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# SINGLE AREA UNIT COMMITMENT PROBLEM USING HYBRID SINE-COSINE ALGORITHM

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**ABSTRACT:** This research paper aims to solve Single Area Unit Commitment problem (UCP) of 14 bus system, 30 bus system and 56 bus system, which is a mixed integer and combinatorial problem of modern power system using recently developed modern technique Sine Cosine Algorithm (SCA) and PSO. The objective function of unit commitment problem contains startup cost, shut down cost and fuel cost. Thus, it is very important for researchers to determine the most economical and optimum schedule of various generating units, which are running with different fuels. The efficiency of these algorithms has been finding by compare five , six and seven units of system.

**KEYWORDS:** Unit Commitment, particle swarm optimization (PSO), SCA (sine cosine algorithm), Hybrid PSO-SCA

## INTRODUCTION

In the present power system, different types of generating resources as nuclear ,thermal , hydro etc are available and also demand is variable throughout the day and achieves different peak values. So that it is necessary to choose that which generating unit should turn on and at what time it is essential in the power system network. And also the sequence at which unit is shut down keeping in mind the cost effectiveness of turning on and shutting down of respective units. The whole process of calculating and producing these decision is recognized as unit commitment. Unit commitment (UC) in power system network refers to the problem of finding the on off states of generating units that reduce the operating cost for a given time horizon. The unit which is decided to be connected to the power system network, when needed, that unit is committed unit. Generators cannot be at once turned on to satisfy the load demand. Therefore it is necessary that the planning of unit commitment (UC) should be so done to meet the load demand along with sufficient reserve generation to avoid malfunctions and failures under difficult conditions. UC provide the unit generation schedule in a power system for reducing fuel cost and operating cost and fulfill most common or frequent constraints like system reserve and load demand requirements under a set of time periods.

## SINGLE-AREA UNIT COMMITMENT PROBLEM FORMULATION

The unit commitment problem (UCP) is mainly about determining the most appropriate schedule to turn- on, turn-off the generating units to complete the load demand and at the same time maintain the cost of generation as it can be minimum. UCP is a large scale, mixed integer, non-linear constrained optimization problem [1] and belongs to combinatorial optimization problems. It is quite a difficult and monotonous task to compute the optimal solution to UCP as there are different types of constraints involved in UCP. The major purpose of UC is to satisfy the constraints imposed on the system like spinning reserve, power generation-load balance, operating constraints, minimum up/down time etc & to reduce the total production cost over the study period. To solve UCP various conventional methods are available and a perfect mathematical model is required for all these models of the system & may be there is a possibility of getting stuck at the local optimum. The generation scheduling problem is to reducing the total generation cost over the scheduling period while meeting the load demands and fulfilling all unit constraints. The generation scheduling problem comprises two different problems, i.e. the Economic Load Dispatch Problem(ELD) and the Unit Commitment Problem(UCP). Economic Load Dispatch (ELD) seeks the best generation schedule for the generating plants to supply the required demand plus transmission loss with the minimum generation cost..[1-3] To meet a load demand, the UCP is to find out a minimum turn-on, minimum turn-off cost schedule of a set of electrical power generating units ,while fulfilling a set of operational constraints. To find out the optimal commitment approach for generating units ,Single-Area Unit Commitment Problem(SAUCP) is used which is located in single area, while Multi-Area Unit Commitment Problem (MAUCP) is to search out the optimal commitment approach for generating units located in multiple areas that are interconnected via tie–lines. A multi-area unit commitment (MAUC) means two or more than two interconnected regions of a power system and numerous generation areas are interconnected by tie lines. [4,5]. The exchange of energy between two utilities having huge difference in their marginal operating costs. The utility with the higher operating cost get power from the utility with low operating cost. This arrangement usually on an hour to hour basis and is performed by the two system operators. In these days, customer demand for high service reliability and lower electricity prices. Hence, it is an important to exploit own profit with high reliability and reduce overall operating cost. The difference between the multi-Area formulation and the Single-Area formulation lies mainly in the description of Energy feasibility and Capacity feasibility. In an interconnected Multi-Area system, Capacity and Energy are shared by all area via transmission interconnections. So that, the transmission interconnection constraints must be reflected in the feasibility inequalities.[6,7]

## Unit Commitment Problem

The Unit Commitment Problem (UCP) is mostly about finding the most appropriate schedule to turn- on or turn- off the generating units to meet the load demand and at the same time keep the cost of generation as much minimum as possible. UCP is a non- linear, large scale, mixed integer constrained optimization problem [2] and happens to belong to combinatorial optimization problems. There are many constraints involved in UCP and hence it is fairly a complex and difficult task to compute or find the optimal solution to unit commitment problem. An optimal unit schedule must be able to accomplish the forecasted load demand, spinning reserve requirements, and the other constraints during a given time period.

The unit commitment problem (UCP) in power system is defined as determining the start-up and shut-down schedules of units to meet the forecast load demand and spinning reserve over a scheduling period so that the total production cost is minimized while satisfying various system and unit constraints [1]. There are various concerns in the unit commitment problem like the fuel requirement for operation of generating units, high dimensionality of search space, and minimum up time and down time constraints and spinning reserve requirements constraint, crew constraints, emission constraints, and etc. Constraints have a remarkable effect on the unit commitment problem as well as on the solution of the problem. The constraints tend to introduce problems and enhance complicacy of unit commitment problem. For instance, in accomplishing the spinning reserve requirements the cost rises and thus solving the problem of minimizing the cost of generation becomes much more complicated. Thus unit commitment problem becomes complex, non linear and gigantic in nature which needs to be solved by using effective, robust and fast techniques.

## MATHEMATICAL FORMULATION OF SAUCP

The purpose of classical UC is to located the optimal schedule for operating the obtainable generating units in order to reduce the whole operating cost of the power generation. The total operating cost consists start up cost, shut down cost and fuel cost[8,9]. The fuel costs are evaluated using the data of fuel price & unit heat rate information which is normally a quadratic equation of power output of each generator at each hour determined by (ELD) as per equation (1):

$$FC_i(P_{ih}) = \sum_{i=1}^{NG} \alpha_i P_{ih}^2 + \beta_i P_{ih} + \gamma_i \tag{1}$$

Where, $\alpha_i$ (\$/MW$^2$h), $\beta_i$ (\$/MWh) and $\gamma_i$ (\$/h) are fuel consumption coefficients of i$^{th}$ unit.

Eqn (1) presents the fuel cost for different units without valve point effects. To take the effects of valve points, a sinusoidal function is added to the convex cost function and can be represented as:

$$FC_i(P_{ih}) = \sum_{i=1}^{NG} [\alpha_i P_{ih}^2 + \beta_i P_{ih} + \gamma_i + \left|\delta_i \sin\{\varepsilon_i (P_{ih}^{\min} - P_{ih})\}\right|] \tag{2}$$

The fuel cost for each thermal generating unit in the system is usually determined by a second order function of the active power generation. The drawing effect occurs during opening of all admission value in a steam turbine. This rippling effect is a modeled as sinusoidal function of the active power generation. Consequently, the fuel cost function is written as a non-convex and non-linear function [5] as below:

$$FC_i(P_{ih}) = \sum_{h=1}^{H} \sum_{i=1}^{NG} [\alpha_i P_{ih}^2 + \beta_i P_{ih} + \gamma_i + \left|\delta_i \sin\{\varepsilon_i (P_{ih}^{\min} - P_{ih})\}\right|] \tag{3}$$

where, $\alpha_i$ =\$/MW$^2$, $\beta_i$ =\$/MWh, $\gamma_i$ =\$/h, $\delta_i$ =\$/h, $\varepsilon_i$ =rad/MW are constants unique for all generating units, $P_{ih}$ is the power output of the i$^{th}$ thermal unit, H is the duration of the time interval in hours and $P_{ih}^{\min}$ is the minimum power output of the i$^{th}$ thermal unit.

