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# Unit Commitment in Power System t by Combination of Dynamic Programming (DP), Genetic Algorithm (GA) and Particle Swarm Optimization (PSO)

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## Abstract

Unit commitment is a key and important function in power system operation. The goal of this function is to supply the load demand economically. In order to achieve this goal, unit commitment function determines the condition of the units to be on or off and the amount of generation for generating units of power system for a period of time.

The extended form of this operational function, *i.e.* Security constrained unit commitment, which is the objective of this paper, considers the security constraints, for example transmission lines overload, beside the other constraints in determining the condition of the generating units to be on or off.

In this paper, a hybrid method is proposed for dynamic programming, genetic algorithm and particle swarm optimization. In order to solve the unit commitment of power systems considering system security constraints. The condition of the units to be on or off and economic dispatch are determined and solved by considering system security constraints through previously mentioned combination method.

**Keywords:** Combinatorial Solution Strategy, Dynamic Programming (DP), Genetic Algorithm (GA), Particle Swarm Optimization (PSO), SCUC Security Constrained Unit Commitment

## 1. Introduction

Due to heavy consumption of industrial loads and the lights, the network is heavily loaded through the day and early in the evening and in contrast, it experiences much lower load late at the night and early in the morning when most of the lights are out. The power consumption is periodic through the week. In a way that through the working days it is higher than holidays. But the question is, if it is reasonable or not to enter enough units into the network and keep them active in order to supply the peak demand? It is obvious that unit commitment with large numbers of units is not economical and will result in a costly schedule but it would save a lot of money if unnecessary units are turned off [1].

Unit Commitment (UC) in power system include determination of planning the units to be on and off in order to supply the forecasted load in a period of time. Constraints such as load balance, system spinal reserve, unit generation limit, pollution and etc. are included in this planning schedule which is go minimizing the cost of power system operation[2].

There are two process ahead in solving the unit commitment problem. First to determine the units to be on or off. The numbers "1" and "0" represent the condition of the units whether is on or off respectively. In the other

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process the economic dispatch should be analyzed, in the other words, how much power should be allocated to each unit from whole generated power in a period of time which the unit in on.

But solving the UC problem alone is not acceptable, since the network security constraints are not considered. Generation configuration is considered in power system and security constraints is determined for UC operation function. Transmission lines overload which is known as "security constrained unit commitment (SCUC)".

The goal of SCUC is generation configuration planning with the lowest cost and reliability[3].

Large modern units are equipped with multi-valves turbines which by opening the valves one after the other more steam will pass through the turbine blades and the generation capacity will increase and therefore the unit output would have a waveform curve which is called valve point effect[4]. By considering this form of output the problem will be so complicated.

The complexity of this problem make us to get through dimensions and limitations of this problem and considering proposed solution which were presented before to solve the SCUC problem in order to propose a new method to optimize the solution of this problem.

## 2. Problem Description

Here the goal is to supply the load demand of costumers in an economic and secure way. System security constraints along with other constraints should be considered in generation and cost function should be minimized too.

## 3. Importance and Necessity of Study

Since economic issues and minimizing the cost are always important and necessary and in accordance to the fact that different units have different cost functions and also by considering the point that in time of contingencies or normal conditions in order to supply the consumers and also to keep the network in a secure condition, the system should be able to supply the loads with the minimum cost, therefore in order to determines the optimal unit commitment considering system security a plan seems essential. This plan should be updated accordance to existing load and other conditions such as system topology (for example available transmission lines).

## 4. Goals

There are always various techniques to reach better and optimal answers which can be achieved by research and analysis. It would be possible to generate a new idea through considering the attempt have been made by others and find a new technique and second, complete the other methods or reach a better and optimum way by combining them.

In this paper the goal is to find out and present a suitable and economic method to determine the unit commitment arrangement considering system security constraints which may lead to minimizing the cost and improving the security level of the network.

## 5. Proposed Algorithm to Solve the SCUC Problem

In order to solve the SCUC problem using the combination of binary PSO algorithm and genetic algorithm which are included with Dynamic Programming (DP). First the condition of the units to be on or off should be determined one by one and then each unit generation will be defined. Sometimes in some optimization problems the PSO optimization algorithm involves in local optimization and would not be able to define the global optimization, which by using the mutation and cutting operators of genetic algorithm it would be possible to modify change the motion laws in time of getting close to local optimization. Using these operators causes while the velocity is maintained, the convergence of data exchange is done better and response is searched more to find the global optimization. Therefore, these operators improve the functionality of PSO algorithm in getting away from local optimal point.

