Effectuation of QP- PSO and Dynamic Programming Method on a Constrained Single Area Unit Commitment Problem: A Comparative Analysis

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Abstract- Optimization plays an important role in the area of engineering and has gained much popularity for solving the constrained problems mainly. Unit commitment is a complex optimization task for planning and operation of a power system network. Dynamic programming is one of the successful approaches to unit commitment problem a chief advantage of reduction in the dimensionality of the problem. Also, a hybrid of Particle Swarm Optimization with Quadratic Programming which is refined algorithm design standard and is a powerful tool which yields definitive algorithm for optimization problems. This research paper presents Single Area Unit Commitment Problem solution for IEEE 14-Bus System and IEEE 10- Unit System using Dynamic programming approach and Hybrid PSO method.

Index Terms- Unit Commitment Problem (UCP), Dynamic Programming (DP), Economic Load Dispatch (ELD)

1. INTRODUCTION

There are various generating resources like thermal, hydro, nuclear etc in the modern power system and the load demand is also variable in a certain period of time, say, a day and happens to attain diverse peak values. Hence, it is necessary to choose which generating unit must be turned on, at what time it is required in the power network as well as the order in which the units must be shut down to obtain a cost effective fulfillment of load demand. The whole process of computation and making decisions is known as unit commitment (UC). Unit commitment in power systems refers to the problem of determining the on/off states of generating units that minimize the operating cost for a given time horizon [2].

Unit commitment handles the unit generation schedule in a power system for minimizing operating cost and satisfying prevailing constraints such as load demand and system reserve requirements over a set of time periods [3]. Generating units cannot be instantly turned on when the demand varies. Thus the unit commitment (UC) must be such that there is sufficient generation available to fulfill the load demand along with ample reserve capacity to avoid failures and breakdown under adverse situations. The unit commitment problem (UCP) is chiefly about finding the most appropriate schedule for turning- on or turning- off the generating units in order to meet the load demand as well as to keep generation cost as low as possible. UCP is a non- linear, large scale, mixed integer constrained optimization problem [2] and essentially belongs to combinatorial optimization problems. UCP has many constraints involved which make it very complex and difficult to compute the optimal solution. The Unit Commitment Problem (UCP) is represented mainly by scheduling the generating units to fulfill the load over a specified time period along with the allocating the generation quantities. UCP is all about determining a least cost turning-on and turning-off schedule of set of generating units for meeting the load demand and also satisfying the operational constraints. The cost of production includes fuel, startup, shutdown, and no load costs.

The operational constraints that must be taken into account include 1. The total power generated must meet the load demand plus system losses. 2. There must be enough spinning reserve to cover any shortfalls in generation. 3. The loading of each unit must be within its minimum and maximum allowable rating. 4. The minimum up and down times of each unit must be observed. The unit commitment is aimed at devising a proper generator commitment schedule for a power system over a period of one day to one week. The main objective of unit commitment is to minimize the total production cost over the study period & to satisfy the constraints imposed on the system such as power generation-load balance, spinning reserve, operating constraints, minimum up time & minimum down time, etc. Several conventional methods are available to solve the unit commitment problem. But all these methods need the exact mathematical model of the system & there may be a chance of getting stuck at the local optimum.

2. PROBLEM FORMULATION FOR SINGLE AREA UNIT COMMITMENT

Unit commitment is a complex decision making process because of the multiple constraints that must not be violated when finding optimal or near optimal commitment schedules. Mathematically, the Unit Commitment Problem is a non-linear, mixed-integer combinatorial optimization problem. The optimal solution to the above complex combinatorial optimization problem in power system can be obtained by global search techniques.
The objective function of the short term thermal Unit Commitment Problem is composed of the fuel cost, start-up cost and shut-down cost of the generating units and mathematically can be expressed as [8]:

$$Cost_{NH} = \sum_{h=1}^{H}\sum_{i=1}^{NG}\begin{bmatrix} FC_i(P_{ih})*U_{ih} + STUC_{ih}*(1-U_{i(h-1)})*U_{ih} \\ +SDC_{ih}*(1-U_{ih})*U_{i(h-1)} \end{bmatrix} \quad (1)$$

Where,
$Cost_{NH}$ is the total operating cost over the scheduled horizon
$FC_i(P_{ih})$ is the fuel cost function
$U_{i(h-1)}$ is the ON/OFF status of of ith unit at $(h-1)^{th}$ hour.
U_{ih} is the ON/OFF status of ith unit at hth hour.
U is the decision matrix of the U_{ih} variable. for i=1,2,3,........NG.
P_{ih} is the generation output of ith unit at hth hour.
$STUC_{ih}$ is the start-up cost of the ith generating unit at hth hour.
SDC_{ih} is the shut-down cost of the ith generating unit at the hth hour.
NG is the number of thermal generating units
$U_{ih} \in \{0,1\}$ and $U_{i(h-1)} \in \{0,1\}$
H is the number of hours in the study horizon.

