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# A Novel Sine Cosine Algorithm for the solution of Unit Commitment Problem

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**Abstract:** This research paper aims to solve 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). 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.

## 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. To attain the most economic generation and to meet out the local demand without violating tie-line capacity limits constraints ,we used MAUC [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]. Economic Dispatch (ED) and Unit Commitment (UC) have been used in planning and controlling the operation of generating units in order to find the most economical schedule of running/ committing the generating units to meet the load demands and satisfy the constraints at the same time. The total production cost includes various costs such as fuel cost, operating labour cost, maintenance cost, etc. The schedule which yields minimum total production cost is said to be the optimal solution of unit commitment. Since unit commitment is complex task and essentially a large-scale non-linear mixed-integer problem, it poses to be a huge challenge for finding the optimal solution.

### 1.1. 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):

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

(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:

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

(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:

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

(3)

where, $\alpha_i = \$/\text{MW}^2$, $\beta_i = \$/\text{MWh}$, $\gamma_i = \$/\text{h}$, $\delta_i = \$/\text{h}$, $\varepsilon_i = \text{rad/MW}$ 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

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

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

(5)

$$Cost_{NH} = \sum_{h=1}^{H} \sum_{i=1}^{NG} [FC_i(P_{ih}) * U_{ih} + STC_{ih} * (1 - U_{i(h-1)} \tag{6}$$

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:

$$STC_{ih} = \begin{cases} HSC_i, & if \quad MDT_i \le DT_i < (MDT_i + ( \\ CSC_i, & if\ DT_i > (MDT_i + CSH_i) \end{cases} \tag{7}$$

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.

## 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).

**Particle Swarm Optimization**

Yun-Won Jeong et.al[32] projected a new binary particle swarm optimization (BPSO) approach encouraged by quantum computing, namely quantum-inspired binary particle swarm optimization (QBPSO) solving unit commitment problem up to 100-units with 24-h demand horizon. Xiaohui Yuan et. al.[33] described an enhanced particle swarm optimization (EPSO) approach to solving numerous unit commitment problem UCP for units in the range of 10 to 100 and T. Logenthiran et. al. [34] described that Particle Swarm Optimization (PSO) based heuristic optimization algorithms have been used for obtaining higher quality solutions to solve the UCP problem. Vikram Kumar Kamboj [35]presents solution to single-area unit commitment problem for 14-bus system, 30-bus system and 10-generating unit model using swarm-intelligence-based particle swarm optimization algorithm and a hybrid PSO–GWO algorithm.

**Shuffled Frog-Leaping Algorithm**

Javad Ebrahimi et. al. [36] described the new evolutionary algorithm known as Shuffled Frog Leaping Algorithm SFLA applied to ten up to 100 generating units, taking into account one-day and seven-day scheduling periods. To solve travelling salesman problem , Xue-hui L. et al. [37] adopted , the shuffled frog-leaping algorithm (SFLA) and meta-heuristic algorithm. For solving the economic emission load dispatch problem ,Reddy A. S. and Vaisakh K. [38] customized the shuffled frog-leaping algorithm into a modified shuffled frog- leaping algorithm (MSFLA) , for IEEE- 30 bus system. Pourmahmood M. et al. [39] also planned a modified shuffled frog- leaping (MSFL) algorithm .To optimize the size of the two FACTS devices, SVC and TCSC and also location , Jebaraj L. et al. [40] applied SFLA shuffled frog-leaping algorithm, for IEEE 30-

bus system under definite considered conditions. For searching the solution of UCP Anita J. M. et.al. [41] represented the purpose of SFLA optimization algorithm , for a 10- unit thermal system.

## Sine Cosine Algorithm (SCA)

In order to overcome the above GAPS to the larger extent, Sine Cosine algorithm has been developed. 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.

$$X^{t+1}_{i}= X^{t}_{i}+r_1\times\sin(r_2)\times r_3P^{t}_{i}-X^{t}_{i}\ldots\ldots\ldots\ldots\ldots(1)$$

$$X^{t+1}_{i}= X^{t}_{i}+r_1\times cos(r_2)\times r_3P^{t}_{i}-X^{t}_{ii}\ldots\ldots\ldots\ldots..(2)$$

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.

