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Original article

Security Constrained Unit Commitment (SCUC) formulation and its solving with Modified Imperialist Competitive Algorithm (MICA)

Farid Hamzeh Aghdam [a,*], Mehrdad Tarafdar Hagh [b]

[a] Department of Electrical Engineering, Azarbaijan Shahid Madani University, Tabriz, Iran
[b] Department of Electrical Engineering, University of Tabriz, Tabriz, Iran

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ABSTRACT

One of the most important optimization problems in operation planning of power systems is unit commitment (UC). Consideration of transmission lines and operation constraints in UC problem leads to a more general problem known as Security Constrained Unit Commitment (SCUC). The SCUC can be formulated as a very large scale mixed-integer problem in practical utility grids. Solving SCUC can take tremendous time due to its huge dimension. In this paper, a formulation of SCUC problem, considering practical constraints and nonlinear characteristics including bus voltage limits, line flow limits, in addition to prevailing constraints such as hourly power demand, system spinning reserves, ramp up and down limits, minimum up and down time (MUT/MDT) limits, and emission limits, is presented. The Modified Imperialistic Competitive Algorithm (MICA), using a priority list (PL) for defining the initial state, is used to solve the mentioned optimization problem. The effectiveness of MICA method to solve the SCUC problem is shown on IEEE 30-bus and 118-bus test systems and is compared with the application of some heuristic methods i.e. genetic algorithm (GA), particle swarm optimization (PSO) and other mathematical approaches i.e. mixed integer programming (MIP).

1. Introduction

Many systems, such as transportation systems, communication systems, electrical power systems, etc. which provide a huge number of people, need periodic scheduling. In power systems, during the day and early hours of the night, electrical power demand would be high, on the other hand in early morning hours there will be less electrical power demand. Unit Commitment (UC) problem indicates the daily schedule of generators in the utility grid with the aim of minimizing the operation cost of the whole system (Wood and Wollenberg, 2015). The UC problem is one of the most challenging optimization problems and can be considered as a very large scale mixed-integer problem in practical utility grids (Jeong et al., 2009).

The UC problem faces many constraints such as power balance constraint, generation limits, spinning reserve, minimum up and down time, ramp rate, crew constraints, cold-start and banking costs, hydro constraints, must run units, must out units and emission constraints (Wood and Wollenberg, 2015).

However, the output of the UC problem does not guarantee that the generated power would flow successfully to the loads through the transmission system. Security Constrained Unit Commitment (SCUC) has been introduced to consider the successful power flow in the system (Fu et al., 2005). The SCUC problem contains more constraints than the conventional UC problem including bus voltage limits, line flow limits, emission constraints, interruptible load contracts and prohibited operating zones (Fu et al., 2005; Pinto et al., 2006).

Complete enumeration can lead to the exact solution of the problem which seems to be impossible to be applied to real power systems due to computational complexity (Wood and Wollenberg, 2015). So much work has been done in recent decades on developing methods for solving the SCUC problem. Fu et al. (2005), solve the SCUC problem by separating it into the unit commitment (UC) as the master problem and the network security check as the subproblem using Benders decomposition, to obtain the minimum system operating cost. Amjady and Nasiri-Rad (2011), introduce an efficient fast SCUC (F-SCUC) for large-scale power

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* Corresponding author.
E-mail addresses: farid.hamzeh@gamil.com (F.H. Aghdam), tarafdar@tabrizu.ac.ir (M.T. Hagh).

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Nomenclature

i	index for generation unit
h	index for time of study
l	index for transmission line
P_{ih}	power generation of unit i at time h
I_{ih}	commitment of state of unit i at time h, 1 for ON and 0 for OFF
$down_i$	down time of unit i
CST_i	cold start time of unit i
SU_{ih}	start-up cost of unit i at time h
HSC_i	hot start cost of unit i
CSC_i	cold start cost of unit i
P_{Dh}	power demand at time h
P_{Lh}	power loss at time h
SR_{ih}	spinning reserve of unit i at time h
SR_h	desired spinning reserve at time h
RU_i	ramp-up rate of unit i
RD_i	ramp-down rate of unit i
MUT_i	minimum up time of unit i
MDT_i	minimum down time of unit i
P_{iMin}	minimum generation limit of unit i
P_{iMax}	maximum generation limit of unit i
E_{ih}	the quantity of CO_2 gas emission of unit i at time h
E_{Max}	maximum allowed emission
$CoEff_i$	the emission coefficient of unit i
λ_{fi}	fuel cost of unit i
NTV_i	net thermal value of the fuel of unit i
EF_i	emission factor of unit i
OF_i	oxidation factor of unit i
N	total number of units
Nl	total number of transmission lines
Pl_{lmax}^h	maximum power capacity of line l at time h
Pl_l^h	power transmission of line l at time h
Nb	total number of buses
$Cost_n^{norm}$	normalized cost of nth imperialist
$Cost_n^{imp}$	cost of nth imperialist
$Cost_j^{col\_n}$	cost of jth colony in empire n
N_{imp}	total number of imperialists
NC_n	number of colonies in possession of imperialist n
N_{col}	total number of colonies
$Pos_{col(i-n)}^d$	positions of colony i of empire n at decade d
$Pos_{imp(n)}^d$	positions of imperialist n at decade d
r_i	uniform random number within 0 and 1
β	assimilation weight factor