In PSO algorithm, if all the group members considered as neighboring of a single member then the best member of the group will be always the leader of the other members. The question is which member is the guide for the best member?

Referring to the algorithm motion law and by considering the equation $p_{best} = g_{best} = x_i$ for the best member of the group, it can be understand that this member has no leader and is moved only based on its velocity vector. Therefore, if a better point is not discovered, after some iterations the position of the best member is fixed and due to the nature of the motion law, it would be possible that all the members are convergent to the local optimal, so any solution that can improve the movement and searching process in a proper way will be considered.

In this section, the operation of PSO algorithm is improved using genetic algorithm operators "crossover" and "mutation". In proposed method in order to solve the problem the crossover operator is used to transfer data between two optimal particle and mutation operator is used to escape from the local optimum. For every iteration by choosing two particle as parents randomly and using the crossover operator, a new member is added to set and by using the mutation operator fraction of particles are thrown to random locations in order to replace the pervious "gbest" in case of finding better points. Considering the fact that particles do have memory, the point in using mutation and crossover operators in proposed algorithm, is that, the convergence velocity of PSO algorithm will remain at its pervious value and if by using these operators a more optimum location is found, the particle will move to that location, otherwise the movement won't be deviated. Therefore the convergence velocity will remain standstill. It is possible to use equation below to apply mutation operator on particles[35].

$$\Delta X=(var_{hi}-X_i)*(1-rand^{(1-(iter/maxiter))5})-(X_{i-}var_{lo})*(1-rand^{(1-(iter/maxiter))5})$$

Where:

ΔX: Change in the position of members which are mutated.

$var_h$: Maximum value of X

$var_{lo}$: Minimum value of X

rand: Random number generation function which produce numbers between 0 and 1 with monotonous probability distribution.

iter: Loop Counter of algorithm.

maxiter: Maximum number of algorithm loop repeat.

The created mutation using the above equation causes some members to be out of the specified range of search. So the locations which are out of the range of search space are investigated randomly. It should be noted that the memory of PSO algorithm causes the particle swarm movement not to deviated in the case of the locations which are obtained from mutation are not optimum.

So by using mutation operator, convergence velocity won't decrease.

## 5.1 The Proposed Algorithm is as Follows:

1 – Form the initial population.
2 – Evaluation of each particle current position.
3 – Determine the best location ever experienced by any particle.
4 – Determine the best position experienced by the group of particles up to now.
5 – Set the velocity and new location of each particle.
6 – Apply crossover operators to the particles and adding a new member.
7 – Apply mutation operator to the percentage of particles randomly.
8 – Form a new population.
9 – Check the stopping criterion for the new population, go to step 10 if the criterion is met, go to step 2 if it is failed to fulfill the criteria.
10 – Show new population.

## 5.2 Applying the Proposed Algorithm to Solve the Problem" SCUC"

In this section, in order to implement and apply the proposed algorithm. An IEEE 30 buses system in which two hydroelectric units are added to its buses number 15 and 20, is considered and will have the following steps:

### *5.2.1 First Step*

In this step the initial population is set. Since the power system is consists of N generation units and also the time period which is considered in this study is a season which every month of it is divided into sections. And for each section, three levels of load are considered includes minimum, average and maximum. 18 time intervals are considered in planning so every group of population can be shown using a N*18 matrix which is specified through following equation:

$$I=\begin{bmatrix} I_{11} & I_{12}\cdots\cdots & I_{1T} \\ I_{21} & I_{22}\cdots\cdots & I_{2T} \\ . & . & \\ . & . & \\ . & . & \\ I_{N,1} & I_{N,2} & I_{N,T} \end{bmatrix}$$

Where "T" represents the time intervals in the schedule and here is equal to 18. Also "Ix,y" is the position of the "x" unit in the time period of "y". It should be noted that each element of matrix "I" is determined randomly and is equal to 1 or 0 and the previously mentioned matrix is only related to one group of population and in order to

