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Optimization techniques for Solving Unit Commitment (UC) using MATLAB software

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***Abstract*—The unit commitment problem represents a significant challenge in the optimization of power systems, as it requires determining the most efficient schedule for power generation units to meet electricity demand while minimizing operational costs. This study investigates various optimization techniques implemented in MATLAB, specifically Dynamic Programming (DP), Particle Swarm Optimization (PSO), and a hybrid approach combining both DP and PSO. These methods aim to effectively optimize the scheduling of generating units with a focus on reducing operational expenses. Each technique is initially evaluated independently, followed by the integration of DP and PSO into a hybrid method. To evaluate the performance of the proposed approaches, they are applied to the IEEE 14-Bus system with five generating units. A detailed comparison of the results obtained through MATLAB demonstrates the effectiveness of the proposed methods in achieving optimal solutions for the unit commitment problem**

***Keywords*— Unit Commitment ; Dynamic programming (DP) ;Particle Swarm Optimization (PSO) ; MATLAB Code**.

I. INTRODUCTION

The Unit Commitment (UC) problem is a critical optimization challenge in power system operations, focused on scheduling the on/off states of generating units to meet demand at the lowest cost while adhering to system and operational constraints [1].

Optimizing thermal unit scheduling is essential for minimizing both production costs and emissions in Unit Commitment (UC) problems[2]. Numerous methods have been proposed to achieve optimal solutions, with traditional techniques, such as the Lagrangian method (LM)[3], dynamic programming (DP)[4], priority list (PL) method, and mixed-integer method (MI), being widely employed due to their efficiency and ease of implementation[5]. However, these approaches are often hindered by limitations related to solution quality and numerical convergence, which can undermine their effectiveness.

To overcome these challenges, heuristic methods, including tabu search (TS), simulated annealing (SA), particle swarm optimization (PSO)[6], genetic algorithms (GA)[7], and the self-adaptive learning bat algorithm (SALBA)[8], have been introduced as alternative solutions. These evolutionary algorithms, while offering distinct advantages and limitations, are particularly well-suited for solving UC problems in medium-sized and standard power systems, effectively addressing complex constraints.

Furthermore, hybrid methods, which combine two or more heuristics to enhance performance, have gained increasing attention in UC optimization. These hybrid approaches[9-11], such as those integrating dynamic programming with neural networks or combining simulated annealing with tabu search, have demonstrated superior performance compared to standalone methods. By leveraging the strengths of multiple techniques, hybrid methods offer a more robust and efficient solution to the complex challenges of UC optimization[12].

Many optimization techniques inherently involve randomness, which can result in increased iteration times and computational cost [12-15]. This paper addresses the unit commitment problem by utilizing MATLAB to implement three optimization techniques: Dynamic Programming (DP), Particle Swarm Optimization (PSO), and a hybrid DP-PSO approach. Each method is applied separately to the IEEE 14-Bus system, which consists of five generating units, in order to determine the optimal scheduling of power generation. The effectiveness of each method is evaluated based on its ability to minimize operational costs. A comprehensive comparison of the results highlights the efficiency of the proposed methods in solving the unit commitment problem.

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II. UNIT COMMITMENT PROBLEM

The UC problem aims to minimize total operating costs while adhering to system and unit constraints over a specified period. Consequently, the production cost (PC_{ig}) of each generator (i) over a given time period is determined as a quadratic function of its power output :

$$F(P_{ig}) = a_i P^2_{gi} + b_i P_{gi} + C_i \tag{1}$$

Where :

a_i, b_i, and c_i are the cost coefficients associated with unit i. This allows for a more accurate modeling of the cost associated with varying levels of generation, capturing the complexities of real-world electricity production.

The overall Operating Cost (**OC_{total}**) for the scheduling horizon T combines both production and start-up costs:

$$OC_{total} = \sum_{i=1}^{T} \sum_{i=1}^{NG} [U_i^t FP_{gi} + U_i^t(1 - U_i^{t-1})STC_i + U_i^t(1 - U_i^t)STD_i \tag{2}$$

Here, (U_i^t)is a binary variable indicating the operational status of unit i at time t (where 1 signifies the unit is on and 0 signifies it is off).

The primary goal is to minimize (OC_{total}) while complying with several constraints related to system operation and unit capabilities. All generators are assumed to be connected to a single bus that meets the overall system demand, so network constraints are not included in this formulation.

