Volume 3, Issue 3 (2015) 514-519 ISSN 2347 - 3258
International Journal of Advance Research and Innovation

An elucidation for unit commitment problem viaImperialistic Competition Algorithm

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Article Info

Article history:
Received 12 July 2015
Received in revised form
20 July 2015
Accepted 28 August 2015
Available online 15 September 2015

Keywords
Unit Commitment,
Genetic Algorithm,
Imperialistic Competition Algorithm

Abstract

Unit Commitment is large scale short-term optimization problem, in which main objective is to schedule generation to minimize the total fuel cost, subjected to large number of constraints that must be satisfied. In this paper unit commitment problem is solved by using a new evolutionary algorithm known as imperialistic algorithm. In ICA the initial populations individuals (countries) are the countries are in two types: imperialistic and colonies that all together form some empires .Imperialistic competitions among these empires converge to state in their exist only one empire. In the proposed ICA for the unit commitment problem, the scheduling variables are coded as integers; therefore the some constraints are handled are handled directly as minimum up and down type constraints. A new method for initializing the countries is proposed. To verify the performance of the Imperialistic Competition Algorithm (ICA), it is applied to systems with ten number of generating units in one-day scheduling period.

Nomenclature

N_{gen}= Number of units
H = Scheduling horizon(in hours)
P_D(t) = load demand at t^{th}hour.
P_R(t) = system reserve at t^{th}hour.
C = No. of operating cycle for each unit
T_{IC}= Duration of operating cycle c for unit i
P_i(t) = output power of unit i
$P_{max,I}$= Maximum output power of unit i
$P_{min,I}$= Minimum output power of unit i
$P_{i,max}$(t)=Maximum output power of unit i at hour t
$P_{i,min}$(t)= Minimum output power of unit i at hour t
MUT_i= Maximum up-time limit of unit i
MDTi= Minimum down time limit of unit i
RU_I= Ramp up rate of unit i
RD_i= Ramp down rate of unit i
SUCi = start up cost of unit „i‟
HSC_i= Hot start cost of unit i
CSC_i= cold start cost of unit i
CSH_i= cold start hour of unit i
FC_i= Fuel cost of unit i
TFC = total fuel cost
IS_i= Initial state of i

1. Introduction

Unit commitment (UC) aims to schedule the most cost-effective combination of generating units to meet forecasted load and reserve requirements, while adhering to generator and transmission constraints. The objective function includes costs associated with energy production and start-up and shut-down decisions, along with possible profits. The resulting problem is a large scale nonlinear optimization problem for which there is no exact solution technique. The electric power industry has been using efficient methods for many years to solve the unit commitment problem to optimize the overall cost. However, as the power industry undergoes radical restructuring, the role of unit commitment models is changing. Due of the problem's sue and complexity, and because of the large economic benefits that could result from its improved solution, considerable attention has been devoted to development of better optimization algorithms. Lagrangian relaxation has been most successful and widely used approach for quick development of good, if not optimal, generator schedules. Modern power systems are usually large scale systems, and as the number of solutions to the UC problem grows exponentially with the number of units, the computation time would be excessive.

In this paper Imperialistic Competition Algorithm (ICA) to solve unit commitment problem for better results. Atashpaz-Gargari and Lucus first introduced Imperialistic competition algorithm (ICA) in 2007. Imperialistic Competition Algorithm ICA method is inspired the imperialistic competition. Here all the countries are divided among imperialists and colonies .These colonies are divided among imperialists. These imperialists and colonies are together forming an empires. Then the imperialists competition among the empires begins. At the end of imperialistic competition, only one empire remains. The colonies of this empire are in the same position as the imperialist of this empire and have the same cost.

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2. Literature Review

In the field of power system many research are performed to obtain the best way for the unit commitment.