The Total Cost[4] for Unit commitment problem including start-up cost and fuel cost over the time period ‘H’ is given by

$$Cost_{NH} = \sum_{h=1}^{H} \sum_{i=1}^{NG} [FC_i(P_{ih}) + STC_{ih}] \tag{4}$$

$$Cost_{NH} = \sum_{h=1}^{H} \sum_{i=1}^{NG} [FC_i(P_{ih}) * U_{ih} + STC_{ih} * (1 - U_{i(h-1)}) * U_{ih}] \tag{5}$$

where, $U_{ih}$ is the status of ith unit at h$^{th}$ hour. Start up cost is the cost involved in bringing the thermal unit online. Start up cost is expressed as a function of the number of hours the units has been shut down (exponential when cooling and linear when banking). Shut down costs are defined as a fixed amount for each unit/shutdown. A simplified start up cost model is used as follows:

$$STC_{ih} = \begin{Bmatrix} HSC_i, & if\ MDT_i \le DT_i < (MDT_i + CSH_i) \\ CSC_i, & if\ DT_i > (MDT_i + CSH_i) \end{Bmatrix} \quad (6)$$

where, $MDT_i$ is Minimum down time , $DT_i$ is shut down duration, $CSC_i$ is Cold start up cost , $HSC_i$ is Hot start up cost, and $CSH_i$ is Cold start hour of ith unit.

$$X_k^{iter} = X_k^{\min} + rand(0,1)(X_k^{\max} - X_k^{\min}) \quad (7)$$

## AN EXTENSIVE LITERATURE REVIEW OF UCP

From the year 1980 onwards, substantial research is made in the area of unit commitment problem(UCP). The unit commitment problem (UCP) is mainly about determining the most. appropriate schedule to turn- on/off the generating units to complete the load demand and at the same time maintain the generation cost as it can be minimum as possible. The brief summary of some important research papers according to different methodologies is listed as following

### Ant Colony Search Algorithm

Chusanapiputt S. et al. [11] projected a new methodology termed (HASP) hybrid ant system/priority list method for solving the unit commitment problem with operating constraints for a test system 100 generating units. Yu D. et al. [12] described a HACO ,hybrid algorithm for ant colony optimization (ACO) algorithm and Lambda-iteration . HACO is effective for finding solution to unit commitment problem in the range of 10 to 60 generating units. Chitra N. et al. [13] innovated for power quality improvement by considering harmonic analysis and voltage frequency (Vf) regulation as the main parameters in independent microgrid.

### Differential Evaluation Algorithm

For economic dispatch (ED) and generator maintenance scheduling (GMS) ,Yare Y. et al. [14] focused on the differential evolution (DE) approach, to optimize the cost of operation of 19 units ,of the Indonesian power system . For solving thermal UC problem integrated , Chakraborty S. et al. [15] offered a fuzzy modified differential evolution approach, which is integrated with wind power system. To solving the economic dispatch (ED) problem ,Sharma R. et al. [16] proposed a new method identified as Self-Realized Differential Evolution(SRDE) which was tested for 10,40 unit system. Hardiansyah et al. [17] investigated the features of differential evolution (DE) algorithm , artificial bee colony algorithm (ABC), and particle swarm optimization (PSO) for 3 and 6-unit systems and found that differential evolution algorithm converges faster than artificial bee colony algorithm and particle swarm optimization. To solve optimal power flow (OPF) problem , Ravi C.N.et. al. [18] described differential evolution (DE) optimization algorithm, considering IEEE 30 bus standard power system. Dilip Datta et. al.[19] proposed a binary-real-coded DE as a complete solution technique of the UCP apply to a set of six power systems up to 100 units for a 24-h time horizon. Vikram Kumar Kamboj et. al. [20] presented a novel and hybrid version of DE algorithm to expand the exploitation ability and global performance of DE algorithm and it is tested with IEEE benchmark systems which is containing 4, 10, 20 and 40 generating units. Same author in [21] presented the similar algorithm to solve multi area and multi objective UCP of electric power system and tested a two area system of IEEE-30 bus system.

### Genetic Algorithm

Babu A.S. et al. [22] portrayed a Hybrid Genetic Algorithm (HGA) for constructing a departmental class timetable. Kushwaha N. et al. [23] futured bacterial foraging (BF) algorithm for optimization of a function which is on GA based. To explain the multi mode resource constrained MMRC project scheduling problem , Bilolikar V.S. et al. [24] offered a hybridized approach using genetic algorithm (GA) and simulated annealing (SA). To overcome the inadequacy in handling large-size instances of the UCP, reference Dilip Datta et. al.[25] presents the GA for scheduling units with and without taking into account the ramp rate constraint for six power systems up to 100 units.

### Harmony Search Algorithm

Vikram Kumar Kamboj [26] innovated global optimal solution of a novel and hybrid version of harmony search to develop the exploitation ability of HS algorithm combined with random search algorithm and tested for standard IEEE systems consisting of 4, 10, 20 and 40 generating units. For improve the established harmony search algorithm, Coelho L.S.et. al. [27] used exponential distribution for a 13- unit system. For solving the ELD problem for a 10- unit system Coelho L.S. et al. [28] innovated a customized harmony search algorithm with differential evolution (DE) and chaotic sequences, CHSDE algorithm. Shukla S.et. al. [29] described harmony search technique for the multi-objective optimization of a styrene reactor. To solve economic load dispatch problem with transmission losses with the varying patterns of consumer load, Arul R. et al. [30] applied harmony search algorithm for standard 6-bus system, standard IEEE-14 – 30 bus system. S. Najafi et.al. described [31] an innovative and effective solution based on modification of the Harmony Search (HS) Algorithm to solve the strategic planning of Generators and is easy compared to Evolutionary Methods (EM).

## Hybrid PSO–SCA algorithm for single-area unit commitment problem

### Particle swarm optimizer

The PSO algorithm is constructed on collective performance of bird flocking which is developed by Kennedy and Eberthart . In this algorithm, it consists no of particle which fly in search space to find the finest solution. So particle consider two value which is called local best and global best. The PSO are using following exposed.

$$v_i(t) = v_i(t-1) + c_1 rand_1(localbest(t) - x_i(t-1)) + c_2 rand_2(globalbest(t) - x_i(t-1)) \quad . \quad (8)$$

$$x_i(t+1) = x_i(t) + v_i(t+1) \quad (9)$$

### Sine Cosine Algorithm

SCA is population based optimization technique, found the optimization process with a set of random solution. These random solutions are repeatedly calculated over the course of iterations by an objective function. The probability of finding global optima is increased ,with the sufficient number of random solutions.

$$X^{t+1}_i = X^t_i + r_1 \times \sin(r_2) \times r_3 P^t_i - X^t_i \quad (10)$$

$$X^{t+1}_i = X^t_i + r_1 \times cos(r_2) \times r_3 P^t_i - X^t_{ii} \quad (11)$$

Where $X^t_i$ is the position of current solution in i-th dimension at t-th iteration, r1/r2/r3 are the random numbers, Pi is position of the destination point in the i-th dimension.