✦ Constraints

1. Power Balance Constraint: The total power generated by the units at each time interval must equal the corresponding load demand (Pd):

$$\sum_{i=1}^{NG} Ui,tP_{gi} = P_d \tag{3}$$

2. Generation Limit Constraint: Each unit's output must remain within predefined minimum and maximum generation limits:

$$P_{gi\,min} \leq P_{gi} \leq P_{gi\,max} \tag{4}$$

3. Minimum Up/Down Time Constraints (MUT_i/ MDT_i): Each unit must remain in the on or off state for a specified minimum duration before it can be shut down or started:

$$T_{on,i} \geq MUT_i \quad ; \; T_{off,i} \geq MDT_i \tag{5}$$

4. Startup Cost (STC) and Shutdown Cost (STD) ; are typically incurred when a generator is turned on or off. These costs are applied as lump sums and are usually part of the operational constraints for unit commitment.

In this formulation, $P_{min,i}$ and $P_{max,i}$ represent the minimum and maximum output levels for unit (i), while (MUT_i) and (MDT_i) denote the minimum up-time and down-time requirements, respectively

III. OPTIMIZATION TEQNICES

A. Dynamic Programming Method (DP)

In dynamic programming, the optimization process follows a systematic approach where decisions are made progressively by evaluating costs from the starting stage. The procedure culminates by tracing back from the least costly solution at the final stage, informing the decision-making process throughout. The following outlines the step-by-step procedure for optimizing unit commitment using dynamic programming:

1. Initial Setup: Start by randomly selecting two units to be considered for optimization.
2. Load Level Aggregation: Combine the output capacities of the two units to create a set of discrete load levels.
3. Economic Evaluation: For each load level, determine the most cost-efficient way to operate the two units, either by running one unit alone or using both units with shared load.
4. Cost Curve Formation: Develop a cost curve representing the combined operation of the two units. This curve will act as the cost curve for a single equivalent unit.

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5. Expansion Process: Introduce a third unit and repeat the evaluation process to derive a cost curve that reflects the operation of all three units combined.
6. Iterative Refinement: Continue adding units one by one, repeating the above steps, until the entire fleet of units has been considered.

The dynamic programming algorithm for the unit commitment problem carefully evaluates all possible states within each time interval. A flowchart illustrating the Dynamic Programming method is presented in Figure 1.

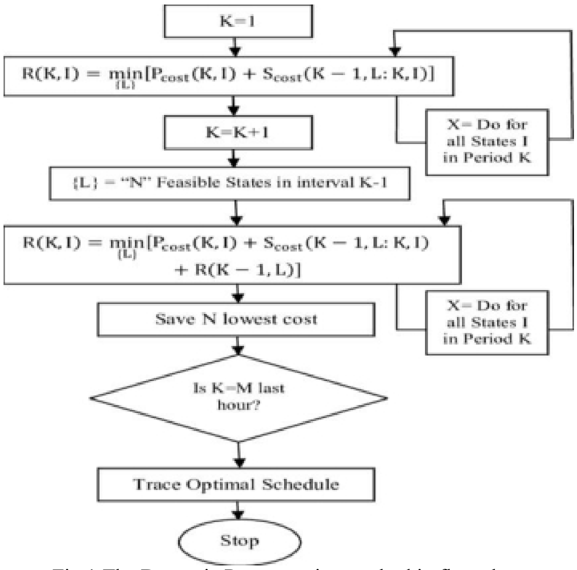

Fig.1 The Dynamic Programming method in flow chart

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B. Particle Swarm Optimization Method (PSO)

In Particle Swarm Optimization (PSO), each particle represents a potential solution and is characterized by two key vectors: position and velocity. For a search space with d dimensions, the position and velocity of the q-th particle are defined as:

- Position: $P_q = (P_{q1}, P_{q2}, P_{q3}, \ldots, P_{qd})$.
- Velocity: $V_q = (V_{q1}, V_{q2}, V_{q3}, \ldots V_{qd})$.

