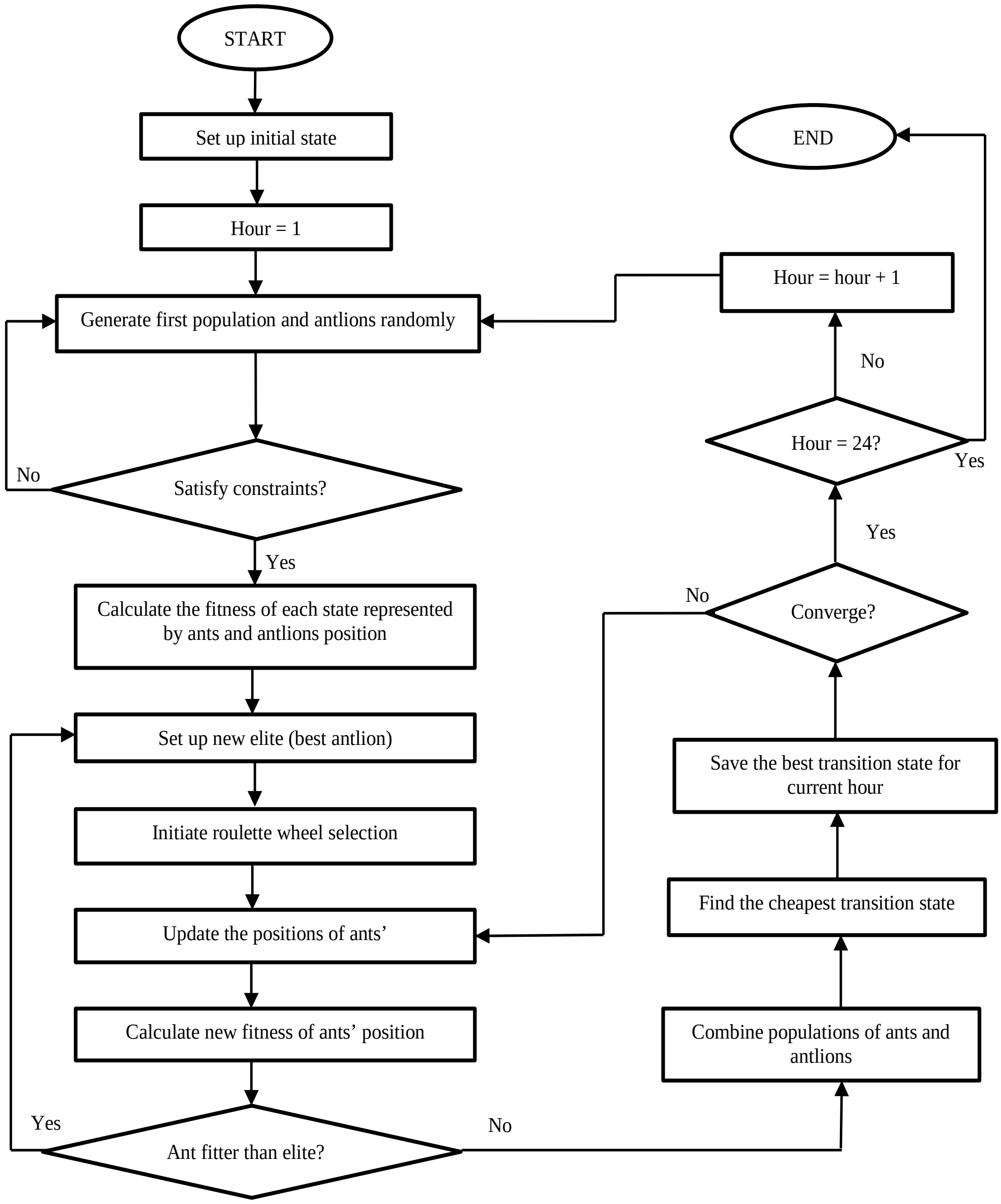

Figure 1. Ant lion optimizer approach towards unit commitment problem

4.1. Results and Discussion

In this paper, a 10-generator power system is applied to investigate the productivity of the recommended approach. The load demand in 24-hours period and parameters of 10-generating units are shown are taken from [8].

Table 1. Generators scheduling and dispatch by using ant lion optimizer in smart grid system

Hour (h)	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10
1	455	245	0	0	0	0	0	0	0	0
2	455	295	0	0	0	0	0	0	0	0
3	455	370	0	0	25	0	0	0	0	0
4	455	455	0	0	40	0	0	0	0	0
5	455	390	0	130	25	0	0	0	0	0
6	455	360	130	130	25	0	0	0	0	0
7	455	409.9872	129.9998	129.923	25	0	0	0	0	0
8	455	442.5401	130	129.9999	25	0	0	0	0	0
9	455	455	130	130	78.55	20	0	0	0	0
10	455	455	130	130	138.407	20.58296	25	10	0	0
11	455	455	130	130	162	34.94	25	10.00855	10	0
12	455	455	130	130	162	77.07	25	10	10	10
13	455	455	130	130	138.22	20	25	10	0	0
14	455	455	130	130	78.38553	20.02448	0	0	0	0
15	455	450.3006	130	129.9995	25	0	0	0	0	0
16	455	297.08	130	130	25	0	0	0	0	0
17	455	260.0008	129.9992	129.9999	25	0	0	0	0	0
18	455	360	130	130	25	0	0	0	0	0
19	455	455	130	130	30	0	0	0	0	0
20	455	455	130	130	162	33	25	10	0	0
21	455	455	130	130	84.99999	20.00001	25	0	0	0
22	455	455	0	0	145	20	25	0	0	0
23	455	425	0	0	0	20	0	0	0	0
24	455	345	0	0	0	0	0	0	0	0

The spinning reserve power is assumed to be 10% of the capacity load demand at each scheduling period. Also, the effectiveness of the proposed technique were also applied to unit commitment scheduling in smart grid system. The number of ant lions is set to be 100, with the maximum iteration of 1000. The lower and upper boundary are set to minimum and maximum power generation for each generator. In this case, the number of variables are set to be 10.