systems including single-hour UC with network security, single-hour UC adjustment, and hourly network security check. A stochastic model for the long-term solution of SCUC considering random disturbances, such as outages of generation units and transmission lines as well as load forecasting inaccuracies and using the Monte Carlo simulation method is presented by Fu and Shahidehpour (2007). A framework of extended Benders decomposition with linear feasibility and optimality cuts is proposed by Chen (2008), for solving the SCUC problem in two stages. A fast bounding technique is proposed by Wang et al. (2012), to improve the branch and cut algorithm which has the ability for improving the calculation speed of SCUC. Aghaei et al. (2015), present the application of a mixed-integer programming (MIP) approach for solving stochastic security-constrained daily hydrothermal generation scheduling. Hu and Wu (2014), propose an efficient approach for deriving robust solutions to the SCUC problem, by simulating load and wind uncertainties via interval numbers and using Benders decomposition. A successive mixed integer linear programming (MILP) method with fuzzy security constraints for solving the SCUC with transmission line outages, is proposed by Yu and Venkatesh (2013).

Likewise, in some works intelligent search based algorithms have been applied to SCUC problem. It is due to difficult implementation of the mathematical based approaches to large scale SCUC problems. Heuristic methods show better and faster performance in large SCUC problems. Amjady and Nasiri-Rad (2011), suggest a hybrid solution method including an adaptive binary PSO and an adaptive real coded GA to solve the SCUC problem. Elsayed et al. (2014), apply a novel GA for solving optimization problems including a short-term hydrothermal scheduling problem. Kumar and Mohan (2010), use the Optimal Power Flow (OPF) with line flow constraint for solving the conventional UC problem by means of GA. Nayak and Sharma (2000), present a solution for the UC problem using a combination of the feedforward neural network and the simulated annealing. Dhanalakshmi et al. (2013), present an Intelligent Genetic Algorithm (IGA) to solve the UC problem which has the capability of handling minimum up/down time constraints of the UC problem. Collett and Quaicoe (2006), employ a hybrid approach that includes particle swarm optimization (PSO) for solving the SCUC problem. Reddy et al., 2016, consider the OPF with line flow constraint in solving the UC problem using GA. Chakraborty et al. (2010), apply a Lagrangian relaxation based algorithm with PSO to the SCUC problem. Chandrasekaran and Simon (2011), present a binary real coded firefly (BRCFF) algorithm for solving SCUC problem. Likewise, Columbus and Simon (2012), develop scheduling algorithm for generation units, using a hybrid PSO. A novel hybrid method for solving SCUC problem is proposed by Shafie-Khah et al. (2014) which requires much less computation time in comparison with other methods. Samiee et al. (2013) present a new combinatorial solution strategy for SCUC problem using an enhanced harmony search technique to determine the unit states.

Main issue in solving SCUC problem is the calculation time reduction without sacrificing optimal solution. Intelligent search based methods could fulfill these aims in problem with large scales.

This work aims on solving SCUC problem by applying a heuristic method called imperialistic competition algorithm (ICA) which is proposed by Atashpaz-Gargari and Lucas (2007). Also there has been an effort to modify the method by combining it with priority list. The major contributions of the present work are as follows:

- A new heuristic method has been applied to the SCUC problem and has been compared to other heuristic and non-heuristic methods.
- A sub-ICA algorithm has been used to solve the economic dispatch problem and the fast decoupled Newton-Raphson (FDNR) method has been applied to the algorithm to attain the load flow.

The mathematical model of the SCUC problem with the prevailing constraints is provided in Section 2. Section 3 introduces an intelligent search based method for solving optimization problems named Imperialistic Competitive Algorithm (ICA). Section 4 has tried to illustrate the priority list method. Final section, applies the proposed method to the IEEE 30-bus and 118-bus test systems.

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Results are compared to other solution methods and the effectiveness of the algorithms to solve the SCUC problem is discussed.

2. Problem formulation

The objective of SCUC is to determine the schedule of generation units for minimizing the system operating cost while meeting the prevailing constraints such as power balance, generation limits, must-run units, system spinning reserve, minimum up and down time limits, ramp rate limits, startup and shutdown characteristics of units, fuel constraints, environmental limits, bus voltage limits and line flow limits.