The positions and velocities are initialized randomly within their respective ranges. The particles' positions and velocities are then updated iteratively according to a specific update rule, which is typically represented by Equation (8).

$$V_{qd}^{l+1} = Z * v_{qd}^{l} + c_1 * rand * (PB_{qd} - p_{qd}^{l}) + c_2 * rand * (GB_{qd} - p_{qd}^{l})$$

$$p_{qd}^{l+1} = p_{qd}^{l} + v_{qd}^{l+1} \quad (8)$$

In Equation (8), c_1 and c_2 are the acceleration coefficients that control how strongly each particle is influenced by its own best position and the best position found by the swarm. PB_{qd} represents the best fitness position of the q-th particle in the d-th dimension, and rand refers to a random number. The coefficients c_1 and c_2 can be further evaluated , which influences the performance enhancement of particle P_q. This performance enhancement is given by Equation (9).

$$H(P_q) = \frac{F(P_q(m_o)) - F(P_q(m))}{F(P_q(m_o))} \quad (9)$$

In Equation (9), At the m_o initial moment, let m represent the present moment for the particle, while an intermediate variable ω is used to predict the particle's performance enhancement. The value of ω serves as an indicator of whether the particle's performance has improved or not. Specifically:

- If $\omega \geq 0$, it indicates an improvement in the particle's performance.
- If $\omega < 0$, it suggests that there has been no improvement in the particle's performance.

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The following outlines the step-by-step procedure for implementing the proposed (PSO) algorithm:

- ✦ Step 1: Initialize the parameters: Randomly assign initial positions and velocities to the swarm particles. Also, set the maximum number of iterations for the algorithm.
- ✦ Step 2: Evaluate particle strengths: Calculate the fitness for all particles and determine each particle's personal best position P_{best} Identify the global best position g_{best} . Then, compute the acceleration coefficients c_1 and c_2 , Update the velocities and positions of the particles .
- ✦ Step 3: Evaluate fitness: For each particle, calculate the economic load dispatch solution and assess its fitness value based on the performance.
- ✦ Step 4: Update best positions. Update the personal best P_{best} and global best gbest

positions. The PSO method in flow chart is shown in Figure 2 .

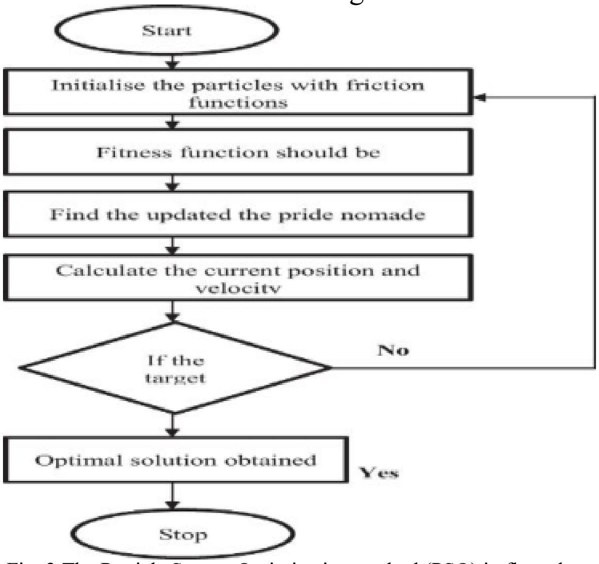

Fig. 2 The Particle Swarm Optimization method (PSO) in flow chart

IV. CASE STUDY TEST SYSTEM

A. TEST SYSTEM DESCRIPTION.

In this study, the IEEE 14-bus test system is utilized to evaluate the proposed techniques, as illustrated in Figure 3. The system consists of five thermal power plants ,The thermal units are located at buses 1, 2, 3,6 and 8.

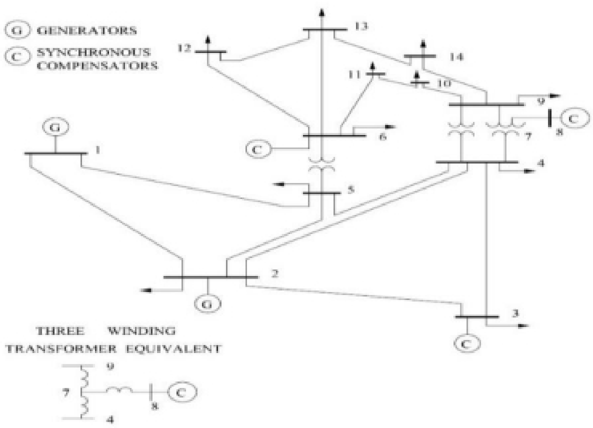

Fig .3. IEEE 14-Bus Test System

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The input data for the test system is given in Tables I and II.