$$X^{t+1}_{i} = \begin{cases} X^{t}_{i}+r_1\times\sin(r_2)\times r_3P^{t}_{i}-X^{t}_{i} & r4 < 0.5 \\ X^{t}_{i}+r_1\times cos(r_2)\times r_3P^{t}_{i}-X^{t}_{ii} & r4 > 0.5 \end{cases} \quad \ldots\ldots\ldots(3)$$

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

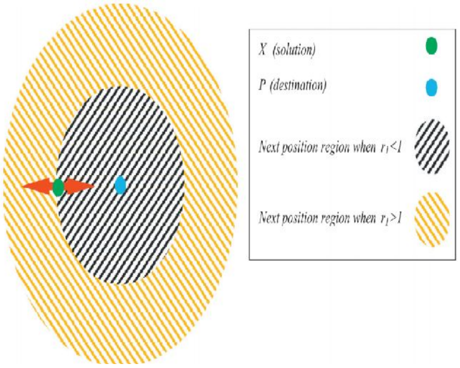


**Fig.1**
*Effect of sine cosine in eqn. (1) and (2)*

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 deemphasize (r3 < 1) the effect of destination in defining the distance. And parameter r4 equally switches between sine and cosine component in eqn. (3)

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.

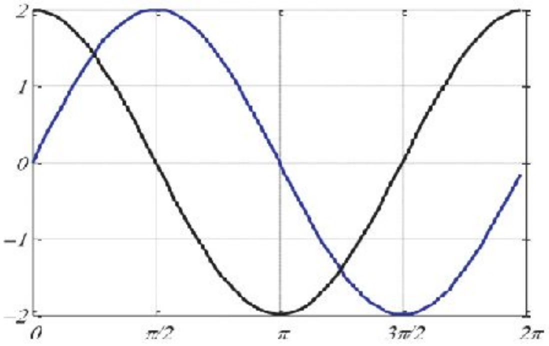


*Fig.2 sine cosine with ranges of [-2,2]*

The Sine Cosine function [-2,2] operation is illustrated by conceptual model as shown in the fig. 3. By changing the ranges of Sine Cosine function we can find the promising region in the search space. Also it ensures the exploration and exploitation of search space.

To make balance between exploration and exploitation, the range of sine and cosine in eqn. (1) to (3) 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.

SCA explores the search space when ranges of sine and cosine function are in [-2,-1] and (1,2] and exploits the search space when ranges are in [-1,1].

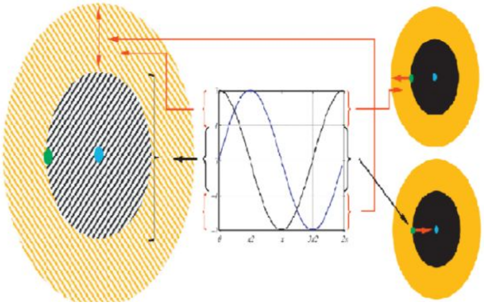


*Fig.3 Sine and Cosine with the ranges in [-2,2] to go around the destination*

General steps of the SCA Algorithm

**Initialize** a set of search agents (solutions) (X)

**Do**

**Evaluate** each of the search agents by the objective function

**Update** the best solution obtained so far ($P=X^*$)

**Update** $r_1$, $r_2$, $r_3$, and $r_4$

**Update** the position of search agents using Eq. (3)

**While** (t< maximum number of iterations)

**Return** the best solution obtained so far as the global optimum

## Unit commitment problem formulation

The main objective of unit commitment is to find the optimal schedule for operating the available generating units to regulate the total operating and generation cost of electric power utilities. Total operating cost of power generation includes fuel cost, shut down and start up costs. The fuel costs are calculated using the data of generating unit characteristics such as fuel price information, turn-on status of unit ,heat rate of generating utilities, turn-off and initial status of units, which is mathematically, a non-convex , quadratic and non smooth equation of power output of each generator at each hour and can be determined by Economic Load Dispatch (ELD) [42], as illustrated as following :

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

Where, $\alpha_i$ (\$/MW$^2$h), $\beta_i$ (\$/MWh) and $\gamma_i$ (\$/h) are fuel consumption coefficients of i$^{th}$ unit The total fuel cost over the given time horizon 'H' is TFC.