In the SCUC problem, the objective is to minimize the cost of supplying the load as formulated below:

$$min : OF = \sum_{i=1}^{N}\sum_{h=1}^{24} F_i(P_{ih}) \times I_{ih} + SU_{ih} \tag{1}$$

where $F_i(P_{ih})$ is considered as the fuel cost and could be illustrated as below:

$$F_i(P_{ih}) = a_i P_{ih}^2 + b_i P_{ih} + c_i \tag{2}$$

SU_{ih} is the start-up cost (SC) of a generating unit and depends on the time of starting the unit and whether the boilers are kept hot during the shut-down period. Thus, the start-up cost could be defined as Eq. (3).

$$SU_{ih} = \begin{cases} HSC_i & \text{if } \mathrm{down}_i \leqslant \mathrm{CST}_i \\ CSC_i & \text{if } \mathrm{down}_i > \mathrm{CST}_i \end{cases} \tag{3}$$

In the SCUC problem, the objective function given in Eq. (1) should be minimized subjecting to the following constraints:

1) Power balance constraints ($h = 1, \ldots, 24$)

$$\sum_{i=1}^{N} P_{ih} \times I_{ih} = P_{Dh} + P_{Lh} \tag{4}$$

2) Spinning reserve constraints ($h = 1, \ldots, 24$)

$$\sum_{i=1}^{N} SR_{ih} \times I_{ih} \geqslant SR_h \tag{5}$$

3) Ramping up/down constraints of units ($i = 1, \ldots, N$ and $h = 1, \ldots, 24$)

$$P_{ih} - P_{i(h-1)} \leqslant RU_i \tag{6}$$

$$P_{i(h-1)} - P_{ih} \leqslant RD(i) \tag{7}$$

4) Minimum up/down time constraints ($i = 1, \ldots, N$ and $h = 1, \ldots, 24$)

$$I_{ih} = 1\text{for} \sum_{t=h-up_i}^{h-1} I_{it} < MUT_i \tag{8}$$

$$I_{ih} = 0\text{for} \sum_{t=h-down_i}^{h-1} (1 - I_{it}) < MDT_i \tag{9}$$

5) Power generation limit constraints ($i = 1, \ldots, N$ and $h = 1, \ldots, 24$)

$$P_{iMin} \leqslant P_{ih} \leqslant P_{iMax} \tag{10}$$

6) Reactive power generation limit constraints ($i = 1, \ldots, N$ and $h = 1, \ldots, 24$)

$$Q_{iMin} \leqslant Q_{ih} \leqslant Q_{iMax} \tag{11}$$

Conventional electricity generation using fossil fuels, such as oil, gas and coal, is the main reason of environmental pollution through emissions of harmful gases such as nitrogen oxides, sulfur oxides, and carbon oxides (Almasoud and Gandayh, 2015). Accordingly, in this research, beside the conventional constraints, environmental and security constraints are considered in this formulation as well.

In order to effectively control global warming, there should be a significant reduction in the amount of heat-trapping emissions that are put into the air. Accordingly, the emissions should be considered in UC problem. The UC problem output should be established under emission limiting of the generating units. The amount of greenhouse gas emissions relies on the amount of used fuel in power plants and the emission coefficient which is given by the below equation:

$$E_{ih} = CoEff_{ei} \times \frac{F_i(P_{ih})}{\lambda_{fi}} \tag{12}$$

where $F_i(P_{ih})$ is the total fuel cost of unit i, λ_f is the fuel price, and $CoEff_e$ is the emission coefficient which depends on net thermal value (NTV), the emission factor (EF), and the oxidation factor (OF) of the unit and the fuel (Kockar et al., 2009; Tang and Che, 2013; Commission Decision Report, 2004) and could be expressed as below:

$$CoEff_{ei} = NTV_i \times EF_i \times OF_i \tag{13}$$

The NTV_i and EF_i depend on the respective fuel type and OF_i relies on the incomplete oxidation of the carbon to CO_2 during the burning process. Table 1 illustrates the emission coefficient according to reference values of the fuel and unit characteristics which is brought in (Commission Decision Report, 2004).

According to Eqs. (12) and (13) and Table 1, the quantity of CO_2 gas emissions, E_{ih}, could be calculated and it should be limited in the SCUC problem as below constraint:

7) Emission constraints ($i = 1, \ldots, N$ and $h = 1, \ldots, 24$)

$$\sum_{i=1}^{N}\sum_{h=1}^{24} E_{ih} \leqslant E_{Max} \tag{14}$$

In addition, to guarantee the successful power flow to the loads through the transmission system, security check should be performed which could be expressed as below equations:

8) Power flow constraints ($l = 1, \ldots, Nl$ and $h = 1, \ldots, 24$)

$$-Pl_{lmax}^h \leqslant Pl_l^h \leqslant Pl_{lmax}^h \tag{15}$$

9) Bus voltage constraints ($b = 1, \ldots, Nb$ and $h = 1, \ldots, 24$)

$$V_{bmin}^h \leqslant V_b^h \leqslant V_{bmax}^h \tag{16}$$

Considering above constraints and large scale of practical power systems, makes solving the SCUC problem so challenging and frustrating.