TABLE. I

IEEE 14-BUS GENERATOR DATA[15]

Unit No	U1	U2	U3	U4	U5
Pmin [MW]	30	130	165	130	225
Pmax [MW]	100	400	600	420	700
Ramp Up	50	80	100	80	70
In Status	-10	-10	-10	-10	-10
MinON (Hour)	5	3	2	1	4
Min Off (Hour)	4	2	4	3	5

TABLE. II

POWER PRODUCTION COST[15]

Unit No	U1	U2	U3	U4	U5
Coef (a) [£]	820	400	600	420	540
Coef (b) [£/MW]	0.023	7.657	8.752	8.431	9.223
Coef (c) [£/MW^2]	0.00113	0.0016	0.00147	0.0015	0.00234
Start-Up cost	2050	1460	2100	1480	2100
Shut-Down Cost	0	0	0	0	0

And 5 generator load demand for 24-hour unit commitment as shown below in Table III.

TABLE III

. LOAD DEMAND FOR 24-HOUR

P load	Hour	P load	Hour	P load	Hour
700	1	1300	9	1000	17
750	2	1400	10	1100	18
850	3	1450	11	1200	19
950	4	1500	12	1400	20
1000	5	1400	13	1300	21
1100	6	1300	14	1100	22
1150	7	1200	15	900	23
1200	8	1050	16	800	24

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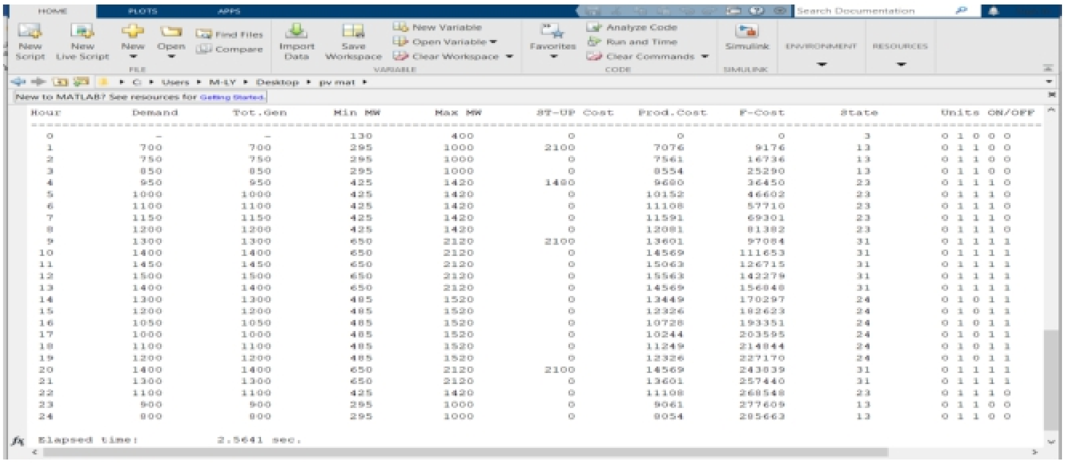
V. SIMULATION RESULTS AND DISCUSSIONS

The Optimization results of the test system using three different methods considering a 24-hour time horizon. MATLAB code is presented in the following sections .

A. *Case 1 : Dynamic programming results.*

Figure .4 shows the hourly schedule for the five generating units. From figure 4 it found that the time to reach the production cost (2.5641 sec) and the total production cost using dynamic programming for 5 generators is (285663£).