$$X^{t+1}_i = \begin{cases} X^t_i + r_1 \times \sin(r_2) \times r_3 P^t_i - X^t_i & r4 < 0.5 \\ X^t_i + r_1 \times cos(r_2) \times r_3 P^t_i - X^t_{ii} & r4 > 0.5 \end{cases} \quad . \quad (12)$$

Where r4 is a random number in [0,1]

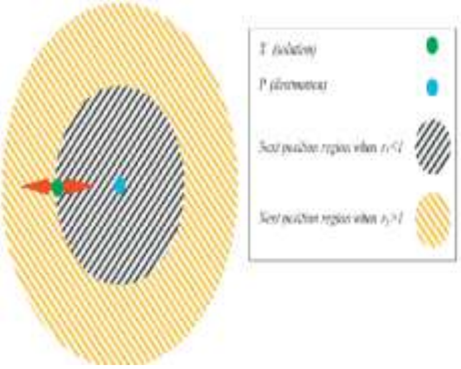


**Fig.1**

*Effect of sine cosine in eqn. (10) and (11)*

In the above equations there are four main parameters r1, r2, r3 and r4. The parameters r1 states that the next position region between solution and destination or outside it. Parameter r2 tells how far the movement should be towards or outwards the destination. The parameter r3 brings the random weight for destination in order to stochastically force (r3 > 1) or deemahasize the effect of destination in defining the distance.

$v_i(t)$ is velocity of particle $rand_1 rand_2$ random variables. $x_i(t)$ is position of destination in defining the distance. And parameter r4 equally switches between sine and cosine component in eqn. (12)

Fig. 1 shows that in the search space how the proposed equations define space between the two solutions. The cyclic pattern of sine and cosine function describes the position of solution around another solution. Also this can give guarantee exploitation of the space between two solutions. We can explore the search space by changing the range of sine and cosine function.

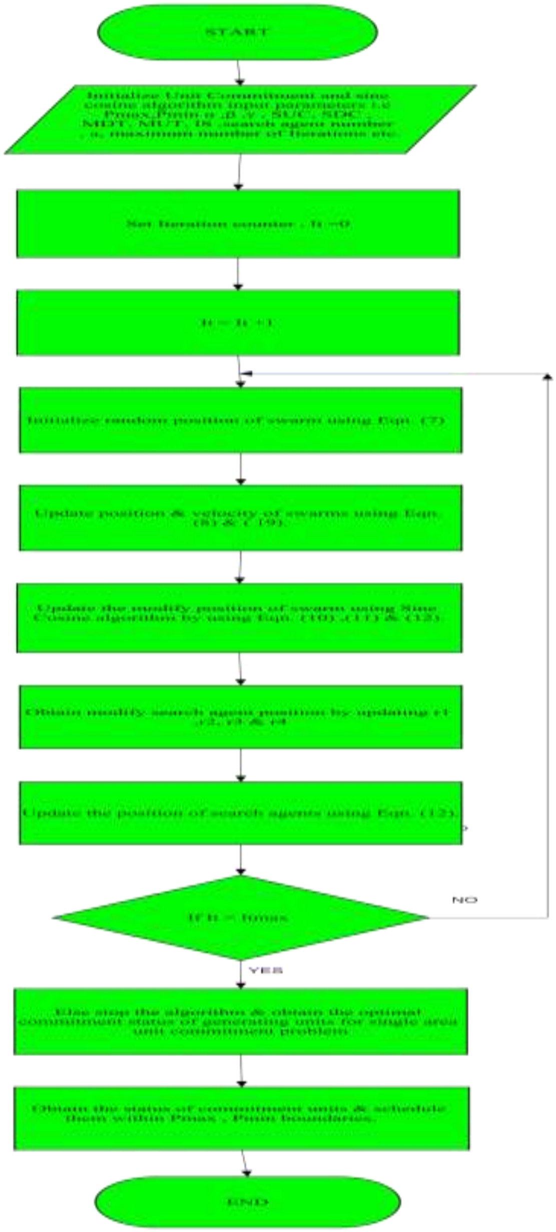
To make balance between exploration and exploitation, the range of sine and cosine in eqn. (10) to (12) is changed adaptively using the below equation:

$$\mathbf{r_1 = a - t\,a/T}$$

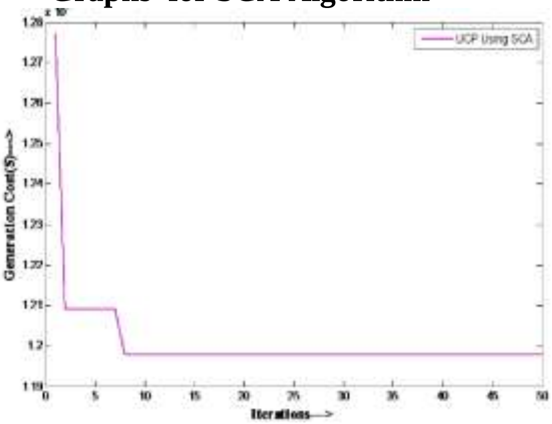
where **t** is current iteration, **T** is maximum number of iterations and **a** is constant.

### Hybrid PSO-SCA Algorithm

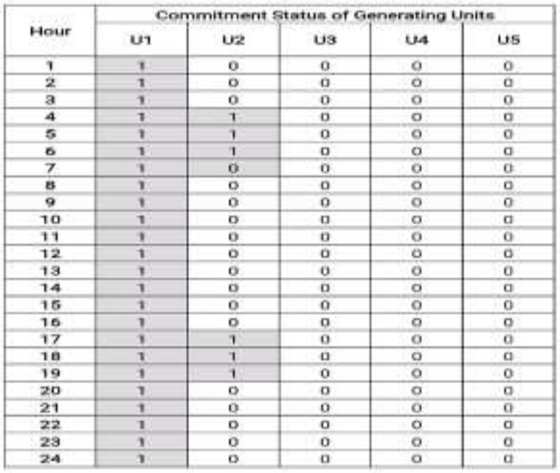
In this paper, we combine PSO with SCA PSO converge prematurely and also its convergence rate is slow. Under such conditions the Hybrid PSO-SCA comes into view which is required to overcome such drawbacks in the original PSO algorithm and its other variants.