3. Imperialist Competitive algorithm (ICA)

As explained earlier, SCUC problem, is considered as a nonlinear mixed integer optimization problem which aims to schedule on and off periods of the generating units at minimum operating cost with respect to the constraints illustrated in section II. In other words, SCUC determines ON/OFF state of generating units at each hour of planning period, and optimally dispatches the load and spinning reserve among the committed units.

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Table 1
The ratio of emission coefficient to fuel price.

Unit type	NTV_i (kJ/kg)	EF_i ($t\ CO_2/TJ$)	OF_i (%)	$CoEff_{ei}$ ($t\ CO_2/m^3$ or $t\ CO_2/tFuel$)
Natural Gas	48000	56.1	99	2.66
Gas/Diesel Oil	43000	74	99	31.5
Coking Coal	28200	94.5	99	2.64

Solving UC problem for large power systems could be challenging and computationally expensive. Intelligent evolutionary search based methods, are effective and computationally inexpensive. These methods, have shown good functioning to solve complex optimization problems due to the fact that they do not need the gradient of the function in its optimization process. Hence in this paper we will try solving SCUC problem using ICA and compare the results to other evolutionary methods to get the effectiveness of the proposed algorithm.

In this section imperialist competitive algorithm, which is an evolutionary algorithm for optimization problems, is introduced. As it is obvious from its name, this algorithm is inspired by imperialistic competition and it was first introduced by Atashpaz-Gargari and Lucas (2007).

Flowchart of the ICA is illustrated in Fig. 1. Like other intelligent algorithms, ICA starts with creating of initial population containing countries which are peers of particles in PSO or chromosomes in genetic algorithm. Some of the countries with best scores regarding their objective functions are selected as imperialists. Other countries get under territory of empires and form the colonies of imperialists.

The normalized cost of an imperialist is defined in terms of Eqs. (17)–(19) to calculate the normalized power of each imperialist and the number of colonies possessed by each imperialist.

$$Cost_n^{norm} = Cost_n^{imp} - max\{Cost_j^{imp}\} \quad j = 1 \ldots N_{imp} \tag{17}$$

$$p_n = \left| \frac{Cost_n^{norm}}{\sum_{j=1}^{N_{imp}} Cost_j^{imp}} \right| \tag{18}$$

$$NC_n = round(p_n \times N_{col}) \tag{19}$$

Then, assimilation process would start. Colonies should start to transfigure some parts of their characteristics to assimilate toward their relevant imperialist. Colonies move towards their relevant imperialist and new positions of assimilated colonies would be created using Eq. (20).

$$Pos_{col(i-n)}^{d+1} = Pos_{col(i-n)}^{d} + \beta(Pos_{imp(n)}^{d} - Pos_{col(i-n)}^{d}) \times r_i \times \tan\theta \tag{20}$$

where θ a uniform random angle between $-\gamma$ and γ. Choosing larger numbers for γ results in increment of the search space around of each leader and choosing small values results in motion of the colonies in vicinity of the leader. Usually choosing a value in vicinity of $\pi/4$ for θ is appropriate. r_i is a uniform random number between 0 and 1. Also, β is a number with value more than 1 and usually in vicinity of 2. Choosing a value more than 1 for β results in different direction for moving toward the leader for the colonies.

Revolution operator would be applied to the problem to prevent the algorithm to stymie in a local optimal point. Then, the imperialist competition would begin based on power of the empires which can be modelled by the power of imperialist country in addition to mean power of its colonies which is demonstrated in Eq. (21).

$$TCost_n = Cost_n^{imp} + \mu \times mean(Cost_j^{col\_n}) \tag{21}$$

where μ is a positive number between 0 and 1. Small values of μ state that the cost of the whole imperialist is almost the same as the leader country and increasing it causes the higher effect of the colonies on the power of the empire. Choosing 0.05 for μ usually leads to good results.