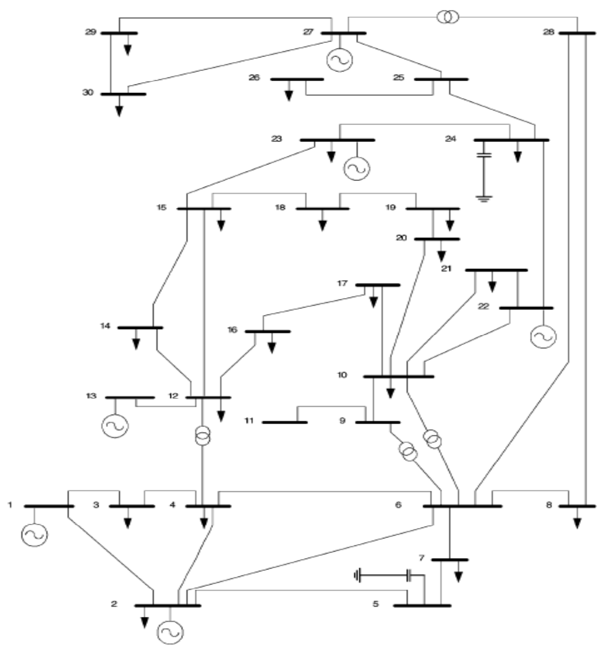


**Figure 1.** IEEE 30 Bus Test System.

produce the whole population, several matrix should be created like matrix "I" equal to number of existing groups in population.

### *5.2.2 Second Step*

After the initial population is generated spinning reserve constraints and periodic inspections and overhauls are checked and if any of these two constraints are not meet various methods can be used to satisfy these constraints. In this study, a method based on the "priority list" of the units is used to satisfy these constraints.

$$T_{i,\,on}^{t+1} = \begin{cases} T_{i,\,on}^{t} + 1 & I = 1 \\ T_{i,\,on}^{t} + 1 & I = 0 \end{cases}$$

Where" I = 1" represents the unit is turned on and "I = 0" means it's off and these values are obtained from "I" matrix and "$T_{i,\,on}^{t}$" is duration of time in which the unit is turned on until the time period "T" of planning schedule. Also, it is possible to define an initial activity duration for each unit which means how many times each unit have been on at the beginning of planning schedule and the duration of this condition can be shown by a positive number and the off condition is shown by a negative number.

### *5.2.3 Third Step*

After determining the initial population and satisfying the mentioned constraints listed in the previous step for each of the categories, now, the production costs should be determined for each category of the units status (on or off). To determine the production cost the "economic dispatch" should be solved considering the units which are on and in order to do so the following steps should be taken into account:

1 – Generate the initial population.
2 – Supply power generation limit.
3 – Supplying "supply and demand balance" constraints.
4 – Supplying maximum allowable pollution constraints.
5 – Supplying generation limit in hydropower units.
6 – Supplying transmission lines limit constraint.
7 – Determine the value of each group, optimal level of personal and global (pbest and gbest).
8 – Set the stop criterion for the economic dispatch algorithm.

There are various ways to determine the stop time of the algorithm. But one of the most common way is considering a certain number of iterations. In this paper 1000 iterations is considered.

### *5.2.4 Fourth Step*

After determining the generation cost for each of the categories, in this section, the best answer should be determined so it can be used for next steps. Therefore, the best answer for each category and group is determined. It should be noted, definition for best response is to satisfy all the constraints and do have the minimum generation cost.

### *5.2.5 Fifth Step*

New population is determined according to the best obtained from the previous steps and the proposed H-DP-PSO-GA hybrid algorithm.

### *5.2.6 Six Step*

The algorithm introduced in the previous steps is applied on the proposed test system and the result of the simulation will be analyzed.


**Figure 2.** Flowchart of the proposed algorithm

## 6. Determining Load Pattern

Load pattern for a period of one year is specified in the following table and graph. In this study, each Season is divided to three months and each month is divided into two parts. And three load level (minimum, average and maximum) is considered for each part, so, 18 load level is determined for each season.

Since each month is divided into two parts in the proposed test system so, the horizontal axis consists of 24 portions instead of 12 in the Figure below.

## 7. Simulation and Analysis of Simulation Results

In order to demonstrate the capabilities of the proposed algorithm, the simulation is carried out as follows. System contains hydro and thermal units. Thermal units in the system are equipped with the effect of opening the steam valve in order to be close to the real model, also the amount of water in the reservoir of dam is considered as a constraint for the hydroelectric unit, therefore, these units do have limitations to produce electric energy. The spinning reserve constraint is also considered in this scenario. Also, in addition to security constraint, periodic controls and overhauls of the units are considered as other constraints of the system.