Hour	Demand	Tot.Gen	Min MW	Max MW	ST-UP Cost	Prod.Cost	F-Cost	State	Units ON/OFF
0	-	-	130	400	0	0	0	3	0 1 0 0 0
1	700	700	295	1000	2100	7076	9176	13	0 1 1 0 0
2	750	750	295	1000	0	7561	16736	13	0 1 1 0 0
3	850	850	295	1000	0	8554	25290	13	0 1 1 0 0
4	950	950	425	1420	1400	9680	36450	23	0 1 1 1 0
5	1000	1000	425	1420	0	10152	46602	23	0 1 1 1 0
6	1100	1100	425	1420	0	11108	57710	23	0 1 1 1 0
7	1150	1150	425	1420	0	11591	69301	23	0 1 1 1 0
8	1200	1200	425	1420	0	12081	81382	23	0 1 1 1 0
9	1300	1300	650	2120	2100	13601	97084	31	0 1 1 1 1
10	1400	1400	650	2120	0	14569	111653	31	0 1 1 1 1
11	1450	1450	650	2120	0	15063	126715	31	0 1 1 1 1
12	1500	1500	650	2120	0	15563	142279	31	0 1 1 1 1
13	1400	1400	650	2120	0	14569	156848	31	0 1 1 1 1
14	1300	1300	485	1520	0	13449	170297	24	0 1 0 1 1
15	1200	1200	485	1520	0	12326	182623	24	0 1 0 1 1
16	1050	1050	485	1520	0	10728	193351	24	0 1 0 1 1
17	1000	1000	485	1520	0	10244	203595	24	0 1 0 1 1
18	1100	1100	485	1520	0	11249	214844	24	0 1 0 1 1
19	1200	1200	485	1520	0	12326	227170	24	0 1 0 1 1
20	1400	1400	650	2120	2100	14569	243839	31	0 1 1 1 1
21	1300	1300	650	2120	0	13601	257440	31	0 1 1 1 1
22	1100	1100	425	1420	0	11108	268548	23	0 1 1 1 0
23	900	900	295	1000	0	9061	277609	13	0 1 1 0 0
24	800	800	295	1000	0	8054	285663	13	0 1 1 0 0

Elapsed time: 2.5641 sec.

Fig .4 Dynamic programming results

B. *Case 2 : Particle Swarm Optimizations (PSO) results*

While Figure.5 Illustrates the hourly schedule for five generating units optimized using PSO, along with the optimal configuration for output power in megawatts (MW). Additionally, Figure.6 Presents the total production cost, as indicated by the results (14136 5.02 £)