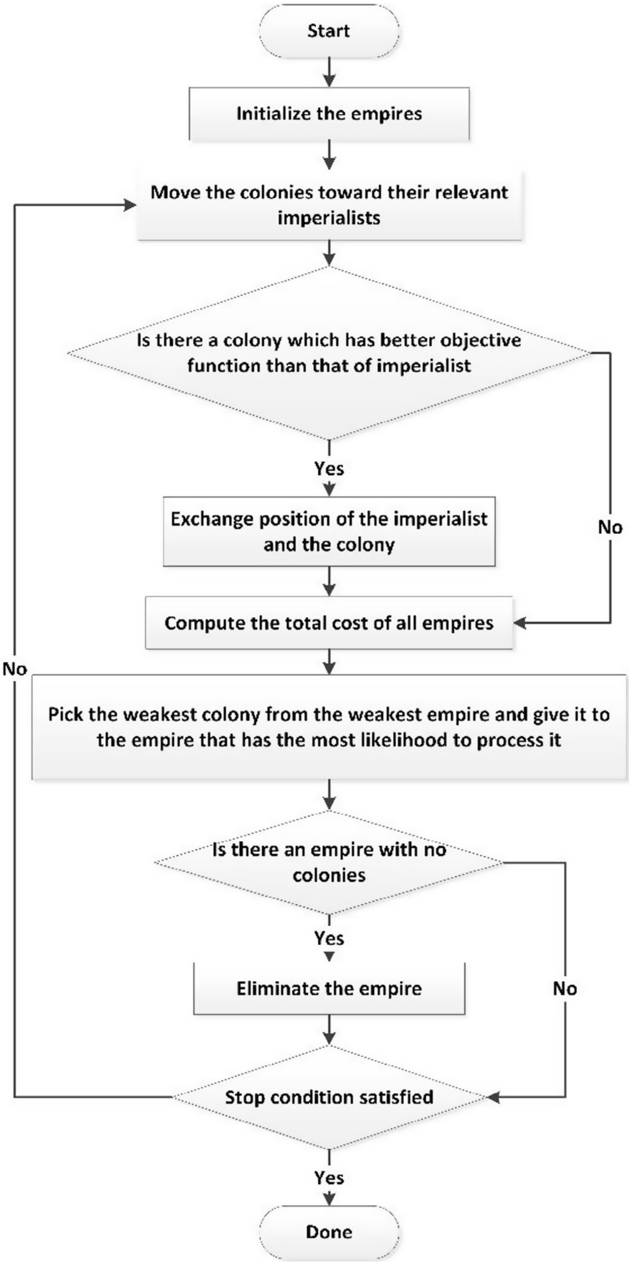

Fig. 1. Flowchart of ICA.

Weaker imperialists shall lose their empires and join the colonies of stronger empires. This mechanism would optimistically lead to having just one empire (Atashpaz-Gargari and Lucas, 2007). In this problem, a binary array would be generated as the populations to establish the states of the units in a specific hour. In the first iteration an initial population would be created arbitrarily satisfying the constraints. According to initial countries, imperi-

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alists and colonies would be chosen. In next iterations, imperialists and colonies would regenerate by means of Eqs. (17)–(21) till getting the least cost using equation (1) as objective function.