2.1 *Fuel Cost,* $FC_i(P_{ih})$

The fuel cost function of the thermal unit $FC_i(P_{ih})$ is expressed as a quadratic equation:

$$FC(P_{ih}) = \sum_{i=1}^{NG} (a_i P_{ih}^{\ 2} + b_i P_{ih} + c_i) \qquad \$ / Hour \qquad (2)$$

Where, a_i (\$/MW^{2}h), b_i (\$/MWh) and c_i (\$/h) are fuel consumption coefficients of ith unit.

2.2 *Start up cost,* $STUC_{ih}$

Start up cost is warmth-dependent. 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. Mathematically, the start-up cost can be represented as a step function:

$$STUC_{ih} = \begin{cases} HSC_i, & if \quad MDT_i \le DT_i < (MDT_i + CSH_i) \\ CSC_i, & if\ DT_i > (MDT_i + CSH_i) \end{cases} \qquad (3)$$

where, DTi is shut down duration, MDTi is Minimum down time, HSCi is Hot start up cost, CSCi is Cold start up cost and CSHi is Cold start hour of ith unit.

2.3 *Shut down cost ,* SDC_{ih}

Shut down costs are defined as a fixed amount for each unit/shutdown. The typical value of the shut down cost is zero in the standard systems. This cost is considered as a fixed cost.

3. SINGLE AREA UNIT COMMITMENT CONSTRAINTS

A Single Area thermal generation unit needs to undergo gradual temperature changes and thus it takes some period of time to bring a thermal unit online. Also, the operation of a thermal unit is manually controlled. So a crew is required to perform the operation and maintenance of any thermal unit. This leads to many restrictions in the operation of thermal unit and thus it gives rise to many constraints.

3.1 *Generation Constraints*

In order to satisfy the forecasted system load demand, the sum of all of the generating units on-line must equal the system load over the time horizon.

$$\sum_{i=1}^{NG} P_{ih} U_{ih} = D_h \qquad (4)$$

Where, D_h is the system load demand at hth hour.
P_{ih} is the power output of ith unit at hth hour
U_{ih} is the On/Off status of the ith unit at the hth hour.
NG is the number of thermal generating units

3.2 *Unit Generation Limitations*

The output generated by the individual units must be within the maximum and minimum generation limits i.e.

$$P_{i(\min)} \le P_{ih} \le P_{i(\max)} \qquad (5)$$

Where, $P_{i(\min)}$ and $P_{i(\max)}$ is the minimum and maximum power output of the ith unit.

3.3 *Minimum up Time*

Once the unit is started up, it should not be shut down before a minimum up-time i.e.

$$T_i^{on} \ge MU_i \qquad (6)$$

Where,
T_i^{on} is the up-time of the ith unit
MU_i is the minimum-up time of the ith unit

3.4 *Minimum Down Time*

Once the unit is shut-down, there is a minimum downtime before it can be started up i.e.

$$T_i^{off} \ge MDT_i \qquad (7)$$

Where, T_i^{off} is the down-time of the ith unit
MDT_i is the minimum down time of the ith unit.

4. SINGLE AREA UCP USING DP

Dynamic programming (DP) is effectively employed to solve the problem of unit commitment for a system having larger number of units. This is mainly because dynamic programming constitutes the enumeration of viable schedules or solutions to the unit commitment problem which becomes tedious and difficult to do manually and it has to be done using a digital computer to make it fast and easier. Dynamic programming approach hourly evaluates possible unit commitment schedules associated with decision made in the proceeding step by considering all constraints before searching for a schedule that yields the minimum cost [8-9]. There are certain data requirements while using dynamic programming. These data include cost characteristic of the units under consideration along with the maximum and minimum load limits and various other constraints. In contrast to the priority listing method for solving the same type of problem, dynamic programming proves to be a better approach. If the listing method is used for an n unit system, then 2 n − 1 combinations would be produced. The dynamic programming technique follows absolute enumeration of feasible alternatives of schedule and their comparison on the basis of operating costs. The main advantage of dynamic programming approach is that once the operating schedule of n units is evaluated, the optimal schedule for n+1 unit can be easily determined. Thus DP reduces the dimensionality of the considered problem.