- V. S. Pappalaet al. explained "A new approach for solving the unit commitment problem by adaptive particle swarm optimization". [1]
- T. O. Ting et al. explained "A novel approach for unit commitment problem via an effective hybrid particle swarm optimization," [2]
- Y. W. Jeong et al. explained "A Method for Solving the fuel Constrained Unit Commitment Problem". here the results achieved are quite encouraging and indicate

the viability of the proposed technique to deal with future UC problems. The results proved the possibility of reduced computation time while getting the maximum profit for the electrical power. [3]

- R. M. Burns et al. explained "A Practical Resource Scheduling with OPF Constraints" where OPF stands for optimal power flow. Here by considering the optimal power flow author given a new approach for finding unit commitment problem. [4]
- G. B. Sheble et al. explained "Short-Term Generation Scheduling with Transmission and Environmental Constraints Using an Augmented Lagrangian Relaxation" but the author concluded that Lagrangian Relaxation method is much time taking and not precise method. It is a systematic and efficient method to schedule generating unit in the short term, but the sensitivity of the unit statuses to adjustment in the lagrangian multipliers may cause process to oscillate around the optimal solution. [5]
- W. L. Snyder et al. explained "heuristics based evolutionary algorithm for solving unit commitment and dispatch" This paper presents an evolutionary algorithm, guided by heuristics, to solve the unit commitment and dispatch problem in large scale power systems. [6]
- Yang PC et al. explained the "Evolutionary Programming Based Economic Dispatch for Units with Non-Smooth Fuel Cost Functions". Evolutionary programming methods are like genetic algorithm. This paper proposes an algorithm to solve the profit based unit commitment problem by incorporating operational constraints in restructured power system. [7]
- Jigneshsolanki et al .explained "a genetic algorithm approach to price-based unit commitment" in this paper author applies a genetic algorithm technique to price based unit commitment for GENCO with 3 generators and compared the solution with dynamic programming solution and then concluded genetic algorithm is better than dynamic programming. [8]
- S. Virmani et al. explained "Implementation of a Lagrangian relaxation based unit commitment problem," but he found it is much time taking method. [9]
- Srinivasan, D. et al. author explained "A Priority List-based evolutionary algorithm to solve large scale unit commitment," here initial population was seeded with priority list solutions to obtain a faster and better convergence. This technique can be very easily adapted to handle any sort of constraints through the modification of the penalty terms.[10]
- • Z. Ouyang et al. Proposed method employs a variable window size according to load demand increments, and corresponding experimental results indicate a substantial saving in the computation time without sacrificing the quality of the solution. [11]
- F. Zhuangand et al. proposed a Lagrangian relaxation algorithm for power system generator unit commitment is proposed. A mathematically based, systematic and generally applicable procedure to search for a reserve-feasible dual solution is presented.[12]
- A. I. Cohen et al. presented a new approach is for solving the unit commitment problem based on branch-and-bound techniques. The method incorporates time-dependent start-up costs, demand and reserve constraints and minimum up and down time constraints. It does not require a priority ordering of the units. [13]
- J. A. Muckstadt et al. presented an optimum solution procedure which takes advantage of the structure of the model and promises computational efficiency in practical applications. The model minimizes the total expected costs of start-up and shutdown.[14]
- G. B. Sheble et al. present a genetic algorithm which is based on the survival-of-the-fittest theory. This paper explains the genetic algorithm, the implementation of this algorithm and the results for a six-generator 24-hour commitment schedule. [15]
- S. A. Kazarlis et al. presents a genetic algorithm (GA) solution to the unit commitment problem for optimization techniques based on principles inspired from the biological evolution using metaphors of mechanisms such as natural selection, genetic recombination and survival of the fittest. [16]

3. Problem Formulation

The objective of the UC problem is to minimize total operating cost of the generating units during the scheduling horizon, while both unit and system constraints must be satisfied. Total operating cost consists of fuel, start-up, and shut-down costs of the generating units. The output powers of the units in each hour are determined by economic dispatch. In general, the fuel cost can be calculated using the fuel cost functions of the units.