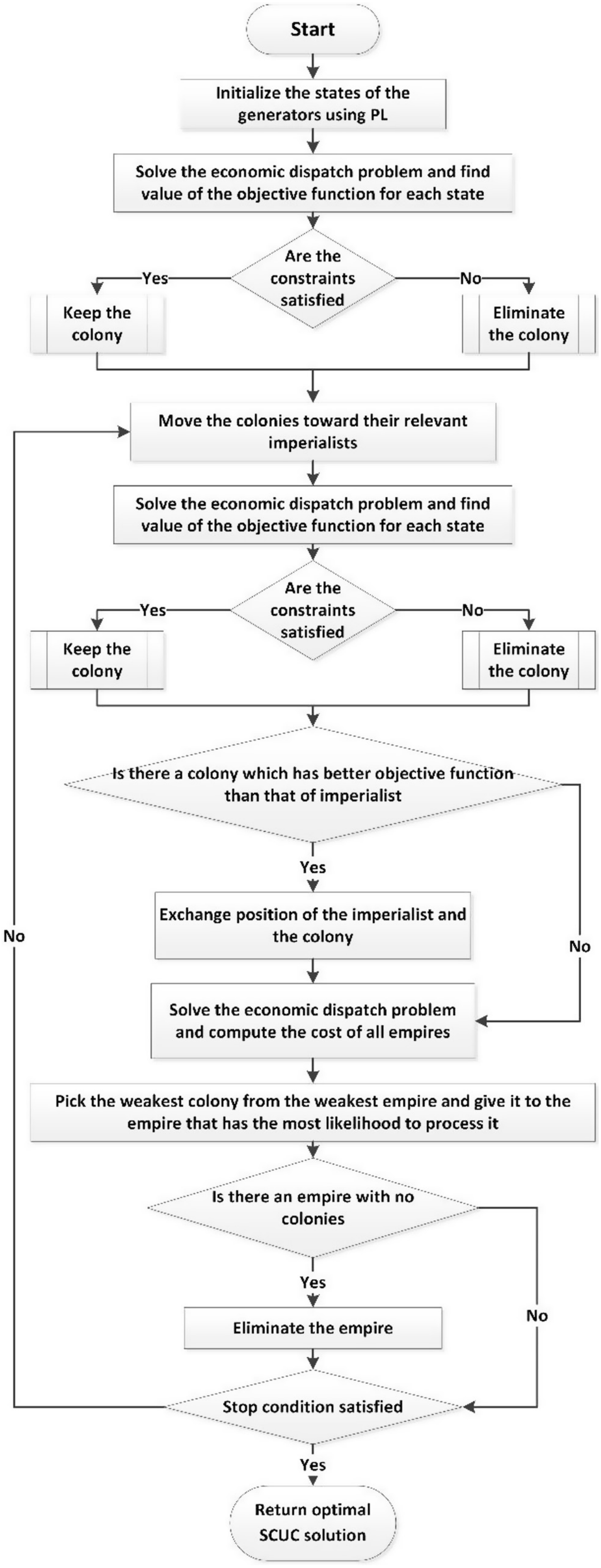

Fig. 2. Flowchart of MICA applied to SCUC problem.

In each iteration, constraints satisfaction should be examined and colonies which do not meet the constraints would be eliminated from the process.

4. Priority list for initializing ICA

The simplest approach for solving the conventional unit commitment problem is generating a priority list (PL) of the generation units (Wood and Wollenberg, 2015). PL methods commit and uncommit units in a certain priority order typically built based on operating and startup/shutdown costs of the generation units. The PL methods are simple, fast and provide feasible solutions, but cannot guarantee optimal solutions. The unit with the least cost, is preferred first for commitment and for uncommitment purpose, the unit with the highest cost is preferred among all committed units.

Using PL information of the generation units, three subsets of generators, always on generators, always off generators and generators with committed status to be determined are predefined (Ke et al., 2015). The results can help to initialize the ICA for faster convergence, according to security constraints.

In next section effectiveness of the proposed MICA would be tested on IEEE 30-bus and 118-bus test systems and compared to other solution methods applied to SCUC problem.

5. Case study and results

In this section, the MICA for solving SCUC problem would be applied to IEEE 30 bus and IEEE 118 bus test systems. The MICA is implemented on Intel® CPU using MATLAB software, version 8.0.0.783. The flowchart of MICA application in SCUC problem is presented in Fig. 2.

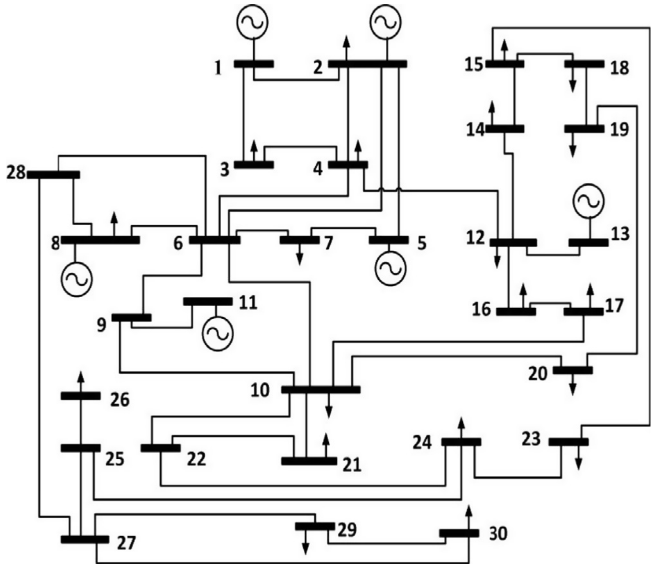

Fig. 3. Single line diagram of IEEE 30 bus test system.

Table 2
Cost Coefficients of the IEEE 30 bus test system generators.

Unit	a_i ($\$/(MWhr)^2$)	b_i ($\$/MWhr$)	c_i ($\$/hr$)
1	0.00375	2.0000	0.0000
2	0.0175	1.7500	0.0000
3	0.0625	1.0000	0.0000
4	0.00834	3.2500	0.0000
5	0.02500	3.0000	0.0000
6	0.02500	3.0000	0.0000

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Table 3
Characteristics of the IEEE 30 bus test system generators.

Unit	*MUT (Hours)*	*MDT (Hours)*	*Pmin (MW)*	*Pmax (MW)*	*Start up cost ($)*	*busbar*
1	5	3	50	200	70	1
2	4	2	20	80	74	2
3	3	2	15	50	50	5
4	3	2	10	35	110	8
5	1	1	10	30	72	11
6	4	2	12	40	40	13

Table 4
Hourly loads for ieee 30-bus system.