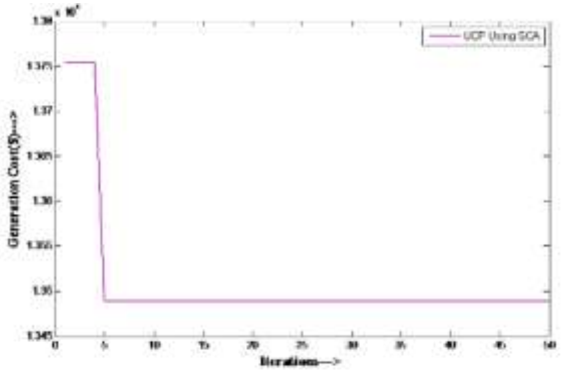
## Graphs for SCA Algorithm



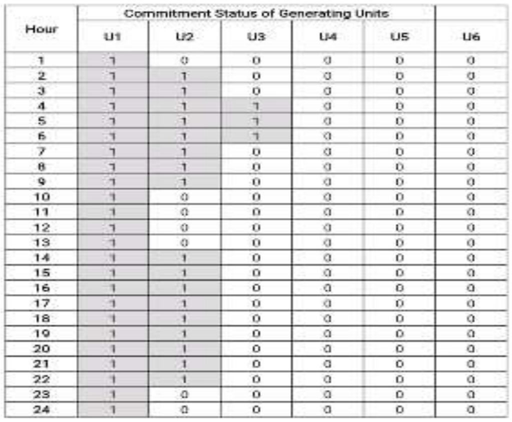
5- Unit Test System



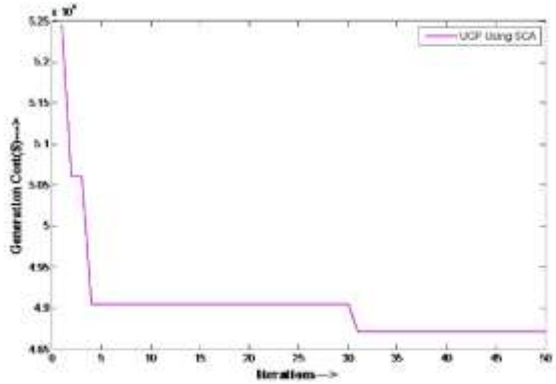
| Hour | Commitment Status of Generating Units | | | | |
|---|---|---|---|---|---|
| | U1 | U2 | U3 | U4 | U5 |
| 1 | 1 | 0 | 0 | 0 | 0 |
| 2 | 1 | 0 | 0 | 0 | 0 |
| 3 | 1 | 0 | 0 | 0 | 0 |
| 4 | 1 | 1 | 0 | 0 | 0 |
| 5 | 1 | 1 | 0 | 0 | 0 |
| 6 | 1 | 1 | 0 | 0 | 0 |
| 7 | 1 | 0 | 0 | 0 | 0 |
| 8 | 1 | 0 | 0 | 0 | 0 |
| 9 | 1 | 0 | 0 | 0 | 0 |
| 10 | 1 | 0 | 0 | 0 | 0 |
| 11 | 1 | 0 | 0 | 0 | 0 |
| 12 | 1 | 0 | 0 | 0 | 0 |
| 13 | 1 | 0 | 0 | 0 | 0 |
| 14 | 1 | 0 | 0 | 0 | 0 |
| 15 | 1 | 0 | 0 | 0 | 0 |
| 16 | 1 | 0 | 0 | 0 | 0 |
| 17 | 1 | 1 | 0 | 0 | 0 |
| 18 | 1 | 1 | 0 | 0 | 0 |
| 19 | 1 | 1 | 0 | 0 | 0 |
| 20 | 1 | 0 | 0 | 0 | 0 |
| 21 | 1 | 0 | 0 | 0 | 0 |
| 22 | 1 | 0 | 0 | 0 | 0 |
| 23 | 1 | 0 | 0 | 0 | 0 |
| 24 | 1 | 0 | 0 | 0 | 0 |



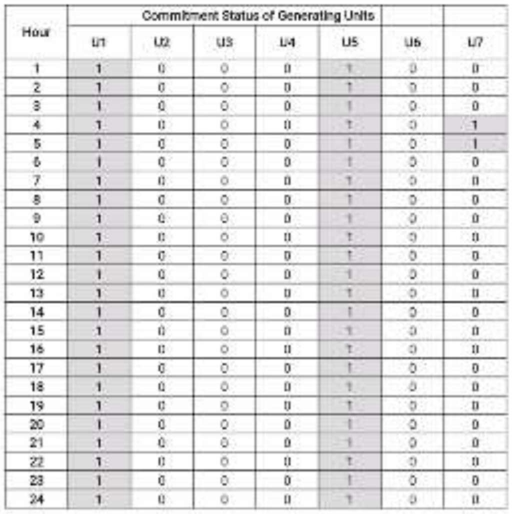
6 – Unit Test System



| Hour | Commitment Status of Generating Units | | | | | |
|---|---|---|---|---|---|---|
| | U1 | U2 | U3 | U4 | U5 | U6 |
| 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| 2 | 1 | 1 | 0 | 0 | 0 | 0 |
| 3 | 1 | 1 | 0 | 0 | 0 | 0 |
| 4 | 1 | 1 | 1 | 0 | 0 | 0 |
| 5 | 1 | 1 | 1 | 0 | 0 | 0 |
| 6 | 1 | 1 | 1 | 0 | 0 | 0 |
| 7 | 1 | 1 | 0 | 0 | 0 | 0 |
| 8 | 1 | 1 | 0 | 0 | 0 | 0 |
| 9 | 1 | 1 | 0 | 0 | 0 | 0 |
| 10 | 1 | 0 | 0 | 0 | 0 | 0 |
| 11 | 1 | 0 | 0 | 0 | 0 | 0 |
| 12 | 1 | 0 | 0 | 0 | 0 | 0 |
| 13 | 1 | 0 | 0 | 0 | 0 | 0 |
| 14 | 1 | 1 | 0 | 0 | 0 | 0 |
| 15 | 1 | 1 | 0 | 0 | 0 | 0 |
| 16 | 1 | 1 | 0 | 0 | 0 | 0 |
| 17 | 1 | 1 | 0 | 0 | 0 | 0 |
| 18 | 1 | 1 | 0 | 0 | 0 | 0 |
| 19 | 1 | 1 | 0 | 0 | 0 | 0 |
| 20 | 1 | 1 | 0 | 0 | 0 | 0 |
| 21 | 1 | 1 | 0 | 0 | 0 | 0 |
| 22 | 1 | 1 | 0 | 0 | 0 | 0 |
| 23 | 1 | 0 | 0 | 0 | 0 | 0 |
| 24 | 1 | 0 | 0 | 0 | 0 | 0 |