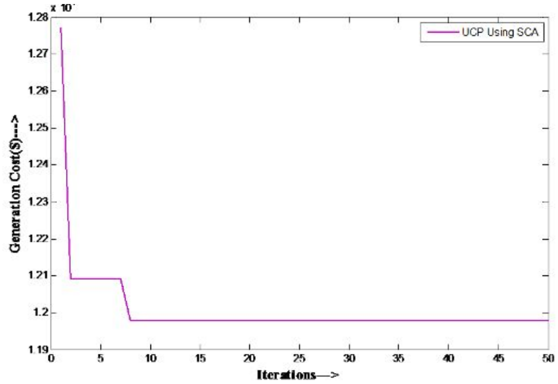
$$Cost_{NH} = \sum_{h=1}^{H} \sum_{i=1}^{NG} [FC_i(P_{ih}) * U_{ih} + STC_{ih} * (1 - U_{i(h-1)}) * U_{ih}]$$

where Uih is the position or status of ith unit at hth hour. Start up cost is warmth-dependent. Start up cost is that cost which take place while bringing the thermal generating unit online. It is expressed in terms of the time (in hours) for which the units have been shutdown. On the other hand, shut down cost is a fixed amount for each unit which is shut down. Mathematically, start up cost can be expressed as:

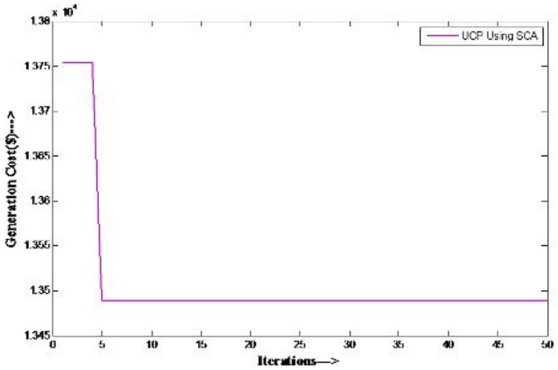
$$STC_{ih} = \left\{ \begin{array}{ll} HSC_i, & if \quad MDT_i \le DT_i < (MDT_i + CSH_i) \\ CSC_i, & if \; DT_i > (MDT_i + CSH_i) \end{array} \right\}$$

where CSCi and HSCi are cold startup and hot start-up cost of ith unit respectively and MDTi is the minimum down time of ith unit, MDT$^{ON}{}_i$ is the number of hours that ith unit has been on-line since it was turned ON earlier and CSHi is the cold start hour of unit i.