Hour	1	2	3	4	5	6	7	8
Load(MW)	166	196	229	267	283.4	272	246	213
Hour	9	10	11	12	13	14	15	16
Load(MW)	192	161	147	160	170	185	208	232
Hour	17	18	19	20	21	22	23	24
Load(MW)	246	241	236	225	204	182	161	131

Table 5
Maximum power flow for each line in (MWs) for the IEEE 30 bus test system.

Line	Max power flow (MW)	Line	Max power flow (MW)	Line	Max power flow (MW)
1	650	15	325	29	160
2	650	16	325	30	80
3	325	17	160	31	80
4	650	18	160	32	80
5	650	19	160	33	80
6	325	20	80	34	80
7	450	21	80	35	80
8	350	22	80	36	325
9	650	23	80	37	80
10	160	24	80	38	80
11	325	25	80	39	80
12	160	26	160	40	160
13	325	27	160	41	160
14	325	28	160		

5.1. IEEE 30 bus test system

The single line diagram for IEEE 30 bust test system is illustrated in Fig. 3. Table 2 demonstrates cost coefficients of the IEEE 30 bus test system generators which were mentioned in equation (2) and participated in objective function of the SCUC problem. Table 3 shows the characteristics of generators in which the *MUT*, *MDT*, *Pmin* and *Pmax* stand for minimum up time, minimum down time in hours, and the minimum and maximum powers in MW, respectively. This table determines the constraints for the SCUC problem illustrated in Section 2. Furthermore Table 4 shows the hourly system load demand.

For fulfilling security constraints, maximum power flow of the lines should be considered. The IEEE 30 bus test system has 41 lines with capability of transmitting a maximum power flow in MW which is demonstrated in Table 5.

Respective minimum and maximum voltage limits, V^{h}_{bmin} and V^{h}_{bMax}, are assumed to be 0.9 p.u and 1.1 p.u.

Applying MICA method as presented in Sections 3 and 4, to SCUC problem with equations discussed in Section 2, and regarding the characteristics presented in Tables 2 through 5, and PL presented in Table 6, SCUC problem would be solved.

Tables 7–10, show the SCUC problem solution using MICA, and heuristic methods as GA and PSO methods, which the last two are the most popular heuristic algorithms, and also MIP method, respectively.

Table 6
PL for Generation Units in IEEE 30 Bus Test System.

Unit	*Average Cost in full load ($/MWh)*
1	2.75
3	3.15
2	3.54
4	4.125
5	2.75
6	4

5.2. IEEE 118-bus test system

MICA has been applied to SCUC problem in IEEE 118-bus test system with the corresponding data available at http://motor.ece.iit.edu/data/SCUC_118.xls. The system consists of 54 units, 186 branches, 14 capacitors, nine tap-changing transformers, and 91 demand sides.

Table 11, shows the cost of SCUC problem using MICA, ICA, GA, PSO and also MIP methods.

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Table 7
IEEE 30-bus test system SCUC problem solution using MICA.

Hour	G1 (MW)	G2 (MW)	G3 (MW)	G4 (MW)	G5 (MW)	G6 (MW)
1	152.8	0	18.6	0	0	0
2	183	0	20.6	0	0	0
3	202	0	23.2	0	0	14.1
4	190.1	51.6	22.3	0	0	14
5	201	55	23.3	0	0	16.3
6	190.3	57.3	21.1	0	0	14.4
7	176	45.4	21.8	0	0	12.3
8	148.3	40.2	18.9	0	0	12.4
9	142.1	38.2	17.8	0	0	0
10	114.5	33.4	17.3	0	0	0
11	104.7	30.8	15.3	0	0	0
12	114.7	33.4	16.1	0	0	0
13	120.5	36.5	17.7	0	0	0
14	134	40	17.4	0	0	0
15	153.2	43.1	19	0	0	0
16	171.4	48.2	21.4	0	0	0
17	177.6	55.3	22.9	0	0	0
18	181.4	47.9	21.4	0	0	0
19	177.6	46.5	21.2	0	0	0
20	166.2	46.5	20.9	0	0	0
21	149.6	42.3	19.1	0	0	0
22	131.5	39	16.9	0	0	0
23	102.4	42	20.8	0	0	0
24	91.1	27.8	15	0	0	0
Total Cost = 13517 $						
Total number of function evaluations = 3930						

Table 8
IEEE 30-bus test system SCUC problem solution using GA.