Periodic controls and overhauls constraints mean that every single unit is removed from the network after specified period of time to be controlled to see whether it needs any overhaul and maintenance process or not. The activity time is considered 18 intervals for hydroelectric units and 15 generator for thermal units. Security constraint put a limit on the power transmission lines in a way that if the power which is carried through the lines exceeded from an acceptable value then the answer will not be accepted. In order to consider this constraints lines 7, 12, and 20 are selected. The maximum permissible

**Table 1.** Proposed load pattern for test system

| mount | Section | load Level | | | mount | Section | load Level | | |
|---|---|---|---|---|---|---|---|---|---|
| | | minimum | Average | maximum | | | minimum | Average | maximum |
| 1 | 1 | 111.72 | 170.02 | 242.88 | 7 | 1 | 133.81 | 198.2 | 283.14 |
| | 2 | 110.655 | 168.39 | 240.55 | | 2 | 131.14 | 194.24 | 277.48 |
| 2 | 1 | 127.47 | 168.01 | 240.137 | 8 | 1 | 126.08 | 172.74 | 246.77 |
| | 2 | 129.19 | 170.28 | 243.26 | | 2 | 127.04 | 174.06 | 248.66 |
| 3 | 1 | 1131.81 | 240.58 | 292.26 | 9 | 1 | 138.31 | 176.03 | 251.47 |
| | 2 | 158.46 | 245.96 | 351.37 | | 2 | 138.10 | 175.76 | 251.1 |
| 4 | 1 | 161.56 | 297.61 | 425.15 | 10 | 1 | 116.71 | 175.01 | 250.01 |
| | 2 | 153.04 | 281.91 | 402.73 | | 2 | 116.58 | 174.82 | 249.74 |
| 5 | 1 | 146.30 | 272.45 | 389.21 | 11 | 1 | 140.78 | 174.44 | 249.20 |
| | 2 | 121.92 | 227.04 | 324.34 | | 2 | 141.10 | 175.96 | 251.37 |
| 6 | 1 | 140.87 | 206.03 | 294.34 | 12 | 1 | 133.47 | 178.70 | 255.28 |
| | 2 | 131.959 | 192.98 | 275.69 | | 2 | 129.86 | 173.87 | 248.39 |

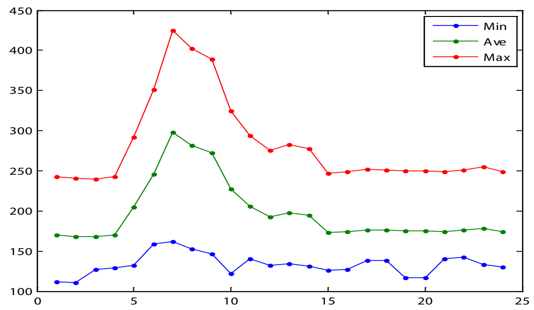


**Figure 3.** Model of proposed load test system.

power that is considered to cross the lines is 260, 100 and 80 MW respectively. Tables 2 and 3 represents the results of implementing the proposed algorithm on the test system. And the total cost is equal to 11,992 $. In Table 2, " 0 " and " 1", represent whether the unit is turned on or off, respectively.

To illustrate the convergence of the proposed algorithm, the convergence of the algorithm is shown in Figure 4, which shows a proper convergence of the algorithm.

## 8. Comparison Between Proposed Method and the PSO Algorithm.

If the PSO Algorithm is applied to the system output will be most likely to what is shown in Figure 5. If the proposed algorithm (DP and PSO and GA) is applied the result would be similar to what is shown in Figure 4. AS it is obvious the proposed algorithm is more efficient and also the cost is much lower Compare to PSO algorithm alone. By using PSO algorithm the cost is 14581 $ and if the proposed algorithm is used the cost would be 11992 $ so it is clear that the proposed algorithm is more capable than PSO algorithm reaching optimal value. There would not any significant change after about 200 iterations by using PSO algorithm but the proposed algorithm reach the cost 12447 $ after about 200 iterations which is less than the corresponding number of iterations in PSO algorithm and by increasing the number of iterations the proposed algorithm will reach better results values and that is because of the algorithm does not trapped by local optimal which is caused by the mutations of genetic algorithm and that is why the proposed algorithm is more capable.