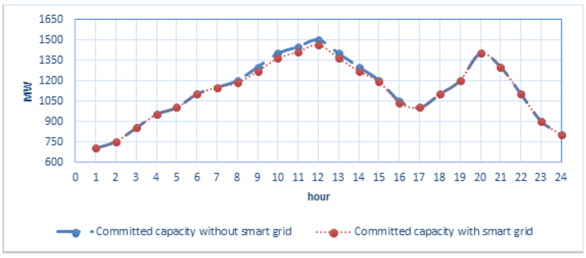

Figure 2. Hourly total committed capacity without smart grid and with smart grid.

Figure 2 shows the committed capacity of power generation is smart grid system and without smart grid system. Solar insolation records are taken from NREL's Solar Radiation Research Laboratory [3], Golden, CO, for the solar farm model in the smart grid system. Based on the figure, the solar irradiation is available from hour 0700 until 1400.

Table 2. Comparison between ant lion optimizer and dynamic programming technique

Technique	UC System		TOC ($)
ALO	Conventional		563807.2155
	Smart Grid	98.5% uncertainties	557758.4018
		100% uncertainties	557224.633
		101.5% uncertainties	557572.8969
DP	Conventional		564915.0000
	Smart Grid	98.5% uncertainties	558306.0000
		100% uncertainties	558201.0000
		101.5% uncertainties	558097.0000

Based from the results shown in Table 7, the simulation indicates that the proposed method are able to find the optimal solution with better performance in terms of cost reducing operating cost and computation time. Both of DP and ALO technique are applied in MATLAB R2015b on an Intel® Core™ i5-4210U CPU at 2.4GHz and 4GB RAM personal computer. For the conventional UC, the cost saving performed by ALO technique is 1107.7845$/day compared than DP technique. The computation time of ALO technique is about 4 minutes, which is faster than DP technique, 17 minutes.

After implementing smart grid system, we can see that there is much more cost saving. It shows that the penetration of solar energy as an alternative source of energy could save up total operating cost in unit commitment system. The UC with smart grid element in this paper consist of penetration of solar power generation. After implementing smart grid system, the cost saving achieved from DP technique is $4321.0367 for 100% uncertainties. The cost saving for ALO technique with the penetration of solar energy is $6582.5525, which is greater than the cost saving performed by DP technique. The computation time of ALO technique in smart grid is about 5 minutes, while the computation time of DP technique is about 19 minutes. Hence, we can see that the proposed method has better convergence and superior computation time.

5. Conclusion

In this paper, solar energy resources are integrated into conventional unit commitment, as the arternative sources in power system operation. ALO technique are proposed to solve unit commitment problems in both conventional UC and smart grid system. The ALO technique indicates significant time and total operating cost improvement, making it as a powerful and reliable technique in solving unit commitment problem. The results show that the integration of solar energy resources in unit commitment scheduling can improve the total operating cost significantly.

Nomenclature

$U_{i,t}$	Status of generating unit i at time t (ON/OFF)
FC_i	Fuel cost of generating unit i
$P_{i,t}$	Power generated by generating unit i at time t
$\alpha_i, \beta_i, \gamma_i$	Coefficients of generating unit
$T_{i,t}^{off}$	Continuous off-time duration
MDT_i	Minimum down time of unit i
$T_{cold,i}$	Cold start hours of unit i
$P_{demand,t}$	Load demand at time t
R_t	Spinning reserve at time t
$P_i^{\min}$	Minimum generating capacity of unit i
$P_i^{\max}$	Maximum generating capacity of unit i
$T_{i,t}^{on}$	Continuous ON time of generating unit i at time t
$T_{i,t}^{off}$	Continuous OFF time of generating unit i at time t
M_{ANT}	Matrix of position of each ant
$A_{i,j}$	Value of jth variable (dimension) of ith ant
n	Number of ants
d	Number of variables
c^t	Minimum of all variables at tth iteration

d_i	Maximum random walk of ith variable
c_i^t	Minimum of ith variable at tth iteration
b_i^t	Maximum of ith variable at tth iteration
d^t	Maximum of all variables at tth iteration
$Antlion_j^t$	Position of selected jth antlion at tth iteration
I	Ratio
t	Current iteration
Ant_i^t	Position of ith ant for tth iteration
R_A^t	Random walk around antlion selected by roulette wheel at tth iteration
R_E^t	Random walk around the elite antlion at tth iteration

Acknowledgements

The authors would like to thank the Research Management Institute (RMI), Universiti Teknologi MARA, Malaysia and the Ministry of Higher Education (MOHE), Malaysia through research grant 600-RMI/FRGS 5/3 (142/2015) for the financial support to this research.

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