$F(P_i) = a_i+b_iP_i+c_iP_i^2 \quad i=1,2,3\ldots\ldots N$ (1)

Where a_i, b_i, c_i are fuel cost coefficients generator i

Then the total fuel costs for an H-hour load horizon will be found. Start-up Costs are expressed as an exponential or linear function of the time………..

$$TFC = \sum_{t=1}^{H}\sum_{i=1}^{N_{gen}} FC_i(P_i).u_i(t) \quad (2)$$

3.1 System Constraints

1) Generating units initial operating status
2) Maximum and minimum power limits
3) Ramp up/down rate
4) Power balance of the system

$$\sum_{i=1}^{Ngen} u_i(t)P_i(t) = P_D(t), t = 1,2,3........H \quad (3)$$

5) pinning reserve of the system

$$\sum_{i=1}^{Ngen} u_i(t)P_{i,\max}(t) = P_D(t)+P_R(t) \quad (4)$$

6) Minimum up/down time

$$T_i^c \geq MUT_i \text{ if } T_i^c \geq 0$$
$$-T_i^c \geq MDT_i \text{ if } T_i^c < 0 \quad (5)$$

Where T_i^c is a sign integer which represents the continuous ON/OFF status duration of the c_{th}cycle of the i_{th}unit .The sum of the absolute values of T_i^c for all units must be equal to the scheduling horizon:

$$\sum_{c=1}^{C}\left|T_i^c\right| = H \qquad (6)$$

4. Proposed Algorithm

Atashpaz Gargari and Lucas inspired by imperialistic competitions and applied this method to some of benchmark cost functions. Similar to other evolutionary algorithms, the ICA starts with an initial population that is called countries. Some of the best countries that have the best objective functions are selected to be imperialists. The rest countries form the colonies of these imperialists. The colonies are partitioned among the imperialists. The power of an imperialist in a minimization problem is inversely proportional to its cost function. Then the colonies move toward their relevant imperialist and the position of the imperialists will be updated if necessary. In the next stage, the imperialistic competition among the empires begins, and through this competition, the weak empires are eliminated. The imperialistic competition will gradually lead to an increase in the power of powerful empires and a decrease in the power of weaker ones. Finally the weak empires that are not able to improve their position will be collapsed. These competitions among the empires will cause all the countries to converge to a state in which there exists only one empire in the word and all the other countries are colonies of this empire.

In this competition each empire that cannot increase its power will be eliminated from competition. In the other hand weak empires will lose their power gradually and ultimately they will collapse. These processes ultimately cause that in the long time we have a world with one empire and all other countries will be colonies of this empire. One of the important problem in each is that determine an appropriate format to represent a solution.

The proposed algorithm starts with an initial population (countries in the world). Some of the best countries in the population are selected to be the imperialists and the rest form the colonies of these imperialists. All the colonies of initial population are divided among the mentioned imperialists based on their power. The power of an empire which is the counterpart of the fitness value in genetic algorithm, is inversely proportional to its cost. After dividing all colonies among imperialists, these colonies start moving toward their relevant imperialist country. The total power of an empire depends on both the power of the imperialist country and the power of its colonies. We will model this fact by defining the total power of an empire by the power of imperialist country plus a percentage of mean power of its colonies. Then the imperialistic competition begins among all the empires.

The imperialistic competition will gradually result in an increase in the power of powerful empires and a decrease in the power of weaker ones. Weak empires will lose their power and ultimately they will collapse. The movement of colonies toward their relevant imperialists along with competition among empires and also the collapse mechanism will hopefully cause all the countries to converge to a state in which there exist just one empire in the world and all the other countries are colonies of that empire. A new evolutionary algorithm known as ICA for solving the UC problem is proposed. The efficiency of the proposed method is proved by considering one-day scheduling period with number of units from ten up to 100. The results obtained by the proposed ICA are compared with the results of some previous methods, can find high quality solutions. This algorithm starts by generating a set of candidate random solutions in the search space of the optimization problem.