## 9. Conclusion

Security Constrained Unit Commitment (SCUC) of power systems is one of the most important functions in power system operation. This issue is defined as an optimization problem and it aims to meet the demand of costumers economically in a period of time. The importance of this function in power system operation planning causes to proposed a new method to solve the problem. In proposed method, SCUC problem has both binary variables (on/off condition of the units in form of 1/0) and real variables (real power generation) and the challenge in solving such problems is to establish a logical connection between these two groups of variables. In this research the relationship between these two variable established using PSO and binary algorithms together, then in order to prevent the PSO algorithm from involving in/ trapped in local optimal points combined it with GA algorithm. By considering DP in solving process, repetitive calculation is avoided and optimal response is achieved. Solving the problem by using proposed algorithm resulted in more optimal responses and supplying costumers economically as it is shown in convergence curves.

**Table 2.** Results of the simulation

| Period | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Unit 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Unit 2 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 |
| Unit 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Unit 4 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 |
| Unit 5 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 |
| Unit 6 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Unit 7 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Unit 8 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

**Table 3.** The value of each unit of energy produced

| Period | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| Unit 1 | 13.5 | 13.5 | 13.5 | 13.5 | 13.5 | 13.5 | 11.5 | 11.5 | 0 |
| Unit 2 | 0 | 13.5 | 13.5 | 13.5 | 13.5 | 13.5 | 13.5 | 13.5 | 13.5 |
| Unit 3 | 5 | 5 | 5 | 5 | 5 | 20.218 | 5 | 0 | 50 |
| Unit 4 | 0 | 35.14 | 16.82 | 5 | 5 | 5 | 5 | 5 | 57.54 |
| Unit 5 | 0 | 49.56 | 5 | 5 | 5 | 98.23 | 5 | 72.7 | 27.42 |
| Unit 6 | 88.21 | 48.30 | 36.20 | 64.58 | 73.13 | 89.30 | 90.77 | 61.74 | 110.7 |
| Unit 7 | 5 | 5 | 100 | 5 | 5 | 5 | 5 | 5 | 0 |
| Unit 8 | 5 | 5 | 60 | 5 | 54.69 | 5 | 5 | 5 | 0 |

**Table 3.** Amount of each unit of energy produced

| Period | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|
| Unit 1 | 11.5 | 11.5 | 11.5 | 11.5 | 11.5 | 11.5 | 11.5 | 11.5 | 11.5 |
| Unit 2 | 13.5 | 13.5 | 13.5 | 0 | 11.5 | 11.5 | 11.5 | 11.5 | 11.5 |
| Unit 3 | 5 | 5 | 5 | 5 | 50 | 50 | 5 | 5 | 5 |
| Unit 4 | 60 | 5 | 5 | 0 | 60 | 5 | 60 | 60 | 5 |
| Unit 5 | 1169 | 100 | 100 | 100 | 0 | 100 | 5 | 5 | 100 |
| Unit 6 | 0 | 30.96 | 51.37 | 6.96 | 35.70 | 67.28 | 26.86 | 70.87 | 5039 |
| Unit 7 | 35.31 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Unit 8 | 5 | 5 | 60 | 5 | 5 | 5 | 5 | 5 | 60 |

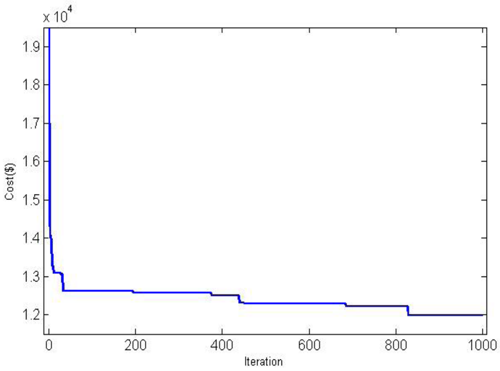


**Figure 4.** Convergence curves of the proposed algorithm (H DP PSO GA).

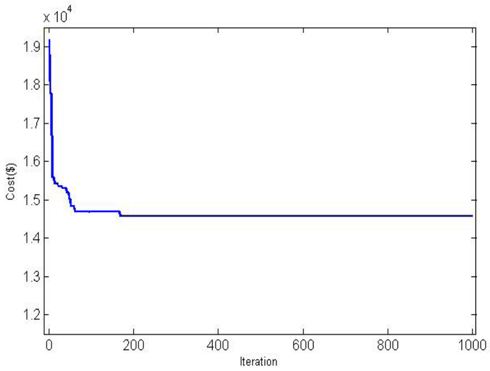


**Figure 5.** Convergence curve of PSO algorithm.

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