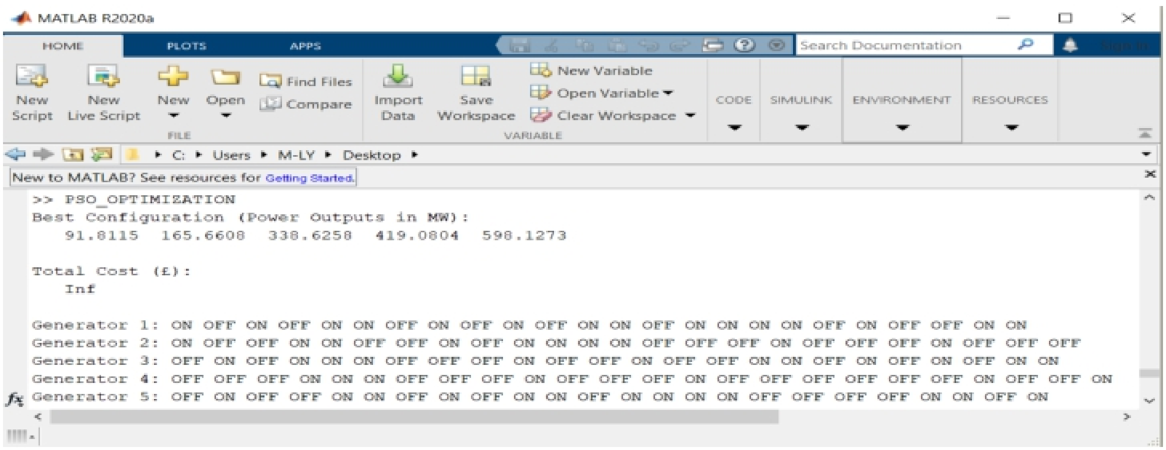


Fig .5 The hourly schedule for five generating units

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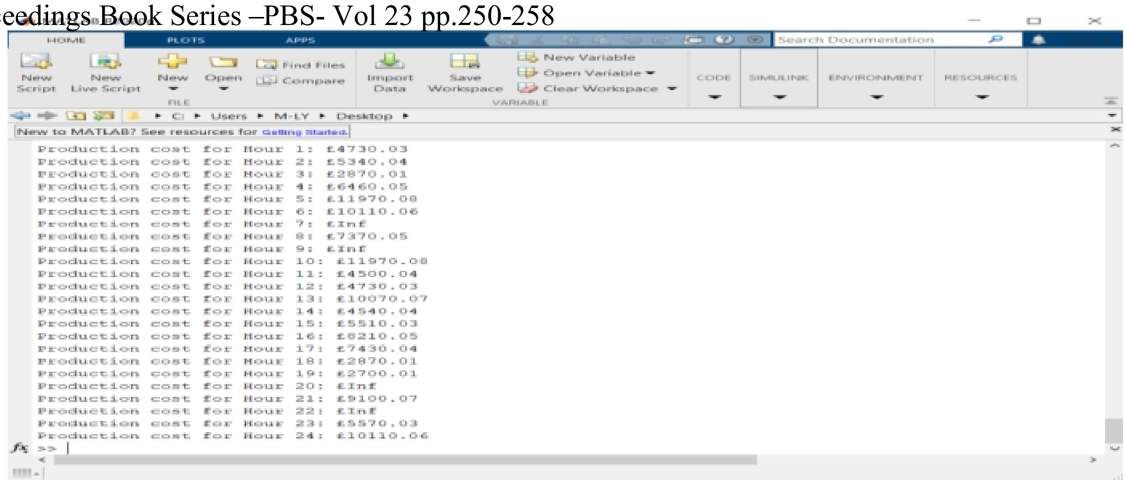

Fig .6 . The total production cost for 24 hour

C. *Hybrid System (DP &PSO) result*

The total production cost, amounting to (135110.91 £), is presented in Figure 7 (Hybrid System: DP & PSO Results). This Figure also highlights the optimal output power configuration in megawatts (MW).

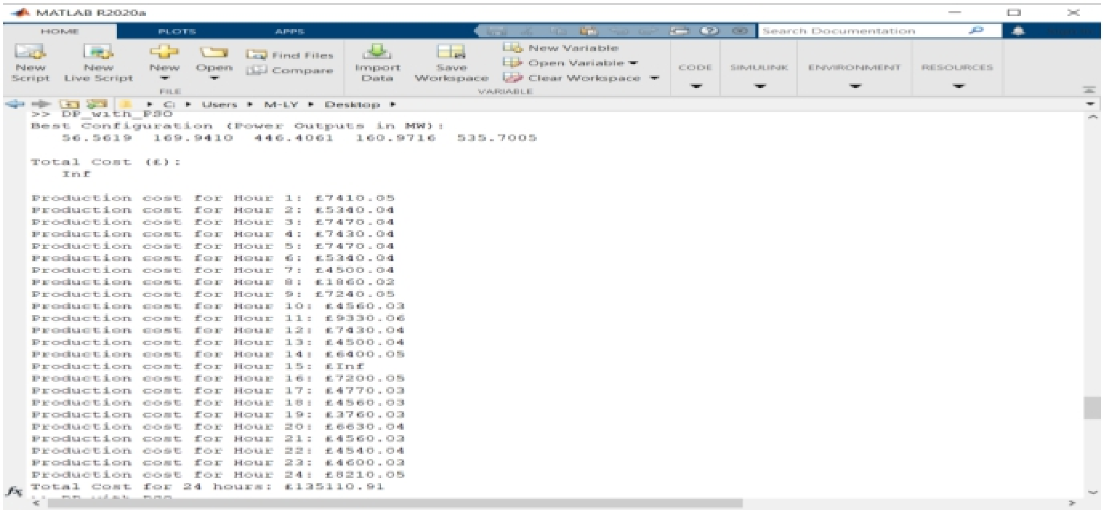

Fig. 7 . Hybrid System: DP & PSO Results

Table IV presents a comparative analysis of the results derived from the investigated optimization methods, with the objective of minimizing operational costs, determining the optimal operational scheduling, and addressing the unit commitment problem

TABLE IV . COMPARATIVE ANALYSIS OF THE RESULTS

Optimization Methods	**Total production cost**
Dynamic programming (DP)	**285663£**
Particle Swarm Optimizations (PSO)	**141365.02 £**
Hybrid System (DP &PSO)	**135110.91 £**

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VI. CONCLUSIONS

This study examines several approaches to solving the unit commitment problem, namely the traditional Dynamic Programming method and the Particle Swarm Optimization technique. These approaches were integrated into a hybrid system (DP & PSO) to capitalize on the strengths of both methods. The methods were tested on the IEEE 14-bus standard test system, and the results were compared to evaluate their efficiency. The findings revealed that DP was less efficient than PSO. Additionally, PSO performed less effectively when used individually compared to the hybrid system. However, the hybrid system (DP & PSO) outperformed the individual methods, particularly in minimizing production costs and optimizing unit scheduling.

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