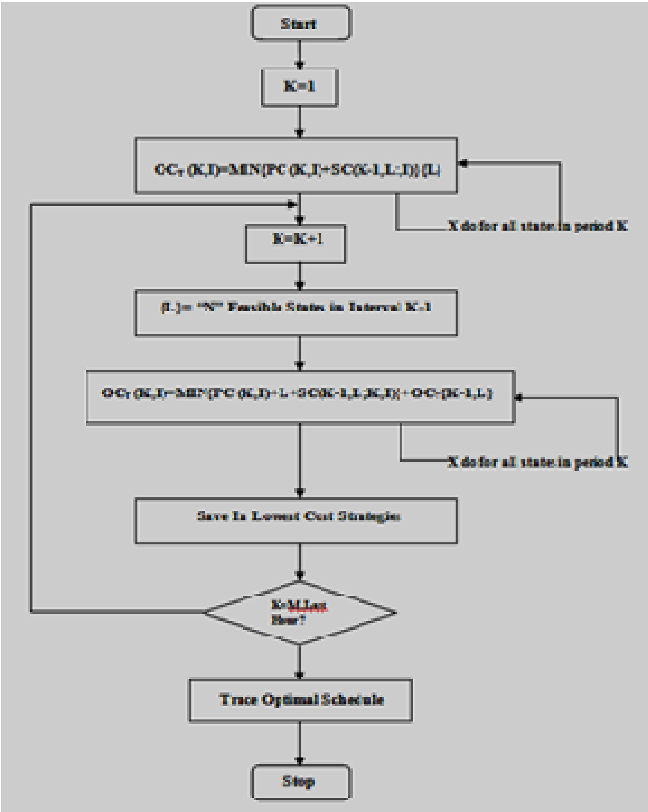

Fig-1: Flow Chart: Single Area Unit Commitment using DP

5. SINGLE AREA UCP USING QP- PSO

Particle Swarm Optimization (PSO) is swarm intelligence based optimization technique which is implemented to find near-optimal solution to various multi- constrained complex problems. PSO is inspired by a group of birds or social insects. PSO considers each particle of swarm as a point in the N-dimensional space moving around in the search space to find the best solution. If one individual in a swarm finds an appropriate path to reach food, the other members also follow its path wherein each individual has its own position and velocity. While moving around the search space, the particles record their best positions. Particles of a swarm communicate with each other to change their velocities and positions to send desirable positions. PSO is an artificial stochastic optimization approach which necessarily searches in a population to find the best solution to any optimization problem having principal advantage of simplicity to execute, lesser parameters to regulate and a performance comparable to Genetic Algorithm.

PSO, one of the fast converging optimization techniques, is useful to solve the problems which become otherwise tedious while solving them using the conventional optimization methods. PSO offers a population based search process wherein each particle is assumed to be moving around in the search space. Particles flying in the multidimensional space adjust their position based on both its own experience and that of their