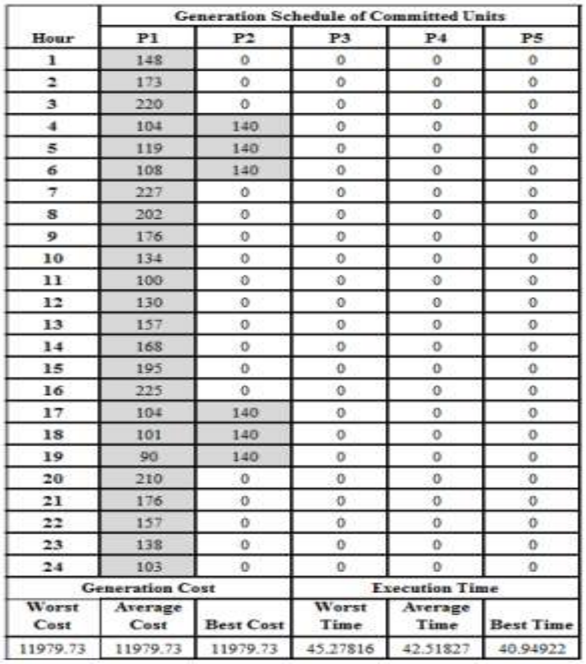
7 – Unit Test System



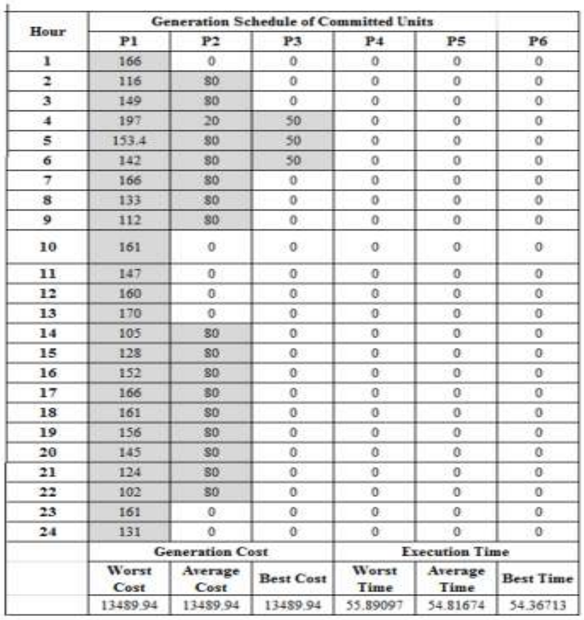
| Hour | Commitment Status of Generating Units | | | | | | |
|---|---|---|---|---|---|---|---|
| | U1 | U2 | U3 | U4 | U5 | U6 | U7 |
| 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 2 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 3 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 4 | 1 | 0 | 0 | 0 | 1 | 0 | 1 |
| 5 | 1 | 0 | 0 | 0 | 1 | 0 | 1 |
| 6 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 7 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 8 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 9 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 10 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 11 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 12 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 13 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 14 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 15 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 16 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 17 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 18 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 19 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 20 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 21 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 22 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 23 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 24 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |

### Committed status of 5-unit, 6unit and 7 unit test system:

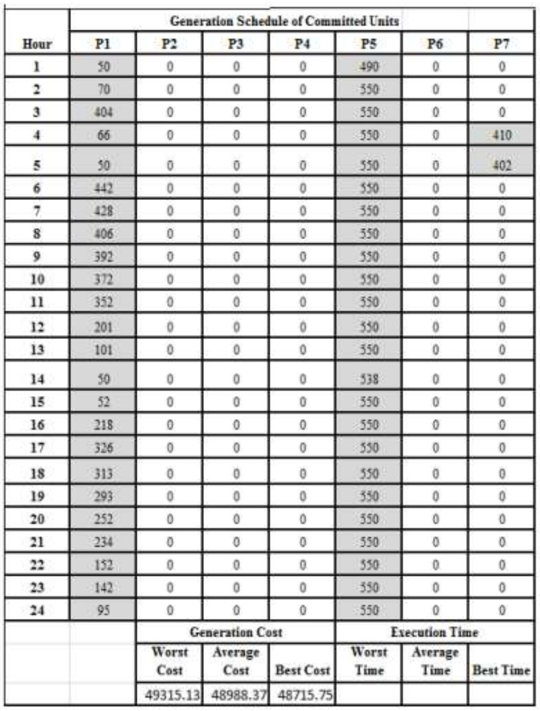
Generation scheduling of committed status of 5 unit, 6 unit and 7 unit system



| Hour | Generation Schedule of Committed Units | | | | |
|---|---|---|---|---|---|
| | P1 | P2 | P3 | P4 | P5 |
| 1 | 148 | 0 | 0 | 0 | 0 |
| 2 | 173 | 0 | 0 | 0 | 0 |
| 3 | 220 | 0 | 0 | 0 | 0 |
| 4 | 104 | 140 | 0 | 0 | 0 |
| 5 | 119 | 140 | 0 | 0 | 0 |
| 6 | 108 | 140 | 0 | 0 | 0 |
| 7 | 227 | 0 | 0 | 0 | 0 |
| 8 | 202 | 0 | 0 | 0 | 0 |
| 9 | 176 | 0 | 0 | 0 | 0 |
| 10 | 134 | 0 | 0 | 0 | 0 |
| 11 | 100 | 0 | 0 | 0 | 0 |
| 12 | 130 | 0 | 0 | 0 | 0 |
| 13 | 157 | 0 | 0 | 0 | 0 |
| 14 | 168 | 0 | 0 | 0 | 0 |
| 15 | 195 | 0 | 0 | 0 | 0 |
| 16 | 225 | 0 | 0 | 0 | 0 |
| 17 | 104 | 140 | 0 | 0 | 0 |
| 18 | 101 | 140 | 0 | 0 | 0 |
| 19 | 90 | 140 | 0 | 0 | 0 |
| 20 | 210 | 0 | 0 | 0 | 0 |
| 21 | 176 | 0 | 0 | 0 | 0 |
| 22 | 157 | 0 | 0 | 0 | 0 |
| 23 | 138 | 0 | 0 | 0 | 0 |
| 24 | 103 | 0 | 0 | 0 | 0 |
| Generation Cost | | | Execution Time | | |
| Worst Cost | Average Cost | Best Cost | Worst Time | Average Time | Best Time |
| 11979.73 | 11979.73 | 11979.73 | 45.27816 | 42.51827 | 40.94922 |

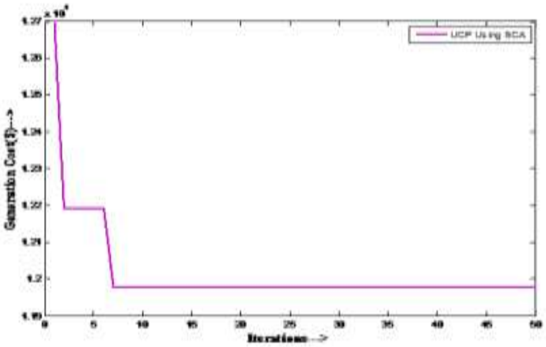


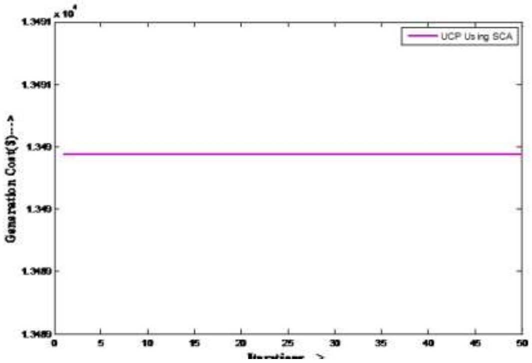
| Hour | Generation Schedule of Committed Units | | | | | |
|---|---|---|---|---|---|---|
| | P1 | P2 | P3 | P4 | P5 | P6 |
| 1 | 166 | 0 | 0 | 0 | 0 | 0 |
| 2 | 116 | 80 | 0 | 0 | 0 | 0 |
| 3 | 149 | 80 | 0 | 0 | 0 | 0 |
| 4 | 197 | 20 | 50 | 0 | 0 | 0 |
| 5 | 153.4 | 80 | 50 | 0 | 0 | 0 |
| 6 | 142 | 80 | 50 | 0 | 0 | 0 |
| 7 | 166 | 80 | 0 | 0 | 0 | 0 |
| 8 | 133 | 80 | 0 | 0 | 0 | 0 |
| 9 | 112 | 80 | 0 | 0 | 0 | 0 |
| 10 | 161 | 0 | 0 | 0 | 0 | 0 |
| 11 | 147 | 0 | 0 | 0 | 0 | 0 |
| 12 | 160 | 0 | 0 | 0 | 0 | 0 |
| 13 | 170 | 0 | 0 | 0 | 0 | 0 |
| 14 | 105 | 80 | 0 | 0 | 0 | 0 |
| 15 | 128 | 80 | 0 | 0 | 0 | 0 |
| 16 | 152 | 80 | 0 | 0 | 0 | 0 |
| 17 | 166 | 80 | 0 | 0 | 0 | 0 |
| 18 | 161 | 80 | 0 | 0 | 0 | 0 |
| 19 | 156 | 80 | 0 | 0 | 0 | 0 |
| 20 | 145 | 80 | 0 | 0 | 0 | 0 |
| 21 | 124 | 80 | 0 | 0 | 0 | 0 |
| 22 | 102 | 80 | 0 | 0 | 0 | 0 |
| 23 | 161 | 0 | 0 | 0 | 0 | 0 |
| 24 | 131 | 0 | 0 | 0 | 0 | 0 |
| | Generation Cost | | | Execution Time | | |
| | Worst Cost | Average Cost | Best Cost | Worst Time | Average Time | Best Time |
| | 13489.94 | 13489.94 | 13489.94 | 55.89097 | 54.81674 | 54.36713 |