4.1 History of Imperialism

Imperialism is the policy of extending the power and the rule of government beyond its own boundaries. A country may attempt to dominate others by direct rule or by less obvious means such as a control of market for goods and raw materials. The latter is often called neo-colonialism. Imperialism changed the public attitude towards the civilization of the west. Social Darwinists interpreted imperialism and support the idea that the culture of west is superior to the east culture. Imperialism was considered a crusade as a result of this attitude .Then along with all its complications, imperialism made the imperialist states start to develop their colonies.

For example in the middle of 18th century two opponent imperialists, France and Britain were competing for taking possession of India as part of their imperialistic ambition to control the entire world. Britain was the winner and could take control of India. After pacifying this country, Britain started to build English speaking schools, roads, railways and telegraph lines. Britain also tried to change the social benefits and customs that were considered wrong in comparison to western cultures. These cultural reforms included the costumes such as self-burning that was followed by Indian widows as a sign of loyalty for their husbands. Also they increase the minimum age of marriage daughters. Britain made the same changes in Malaya by abolishing slavery and arbitrary taxes and by making a new system of wealth care.

Indochina is another example, it was a colony of France. France was interested in Indochina for its natural resources and preventing Britain from increasing its power. Also it was good place for evangelists to proselytize on people. According to the assimilation policy, France intended to construct a New France in Indochina through building French speaking schools and expanding its school and culture. Although these polices could not succeed in increasing the control of imperialists over their colonies, and colonies asked for their political autonomy, they brought about a rapid social and political development for the colonies.

In the Proposed algorithm, the imperialists do the same for their colonies. Here all the imperialists compete for taking possession of colonies of each other. Also assimilation policy is modelled by moving the colonies towards the imperialists.

4.2 Steps to solve imperialistic algorithm

a) Initial population is created i.e. countries
b) Calculate Cost function for all countries
c) Selection of imperialists.
d) Selection of colonies.
e) Movement of colonies towards their imperialists
f) Updating positions of imperialists.
g) Calculating the total power of an empire
h) Imperialistic competition

(a) Generating initial empires:-

The goal of optimization is to find an optimal solution in terms of the variables of the problem. We form an array of variable values to be optimized. In GA terminology, this array is called "chromosome", but here the term "country" is used for this array. In an Nvar − dimensional optimization problem, a country is a 1 Nvar × array.

Countryi=(xi1,xi2............xin) (7)

(b) Initial no. of countries of an empire

The initial no. of colonies of an empire is directly proportional to its power. To do this, the normalized costs of the empires are defined

ICn=icn-max(ici) (8)

Normalized power of each imperialist is given by……..

$$IP_n = \left| \frac{IC_n}{\sum_{i=1}^{N_{imp}} IC_n} \right| \quad (9)$$

Then the initial no. of empires…. NCn=round (IPn. Ncol) (10)

(c) Moving the colonies towards imperialists

Positions of the colonies of of the nth empire are updated as follows

newcolni=colni+rand×B.(In-colni) (11)

Where, colni _ position of ithcolony of the nth imperialist

rand-random no. between (0,1)

B-weight factor

In -position of nth imperialist

(d) Updating positions of the imperialists

During the previous stage, a colony may reach to a position with lower cost than that the imperialist. In such a case, the positions of the imperialist and that colony must be exchanged. Then the rest of the colonies of this empire move towards the new position of the imperialist.

(e) Calculating total power of an empire

The total power of an empire depends on both the power of the imperialist and the power of its colonies. But it is mainly affected by the power of the imperialist. The total power of an empire is defined as

TPn=cost (imperialist)+ξ×mean(cost(colonies of empire)) (12)

where, TPn- Total power of nth empire

ξ - positive no. less than 1

WhereTPn is the total power of the th empire and ξ is a positive number which is considered to be less than 1. In fact, represents the role of the colonies in determining the total power of an empire.