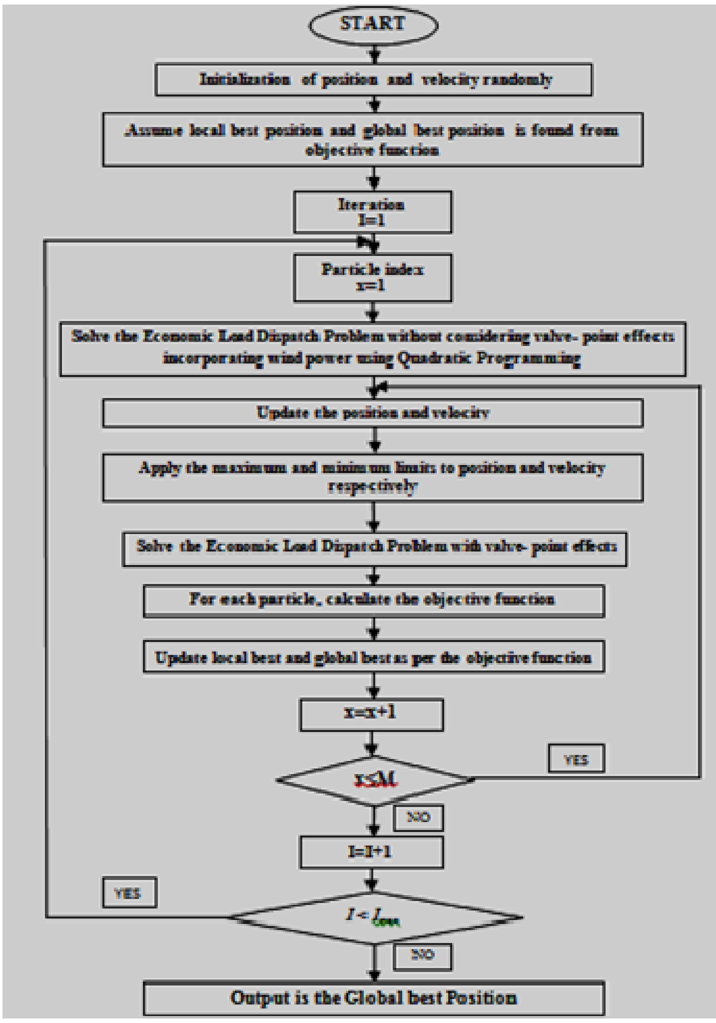

Fig-2: Flow Chart: Single Area Unit Commitment using Proposed QP- PSO

neighbouring companions [12]. Thus PSO constitutes a combination of local and global search to balance the space searching and utilization.

When the searching point is near to the optimal solution or the search gets to the local search area, the convergence rate of PSO becomes slow. Another drawback of the PSO algorithm is that it can converge prematurely. The origin of this drawback lies in the fact that particles of a particular swarm only communicate with each other and get their information from the local and global best positions and this would lead to lack of variety of the swarm population which becomes a significant factor for the premature convergence of particles to local best solutions. Under such conditions the Hybrid PSO comes into view which is required to overcome such drawbacks in the original PSO algorithm and its other variants.

6. TEST SYSTEM, RESULTS AND DISCUSSION

Test System: The standard IEEE 14-Bus System with 5-generating units and standard IEEE 10- Unit System and their Corresponding load demands of 24-hours as shown in Figure-3 and Figure-4 has been taken into consideration to obtain the corresponding results. The generating characteristics of IEEE-14 Bus system are shown in Table-I and the generating characteristics of IEEE-10 Unit system are shown in Table-IV. The Dynamic Programming algorithm is applied to obtain the corresponding units ON/OFF Status of the generating units for 24- hour period for IEEE 14-bus System and IEEE 10-Unit System and the corresponding results are shown in Table-II and Table-V respectively. The flow chart for dynamic programming is shown in Figure-1. Also, the Hybrid Quadratic Programming-PSO (QP-PSO) is applied to obtain the corresponding units ON/OFF Status of the generating units for 24- hour period for IEEE 14-bus System and IEEE 10-Unit System and the corresponding results are shown in Table-III and Table-VI respectively.. The flow chart for QP-PSO is shown in Figure-2. The MATLAB Simulation software 7.12.0 (R2011a) is used to obtain the corresponding results.

TABLE-I: IEEE 14-Bus Test System characteristics [4]

	P_{max}	P_{min}	c	b	a	MU_i	MD_i	H_{cost}	C_{cost}	C_{hour}	IniState
Unit1	250	10	0.00315	2	0	1	1	70	176	2	1
Unit2	140	20	0.0175	1.75	0	2	1	74	187	2	-3
Unit3	100	15	0.0625	1	0	1	1	50	113	1	-2
Unit4	120	10	0.00834	3.25	0	2	2	110	267	1	-3
Unit5	45	10	0.025	3	0	1	1	72	180	1	-2