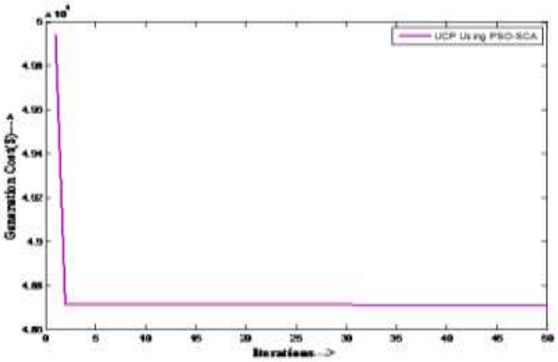


| Hour | Generation Schedule of Committed Units | | | | | | |
|---|---|---|---|---|---|---|---|
| | P1 | P2 | P3 | P4 | P5 | P6 | P7 |
| 1 | 50 | 0 | 0 | 0 | 490 | 0 | 0 |
| 2 | 70 | 0 | 0 | 0 | 550 | 0 | 0 |
| 3 | 404 | 0 | 0 | 0 | 550 | 0 | 0 |
| 4 | 66 | 0 | 0 | 0 | 550 | 0 | 410 |
| 5 | 50 | 0 | 0 | 0 | 550 | 0 | 402 |
| 6 | 442 | 0 | 0 | 0 | 550 | 0 | 0 |
| 7 | 428 | 0 | 0 | 0 | 550 | 0 | 0 |
| 8 | 406 | 0 | 0 | 0 | 550 | 0 | 0 |
| 9 | 392 | 0 | 0 | 0 | 550 | 0 | 0 |
| 10 | 372 | 0 | 0 | 0 | 550 | 0 | 0 |
| 11 | 352 | 0 | 0 | 0 | 550 | 0 | 0 |
| 12 | 201 | 0 | 0 | 0 | 550 | 0 | 0 |
| 13 | 101 | 0 | 0 | 0 | 550 | 0 | 0 |
| 14 | 50 | 0 | 0 | 0 | 538 | 0 | 0 |
| 15 | 52 | 0 | 0 | 0 | 550 | 0 | 0 |
| 16 | 218 | 0 | 0 | 0 | 550 | 0 | 0 |
| 17 | 326 | 0 | 0 | 0 | 550 | 0 | 0 |
| 18 | 313 | 0 | 0 | 0 | 550 | 0 | 0 |
| 19 | 293 | 0 | 0 | 0 | 550 | 0 | 0 |
| 20 | 252 | 0 | 0 | 0 | 550 | 0 | 0 |
| 21 | 234 | 0 | 0 | 0 | 550 | 0 | 0 |
| 22 | 152 | 0 | 0 | 0 | 550 | 0 | 0 |
| 23 | 142 | 0 | 0 | 0 | 550 | 0 | 0 |
| 24 | 95 | 0 | 0 | 0 | 550 | 0 | 0 |
| | | Generation Cost | | | Execution Time | | |
| | | Worst Cost | Average Cost | Best Cost | Worst Time | Average Time | Best Time |
| | | 49315.13 | 48988.37 | 48715.75 | | | |

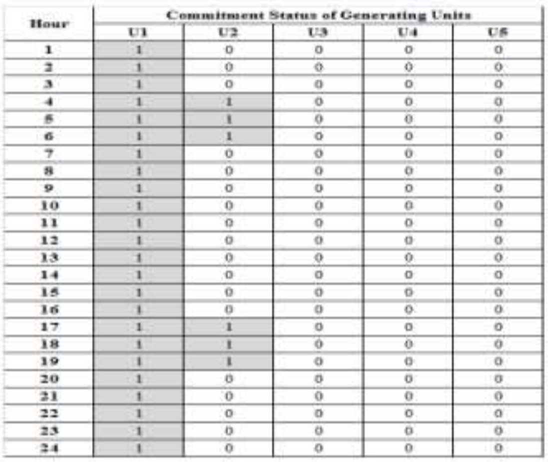
## Graphs for PSO-SCA



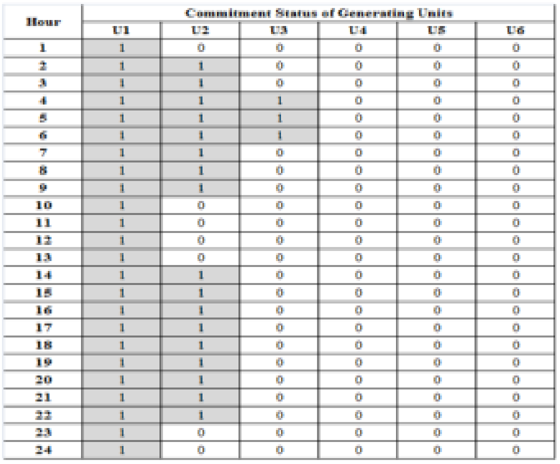




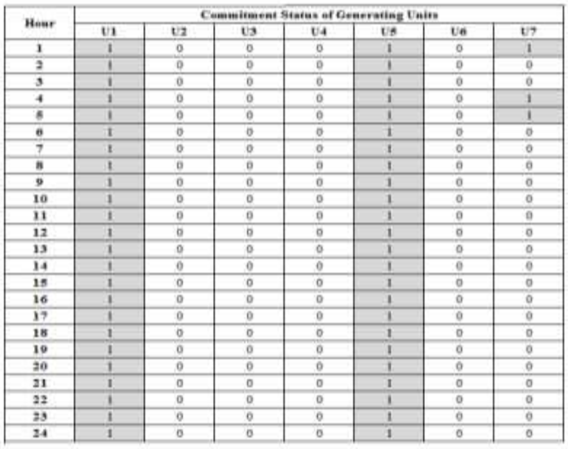
## Commitment status of 5 unit 6 unit 7 unit system of PSO-SCA



| Hour | Commitment Status of Generating Units | | | | |
|---|---|---|---|---|---|
| | U1 | U2 | U3 | U4 | U5 |
| 1 | 1 | 0 | 0 | 0 | 0 |
| 2 | 1 | 0 | 0 | 0 | 0 |
| 3 | 1 | 0 | 0 | 0 | 0 |
| 4 | 1 | 1 | 0 | 0 | 0 |
| 5 | 1 | 1 | 0 | 0 | 0 |
| 6 | 1 | 1 | 0 | 0 | 0 |
| 7 | 1 | 0 | 0 | 0 | 0 |
| 8 | 1 | 0 | 0 | 0 | 0 |
| 9 | 1 | 0 | 0 | 0 | 0 |
| 10 | 1 | 0 | 0 | 0 | 0 |
| 11 | 1 | 0 | 0 | 0 | 0 |
| 12 | 1 | 0 | 0 | 0 | 0 |
| 13 | 1 | 0 | 0 | 0 | 0 |
| 14 | 1 | 0 | 0 | 0 | 0 |
| 15 | 1 | 0 | 0 | 0 | 0 |
| 16 | 1 | 0 | 0 | 0 | 0 |
| 17 | 1 | 1 | 0 | 0 | 0 |
| 18 | 1 | 1 | 0 | 0 | 0 |
| 19 | 1 | 1 | 0 | 0 | 0 |
| 20 | 1 | 0 | 0 | 0 | 0 |
| 21 | 1 | 0 | 0 | 0 | 0 |
| 22 | 1 | 0 | 0 | 0 | 0 |
| 23 | 1 | 0 | 0 | 0 | 0 |
| 24 | 1 | 0 | 0 | 0 | 0 |