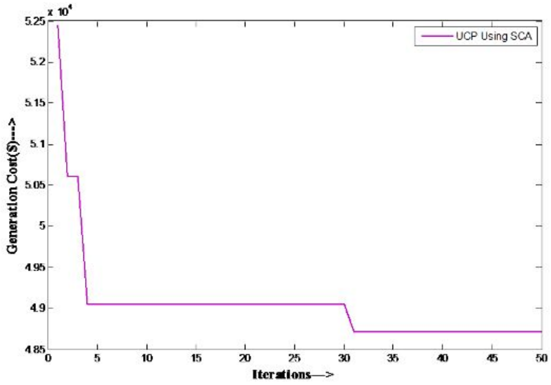
## Graphs for SCA Algorithm



5- Unit Test System

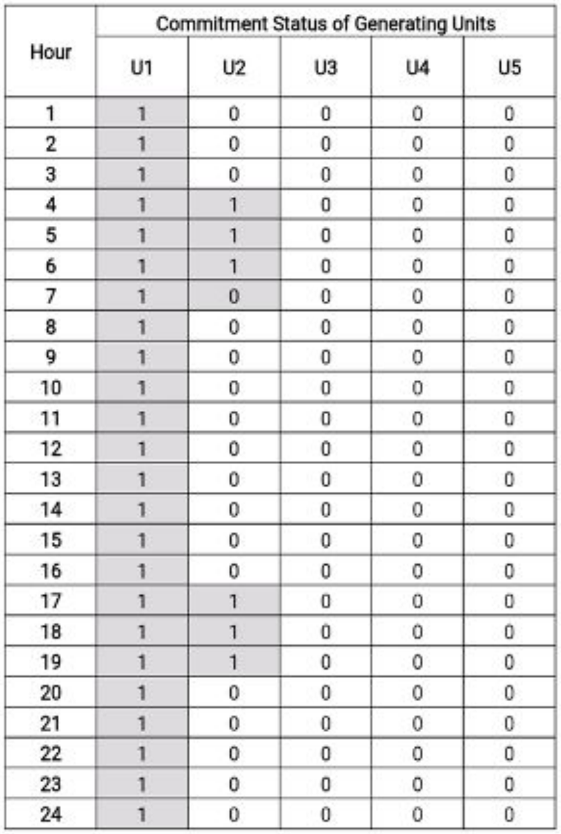


6 – Unit Test System

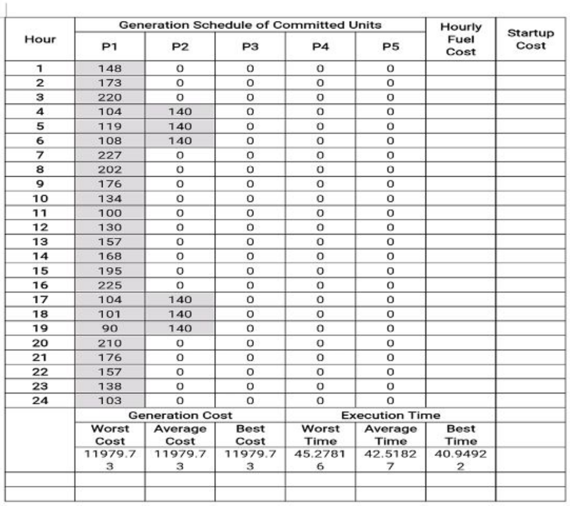


7- Unit Test System

## Committed status and generation scheduling of 5-unit test system

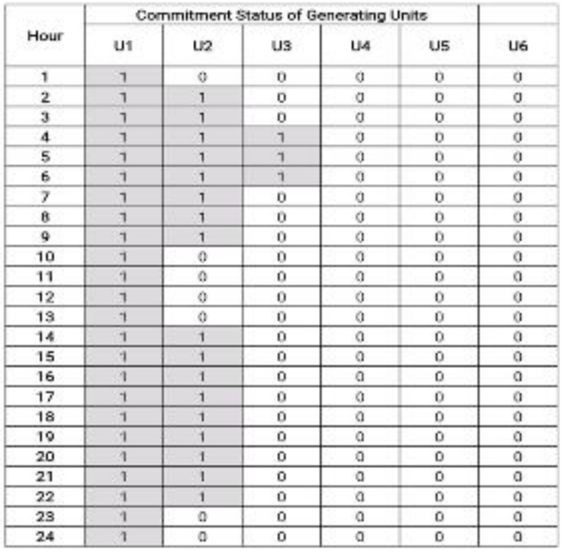


| Hour | Commitment Status of Generating Units | | | | |
|---|---|---|---|---|---|
| | U1 | U2 | U3 | U4 | U5 |
| 1 | 1 | 0 | 0 | 0 | 0 |
| 2 | 1 | 0 | 0 | 0 | 0 |
| 3 | 1 | 0 | 0 | 0 | 0 |
| 4 | 1 | 1 | 0 | 0 | 0 |
| 5 | 1 | 1 | 0 | 0 | 0 |
| 6 | 1 | 1 | 0 | 0 | 0 |
| 7 | 1 | 0 | 0 | 0 | 0 |
| 8 | 1 | 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 |