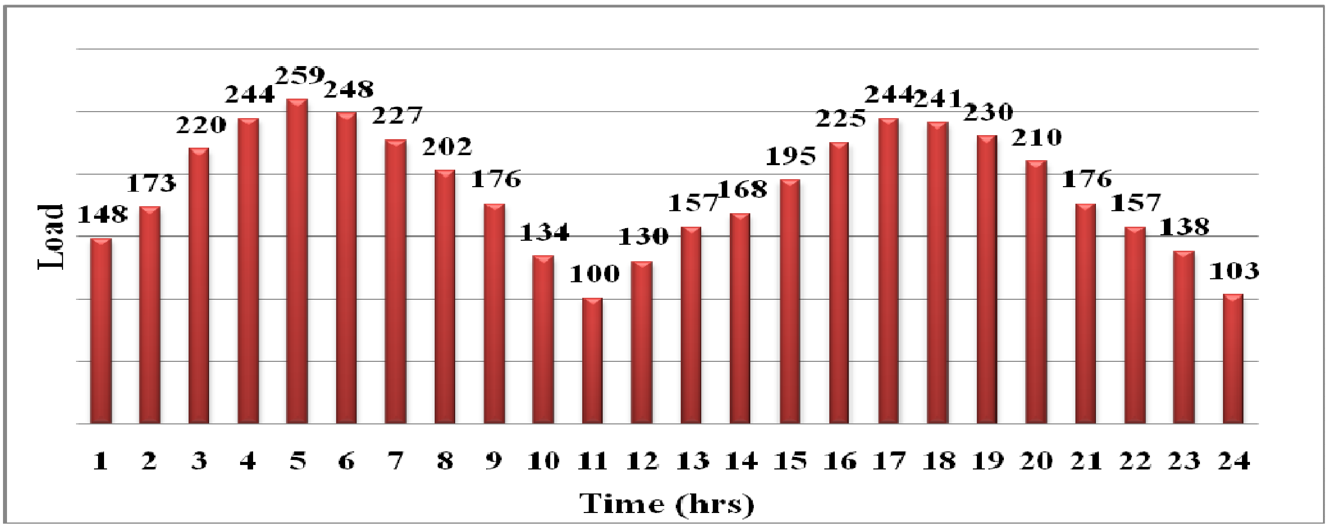

Fig-3: Load Demand pattern for 24-hours for 14-Bus System

Table-II: Unit Commitment Schedule of IEEE 14-Bus System for 24-hours Using Dynamic Programming

Hour	Demand	Min MW	Max MW	Start- Up Cost	Fuel Cost	Generating Units ON/ OFF Status				
						U1	U2	U3	U4	U5
0	-	10	250	0	0	1	0	0	0	0
1	148	45	490	300	487	1	1	1	0	0
2	173	45	490	0	717	1	1	1	0	0
3	220	45	490	0	1029	1	1	1	0	0
4	244	45	490	0	1384	1	1	1	0	0
5	259	55	535	180	1957	1	1	1	0	1
6	248	55	535	0	2332	1	1	1	0	1
7	227	45	490	0	2656	1	1	1	0	0
8	202	45	490	0	2937	1	1	1	0	0
9	176	45	490	0	3173	1	1	1	0	0
10	134	45	490	0	3335	1	1	1	0	0
11	100	45	490	0	3460	1	1	1	0	0
12	130	45	490	0	3615	1	1	1	0	0
13	157	45	490	0	3818	1	1	1	0	0
14	168	45	490	0	4039	1	1	1	0	0
15	195	45	490	0	4308	1	1	1	0	0
16	225	45	490	0	4629	1	1	1	0	0
17	244	45	490	0	4984	1	1	1	0	0
18	241	45	490	0	5333	1	1	1	0	0
19	230	45	490	0	5663	1	1	1	0	0
20	210	45	490	0	5958	1	1	1	0	0
21	176	45	490	0	6194	1	1	1	0	0
22	157	45	490	0	6396	1	1	1	0	0
23	138	45	490	0	6565	1	1	1	0	0
24	103	25	350	0	6679	1	0	1	0	0

Table-III: Unit Commitment Schedule of IEEE 14-Bus System for 24-hours using QP- PSO

Time (hrs)	1	2	3	4	5	6	7	8	9	10	11	12
G1	148	173	220	144	159	148	227	202	176	134	100	130
G2	0	0	0	0	0	0	0	0	0	0	0	0
G3	0	0	0	100	100	100	0	0	0	0	0	0
G4	0	0	0	0	0	0	0	0	0	0	0	0
G5	0	0	0	0	0	0	0	0	0	0	0	0
Time (hrs)	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
G1	157	168	195	225	234	121	220	210	176	157	0	0
G2	0	0	0	0	0	0	0	0	0	0	38	103
G3	0	0	0	0	0	0	0	0	0	0	100	0
G4	0	0	0	0	0	120	10	0	0	0	0	0
G5	0	0	0	0	10	0	0	0	0	0	0	0