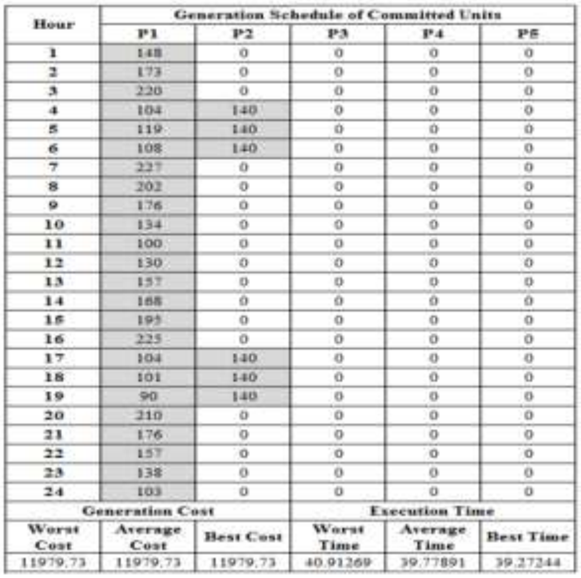


| Hour | Commitment Status of Generating Units | | | | | |
|---|---|---|---|---|---|---|
| | U1 | U2 | U3 | U4 | U5 | U6 |
| 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| 2 | 1 | 1 | 0 | 0 | 0 | 0 |
| 3 | 1 | 1 | 0 | 0 | 0 | 0 |
| 4 | 1 | 1 | 1 | 0 | 0 | 0 |
| 5 | 1 | 1 | 1 | 0 | 0 | 0 |
| 6 | 1 | 1 | 1 | 0 | 0 | 0 |
| 7 | 1 | 1 | 0 | 0 | 0 | 0 |
| 8 | 1 | 1 | 0 | 0 | 0 | 0 |
| 9 | 1 | 1 | 0 | 0 | 0 | 0 |
| 10 | 1 | 0 | 0 | 0 | 0 | 0 |
| 11 | 1 | 0 | 0 | 0 | 0 | 0 |
| 12 | 1 | 0 | 0 | 0 | 0 | 0 |
| 13 | 1 | 0 | 0 | 0 | 0 | 0 |
| 14 | 1 | 1 | 0 | 0 | 0 | 0 |
| 15 | 1 | 1 | 0 | 0 | 0 | 0 |
| 16 | 1 | 1 | 0 | 0 | 0 | 0 |
| 17 | 1 | 1 | 0 | 0 | 0 | 0 |
| 18 | 1 | 1 | 0 | 0 | 0 | 0 |
| 19 | 1 | 1 | 0 | 0 | 0 | 0 |
| 20 | 1 | 1 | 0 | 0 | 0 | 0 |
| 21 | 1 | 1 | 0 | 0 | 0 | 0 |
| 22 | 1 | 1 | 0 | 0 | 0 | 0 |
| 23 | 1 | 0 | 0 | 0 | 0 | 0 |
| 24 | 1 | 0 | 0 | 0 | 0 | 0 |

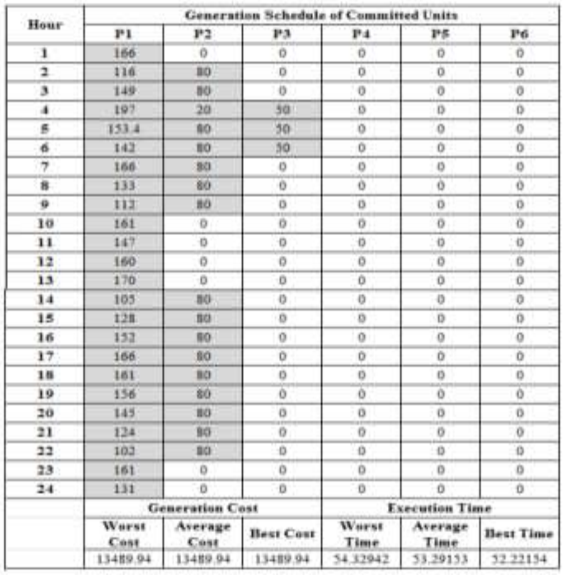


| Hour | Commitment Status of Generating Units | | | | | | |
|---|---|---|---|---|---|---|---|
| | U1 | U2 | U3 | U4 | U5 | U6 | U7 |
| 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 |
| 2 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 3 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 4 | 1 | 0 | 0 | 0 | 1 | 0 | 1 |
| 5 | 1 | 0 | 0 | 0 | 1 | 0 | 1 |
| 6 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 7 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 8 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 9 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 10 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 11 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 12 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 13 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 14 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 15 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 16 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 17 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 18 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 19 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 20 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 21 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 22 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 23 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 24 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |

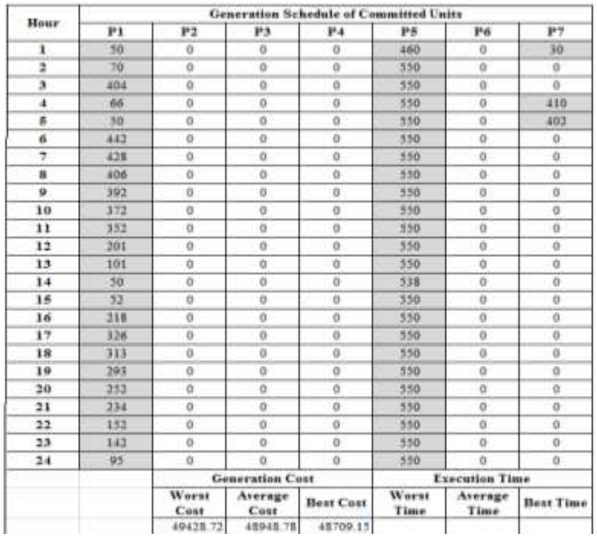
Generation scheduling of 5 unit 6 unit 7 unit system of PSO-SCA