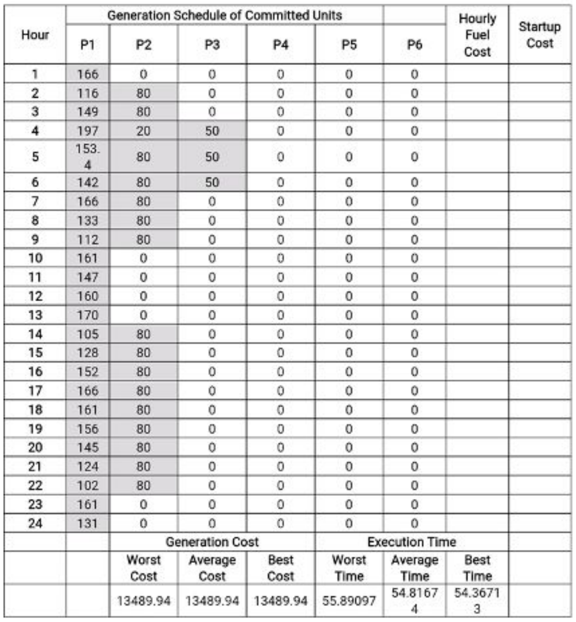


| Hour | Generation Schedule of Committed Units | | | | | Hourly Fuel Cost | Startup Cost |
|---|---|---|---|---|---|---|---|
| | P1 | P2 | P3 | P4 | P5 | | |
| 1 | 148 | 0 | 0 | 0 | 0 | | |
| 2 | 173 | 0 | 0 | 0 | 0 | | |
| 3 | 220 | 0 | 0 | 0 | 0 | | |
| 4 | 104 | 140 | 0 | 0 | 0 | | |
| 5 | 119 | 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 | |
| | | | | | | | |
| | | | | | | | |

## Committed status and generation scheduling of 6-unit test system

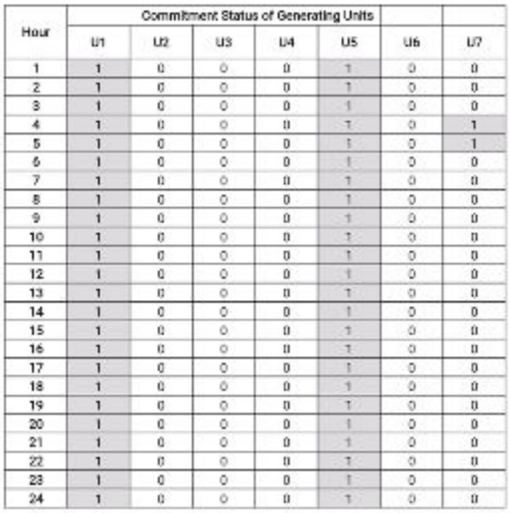


| Hour | Commitment Status of Generating Units | | | | | |
|---|---|---|---|---|---|---|
| | U1 | U2 | U3 | U4 | U5 | U6 |
| 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| 2 | 1 | 1 | 0 | 0 | 0 | 0 |
| 3 | 1 | 1 | 0 | 0 | 0 | 0 |
| 4 | 1 | 1 | 1 | 0 | 0 | 0 |
| 5 | 1 | 1 | 1 | 0 | 0 | 0 |
| 6 | 1 | 1 | 1 | 0 | 0 | 0 |
| 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 |

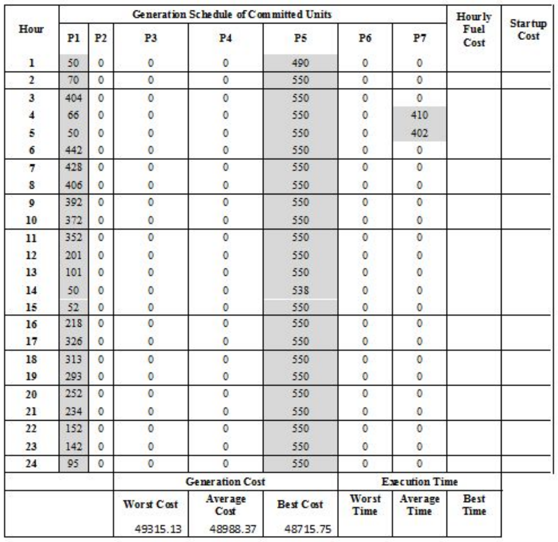


| Hour | Generation Schedule of Committed Units | | | | | | Hourly Fuel Cost | Startup Cost |
|---|---|---|---|---|---|---|---|---|
| | P1 | P2 | P3 | P4 | P5 | P6 | | |
| 1 | 166 | 0 | 0 | 0 | 0 | 0 | | |
| 2 | 116 | 80 | 0 | 0 | 0 | 0 | | |
| 3 | 149 | 80 | 0 | 0 | 0 | 0 | | |
| 4 | 197 | 20 | 50 | 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 | |

## Committed status and generation scheduling of 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 |



| Hour | Generation Schedule of Committed Units | | | | | | | Hourly Fuel Cost | Startup Cost |
|---|---|---|---|---|---|---|---|---|---|
| | 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<br>49315.13 | Average Cost<br>48988.37 | Best Cost<br>48715.75 | Worst Time | Average Time | Best Time | |

## 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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