(f) Imperialistic competition

In this stage, the imperialistic competition begins and all the empires try to take possession of the colonies of other empires. This competition is modelled by picking some of the weakest colonies (usually one) of the weakest empires and making a competition among all empires to possess these (this) colonies. Each of the empires will have a likelihood of taking possession of these colonies based on their total powers; therefore, the more powerful empires have greater chance to possess the mentioned colonies. To do this, the possession probability of each empire must be found. The normalized total power of each empire is calculated as follows:

NTPn=TPn–max(TPi) (13)

Where ,NTPn- normalized power of nth empire

The possession probability of each empire is given by

$$PS_n = \left| \frac{NTP_n}{\sum_{i=1}^{N_{imp}} NTP_i} \right| \quad (14)$$

(g) Eliminating the powerless empires

The powerless empires will collapse in the imperialistic competition. Different criteria can be defined for collapse mechanism. In this paper, an empire is assumed collapsed when it loses all of its colonies. In modelling collapse mechanism different criteria can be defined for considering an empire powerless. In most of our implementation, we assume an empire collapsed and eliminate it when it loses all of its colonies.

(h) Convergence

After some imperialistic competitions, all the empires except the most powerful one will collapse and all of the countries under their possession become colonies of this empire. All the colonies have the same positions and the same costs and there is no difference between the colonies and their imperialist. In such a case, the algorithm stops.

5. Implementation of ICA for UC Problem

(a) Country Position Definition

The position of a country in inter-coded ICA for UC problem consists of sequence of ON/OFF cycle durations of the units during the time horizon of the problem. A positive integer represents duration of continuous ON status while negative integer represents duration of continuous off cycle of unit. It all is done by analysing a load operating cycle operating between base loads, medium load and peak load.

(b) Creating Initial Population

Here we used new technique for the initialization .In these technique units are divided into three classes. The units are divided in base- load, medium-load, and peak-load on the basis of similar characteristics, such as up/down time requirements, output power capacity and start-up costs. Since the base load units are always in ON state, and peak load units are turned on in load peaks based costs, the optimal state of medium-load units must be found. To do this some priority lists are created. The base load units are of highest priority based on their fuel costs. The peak load units are in the lowest priority based on fuel costs. A random permutation of the medium load units is created and placed between the base load and peak load units. The population is created using these priority lists. It should be noted that if only one priority list is used for the whole scheduling period, the search space will be restricted and the results are not appropriate, especially in large systems. To overcome this drawback, different priority lists are created and used for the sequence of turning on or off the units.

(c) Cost function

The cost function used in ICA is sum of total production costs (fuel costs and start-up/shut down costs) over the scheduling horizon and a penalty function that penalizes the violation of system constraints. The fuel costs are calculated using equation 1. The shut down costs are not considered in this paper. The start-up costs are calculated as follows:

SUCT=U(Tic).SUCi(-Tic-1) (15)

Where, SUCT - total start-up cost , U(.)- Unit step function.

Then the total production cost is –

TC= (FCi(Pi).Ui(t)) + SUCT(16)

Here the penalty function used in paper has two terms-

$$\prod_{res} = w\sum_{t=1}^{H}\frac{1}{P_D(t)}\Re\left(\left(P_D(t)+P_R(t)\right)-\sum_{i=1}^{N_{gen}}u_i(i).\tilde{P}_{i,\max}(t)\right) \quad (17)$$

$$\prod_{ex} = w\sum_{t=1}^{H}\frac{1}{P_D(t)}\Re\left(\sum_{i=1}^{N_{gen}}u_i(i).\tilde{P}_{i,\min}(t)-P_D(t)\right) \quad (18)$$