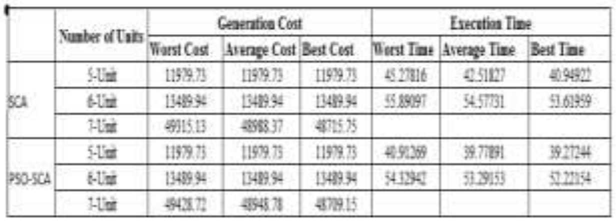
| Hour | Generation Schedule of Committed Units | | | | |
|---|---|---|---|---|---|
| | P1 | P2 | P3 | P4 | P5 |
| 1 | 148 | 0 | 0 | 0 | 0 |
| 2 | 173 | 0 | 0 | 0 | 0 |
| 3 | 220 | 0 | 0 | 0 | 0 |
| 4 | 104 | 140 | 0 | 0 | 0 |
| 5 | 119 | 140 | 0 | 0 | 0 |
| 6 | 108 | 140 | 0 | 0 | 0 |
| 7 | 227 | 0 | 0 | 0 | 0 |
| 8 | 202 | 0 | 0 | 0 | 0 |
| 9 | 176 | 0 | 0 | 0 | 0 |
| 10 | 134 | 0 | 0 | 0 | 0 |
| 11 | 100 | 0 | 0 | 0 | 0 |
| 12 | 130 | 0 | 0 | 0 | 0 |
| 13 | 157 | 0 | 0 | 0 | 0 |
| 14 | 168 | 0 | 0 | 0 | 0 |
| 15 | 195 | 0 | 0 | 0 | 0 |
| 16 | 225 | 0 | 0 | 0 | 0 |
| 17 | 104 | 140 | 0 | 0 | 0 |
| 18 | 101 | 140 | 0 | 0 | 0 |
| 19 | 90 | 140 | 0 | 0 | 0 |
| 20 | 210 | 0 | 0 | 0 | 0 |
| 21 | 176 | 0 | 0 | 0 | 0 |
| 22 | 157 | 0 | 0 | 0 | 0 |
| 23 | 138 | 0 | 0 | 0 | 0 |
| 24 | 103 | 0 | 0 | 0 | 0 |
| Generation Cost | | | Execution Time | | |
| Worst Cost | Average Cost | Best Cost | Worst Time | Average Time | Best Time |
| 11979.73 | 11979.73 | 11979.73 | 40.91269 | 39.77891 | 39.27244 |



| Hour | Generation Schedule of Committed Units | | | | | |
|---|---|---|---|---|---|---|
| | P1 | P2 | P3 | P4 | P5 | P6 |
| 1 | 166 | 0 | 0 | 0 | 0 | 0 |
| 2 | 116 | 80 | 0 | 0 | 0 | 0 |
| 3 | 149 | 80 | 0 | 0 | 0 | 0 |
| 4 | 197 | 20 | 50 | 0 | 0 | 0 |
| 5 | 153.4 | 80 | 50 | 0 | 0 | 0 |
| 6 | 142 | 80 | 50 | 0 | 0 | 0 |
| 7 | 166 | 80 | 0 | 0 | 0 | 0 |
| 8 | 133 | 80 | 0 | 0 | 0 | 0 |
| 9 | 112 | 80 | 0 | 0 | 0 | 0 |
| 10 | 161 | 0 | 0 | 0 | 0 | 0 |
| 11 | 147 | 0 | 0 | 0 | 0 | 0 |
| 12 | 160 | 0 | 0 | 0 | 0 | 0 |
| 13 | 170 | 0 | 0 | 0 | 0 | 0 |
| 14 | 105 | 80 | 0 | 0 | 0 | 0 |
| 15 | 128 | 80 | 0 | 0 | 0 | 0 |
| 16 | 152 | 80 | 0 | 0 | 0 | 0 |
| 17 | 166 | 80 | 0 | 0 | 0 | 0 |
| 18 | 161 | 80 | 0 | 0 | 0 | 0 |
| 19 | 156 | 80 | 0 | 0 | 0 | 0 |
| 20 | 145 | 80 | 0 | 0 | 0 | 0 |
| 21 | 124 | 80 | 0 | 0 | 0 | 0 |
| 22 | 102 | 80 | 0 | 0 | 0 | 0 |
| 23 | 161 | 0 | 0 | 0 | 0 | 0 |
| 24 | 131 | 0 | 0 | 0 | 0 | 0 |
| | Generation Cost | | | Execution Time | | |
| | Worst Cost | Average Cost | Best Cost | Worst Time | Average Time | Best Time |
| | 13489.94 | 13489.94 | 13489.94 | 54.32942 | 53.29153 | 52.22154 |



| Hour | Generation Schedule of Committed Units | | | | | | |
|---|---|---|---|---|---|---|---|
| | P1 | P2 | P3 | P4 | P5 | P6 | P7 |
| 1 | 50 | 0 | 0 | 0 | 460 | 0 | 30 |
| 2 | 70 | 0 | 0 | 0 | 550 | 0 | 0 |
| 3 | 404 | 0 | 0 | 0 | 550 | 0 | 0 |
| 4 | 66 | 0 | 0 | 0 | 550 | 0 | 410 |
| 5 | 50 | 0 | 0 | 0 | 550 | 0 | 403 |
| 6 | 442 | 0 | 0 | 0 | 550 | 0 | 0 |
| 7 | 428 | 0 | 0 | 0 | 550 | 0 | 0 |
| 8 | 406 | 0 | 0 | 0 | 550 | 0 | 0 |
| 9 | 392 | 0 | 0 | 0 | 550 | 0 | 0 |
| 10 | 372 | 0 | 0 | 0 | 550 | 0 | 0 |
| 11 | 352 | 0 | 0 | 0 | 550 | 0 | 0 |
| 12 | 201 | 0 | 0 | 0 | 550 | 0 | 0 |
| 13 | 101 | 0 | 0 | 0 | 550 | 0 | 0 |
| 14 | 50 | 0 | 0 | 0 | 538 | 0 | 0 |
| 15 | 52 | 0 | 0 | 0 | 550 | 0 | 0 |
| 16 | 218 | 0 | 0 | 0 | 550 | 0 | 0 |
| 17 | 326 | 0 | 0 | 0 | 550 | 0 | 0 |
| 18 | 313 | 0 | 0 | 0 | 550 | 0 | 0 |
| 19 | 293 | 0 | 0 | 0 | 550 | 0 | 0 |
| 20 | 253 | 0 | 0 | 0 | 550 | 0 | 0 |
| 21 | 234 | 0 | 0 | 0 | 550 | 0 | 0 |
| 22 | 152 | 0 | 0 | 0 | 550 | 0 | 0 |
| 23 | 142 | 0 | 0 | 0 | 550 | 0 | 0 |
| 24 | 95 | 0 | 0 | 0 | 550 | 0 | 0 |
| | | Generation Cost | | | Execution Time | | |
| | | Worst Cost | Average Cost | Best Cost | Worst Time | Average Time | Best Time |
| | | 49428.72 | 48948.78 | 48709.15 | | | |



| | Number of Units | Generation Cost | | | Execution Time | | |
|---|---|---|---|---|---|---|---|
| | | Worst Cost | Average Cost | Best Cost | Worst Time | Average Time | Best Time |
| SCA | 5-Unit | 11979.73 | 11979.73 | 11979.73 | 45.27816 | 42.51827 | 40.94922 |
| | 6-Unit | 13489.94 | 13489.94 | 13489.94 | 55.89097 | 54.57731 | 53.61959 |
| | 7-Unit | 49315.13 | 48988.37 | 48715.75 | | | |
| PSO-SCA | 5-Unit | 11979.73 | 11979.73 | 11979.73 | 40.91269 | 39.77891 | 39.27244 |
| | 6-Unit | 13489.94 | 13489.94 | 13489.94 | 54.32942 | 53.29153 | 52.22154 |
| | 7-Unit | 49428.72 | 48948.78 | 48709.15 | | | |

## Conclusion

In this paper it has been concluded that many modern as well as classical techniques has been applied to solve unit commitment problem. A newly developed Sine Cosine algorithm is applied to solve IEEE 14 Bus, IEEE 30 Bus and IEEE 56 Bus system and compare with the recently published techniques. Comparison shows better results of SCA with other techniques in optimizing the fuel cost, startup cost and overall generation cost.

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