Hour	G1 (MW)	G2 (MW)	G3 (MW)	G4 (MW)	G5 (MW)	G6 (MW)
1	142.8	0	18	10	0	0
2	165.8	0	19.6	16.9	0	0
3	187.1	0	22.9	27	0	0
4	197.6	0	49.1	29.9	0	0
5	198.7	0	27	32.2	0	35.2
6	195.9	0	26.9	32.4	0	25.9
7	183.6	0	21.7	30.1	0	18.7
8	170.7	0	20.1	17	0	12
9	155	0	19.4	11.4	0	12
10	145.1	0	20.8	0	0	0
11	133.9	0	17.2	0	0	0
12	145.3	0	19.6	0	0	0
13	156.7	0	19.1	0	0	0
14	151.1	0	39.5	0	0	0
15	196.5	0	20.2	0	0	0
16	199.5	0	42.2	0	0	0
17	191.3	0	27.9	0	0	35.9
18	196.5	0	30.1	0	0	22.9
19	192.2	0	24.7	0	0	28
20	190.2	0	24.5	0	0	18.8
21	179.7	0	19.9	0	0	12
22	156.4	0	19.4	0	0	12
23	148.6	0	17.4	0	0	0
24	117.6	0	16.7	0	0	0
Total Cost = 14297 $						
Total number of function evaluations = 5380						

According to the table, MICA has converged faster than the conventional ICA. Besides comparison shows a significant reduction in the total cost and computation time of the SCUC problem solution using MICA instead of GA, PSO and MIP.

6. Conclusion

In this paper, first a formulation of the SCUC problem regarding the power flow and voltage limitations was proposed. Cost function of the problem includes generating units costs and start-up costs.

Moreover, application of MICA solution method, using PL as an initializing tool, was proposed for solving Security Constrained Unit Commitment (SCUC) helping generating units for deciding about the time of operation to obtain the maximum profit.

Finally, this study is the first work using MICA method for the SCUC problem solving and it has been applied to SCUC problem. The IEEE 30-bus and 118-bus test systems are used to acquire the simulation results. In comparison with GA, PSO and MIP, this method showed a better performance for solving the problem in aspect of cost and time of convergence.

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Table 9
IEEE 30-bus test system SCUC problem solution using PSO.

Hour	G1 (MW)	G2 (MW)	G3 (MW)	G4 (MW)	G5 (MW)	G6 (MW)
1	152.8	0	18.6	0	0	0
2	183	0	20.6	0	0	0
3	202	0	37.5	0	0	0
4	190.1	51.6	22.3	0	0	14
5	201	55	23.3	0	0	16.3
6	190.3	57.3	21.1	0	0	14.4
7	176	45.4	21.8	0	0	12.3
8	148.3	40.2	31.5	0	0	0
9	142.1	38.2	17.8	0	0	0
10	114.5	33.4	17.3	0	0	0
11	104.7	30.8	15.3	0	0	0
12	114.7	33.4	16.1	0	0	0
13	120.5	36.5	17.7	0	0	0
14	134	40	17.4	0	0	0
15	153.2	43.1	19	0	0	0
16	171.4	48.2	21.4	0	0	0
17	177.6	55.3	22.9	0	0	0
18	181.4	47.9	21.4	0	0	0
19	177.6	46.5	21.2	0	0	0
20	166.2	46.5	20.9	0	0	0
21	149.6	42.3	19.1	0	0	0
22	131.5	39	16.9	0	0	0
23	102.4	42	20.8	0	0	0
24	91.1	27.8	15	0	0	0

Total Cost = 13527 $
Total number of function evaluations = 5030

Table 10
IEEE 30-bus test system SCUC problem solution using MIP.

Hour	G1 (MW)	G2 (MW)	G3 (MW)	G4 (MW)	G5 (MW)	G6 (MW)
1	152.9	0	19	0	0	0
2	184	0	20.3	0	0	0
3	202	0	23.1	0	0	14.1
4	190.1	51.6	22.3	0	0	14
5	201	55	23.3	0	0	16.3
6	190.3	57.3	21.1	0	0	14.4
7	176	45.4	21.8	0	0	12.3
8	148.3	40.2	33	0	0	0
9	142.1	38.2	17.8	0	0	0
10	114.5	33.4	17.3	0	0	0
11	104.7	30.8	15.3	0	0	0
12	114.7	33.4	16.1	0	0	0
13	120.5	36.5	17.7	0	0	0
14	134	40	17.4	0	0	0
15	153.2	43.1	19	0	0	0
16	171.4	48.2	21.4	0	0	0
17	177.6	55.3	22.9	0	0	0
18	181.4	47.9	21.4	0	0	0
19	177.6	46.5	21.2	0	0	0
20	166.2	46.5	20.9	0	0	0
21	149.6	42.3	19.1	0	0	0
22	131.5	39	16.9	0	0	0
23	102.4	42	20.8	0	0	0
24	91.1	27.8	15	0	0	0

Total Cost = 13520 $

Table 11
Total cost of SCUC problem using MICA, ICA, GA, PSO and MIP methods.

Method	*MICA*	*ICA*	*PSO*	*GA*	*MIP*
Cost ($)	811205.23	811231.32	817299.67	851127.73	812591.27
Time (S)	71.2	87.32	92.58	112.83	90.17

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