Where R(.) is unit ramp function and w is a multiple of the maximum operating cost of system over the scheduling period .Finally the ICA cost function is the formed follows:

$$CF = TC + \prod_{res} + \prod_{ex} \quad (19)$$

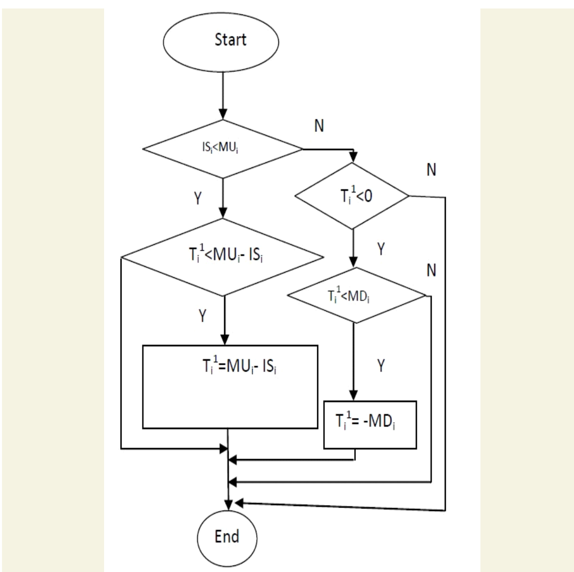

Fig: 1. Flow chart of modifying the first cycle of unit

(d) Constraint Handling

After creating initial population (i.e., countries), the initial empires are created. Now the movement of colonies toward their relevant imperialists begins. Since in UC problem the parameters must be integer the Round function is applied to new positions of the colonies .As said, the position of the colonies is updated using equations. in order to handle the constraints of the problem ,it is necessary to modify the cycles of unit.

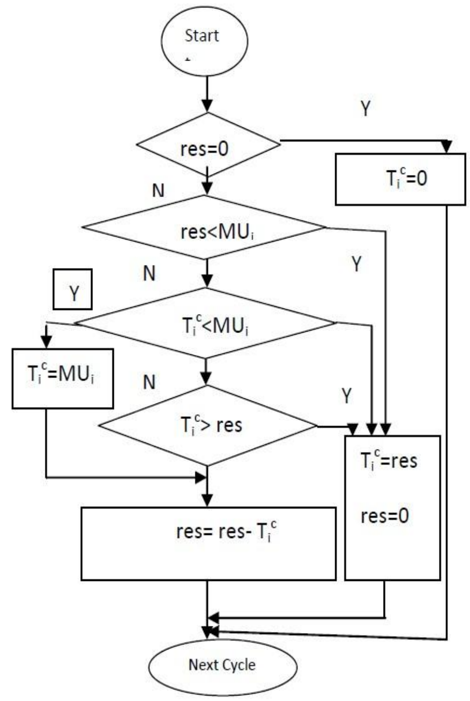

Fig: 2. Flow chart of modifying the cycles of unit

6. Test Results

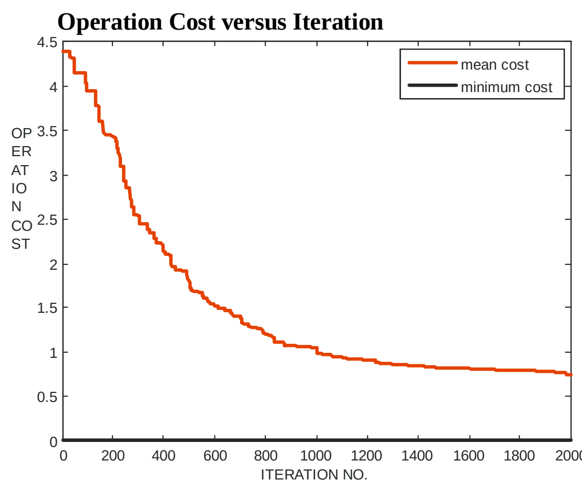

Fig: 3. Convergence characteristics of ICA

Table: 1. Operation Cost

Number of countries	Operation cost($)
100	98345.77

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