TOTAL COST=12886

Table-IV: IEEE 10-UNIT TEST SYSTEM CHARACTERISTICS [4]

	P_{max}	P_{min}	A	B	C	MU_i	MD_i	H_{cost}	C_{cost}	C_{hour}	IniState
Unit1	455	150	0.00048	16.19	1000	8	8	4500	9000	5	8
Unit2	455	150	0.00031	17.26	970	8	8	5000	10000	5	8
Unit3	130	20	0.002	16.6	700	5	5	550	1100	4	-5
Unit4	130	20	0.00211	16.5	680	5	5	560	1120	4	-5
Unit5	162	25	0.00398	19.7	450	6	6	900	1800	4	-6
Unit6	80	20	0.00712	22.26	370	3	3	170	340	2	-3
Unit7	85	25	0.00079	27.74	480	3	3	260	520	2	-3
Unit8	55	10	0.00413	25.92	660	1	1	30	60	0	-1
Unit9	55	10	0.00222	27.27	665	1	1	30	60	0	-1
Unit10	55	10	0.00173	27.79	670	1	1	30	60	0	-1

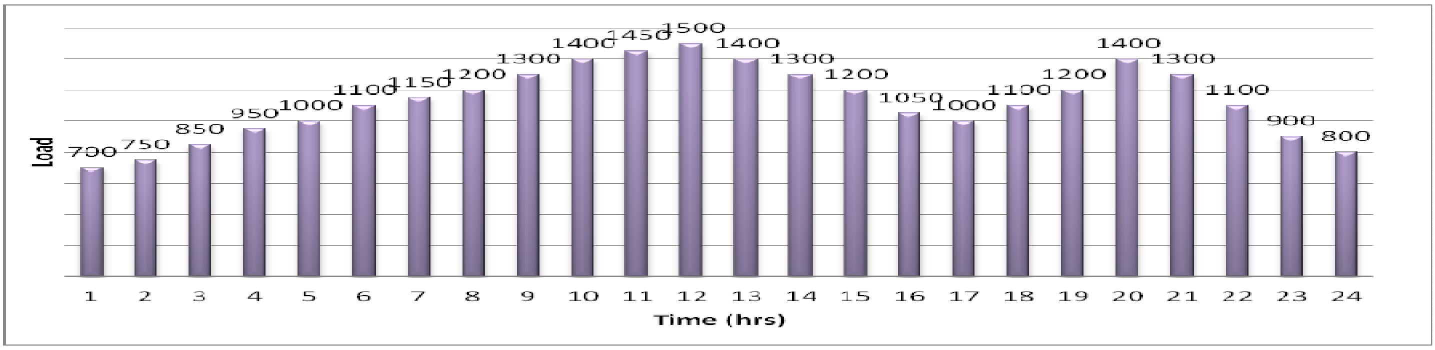

Figure-4: Load Demand pattern for 24-hours for 10-Unit System

Table-V: Unit Commitment Schedule of IEEE 10- Unit System for 24-hours Using Dynamic Programming

Hour	Demand	Min MW	Max MW	Start- Up Cost	Fuel Cost	Generating Units ON/ OFF Status									
						U1	U2	U3	U4	U5	U6	U7	U8	U9	U10
0	-	300	910	0	0	1	1	0	0	0	0	0	0	0	0
1	700	300	910	0	13683	1	1	0	0	0	0	0	0	0	0
2	750	300	910	0	28238	1	1	0	0	0	0	0	0	0	0
3	850	300	910	0	44540	1	1	0	0	0	0	0	0	0	0
4	950	325	1072	900	64037	1	1	0	0	1	0	0	0	0	0
5	1000	325	1072	0	83646	1	1	0	0	1	0	0	0	0	0
6	1100	345	1202	560	106066	1	1	0	1	1	0	0	0	0	0
7	1150	365	1332	550	129878	1	1	1	1	1	0	0	0	0	0
8	1200	365	1332	0	154028	1	1	1	1	1	0	0	0	0	0
9	1300	385	1412	170	180787	1	1	1	1	1	1	0	0	0	0
10	1400	410	1497	260	210413	1	1	1	1	1	1	1	0	0	0
11	1450	420	1552	30	241663	1	1	1	1	1	1	1	1	0	0
12	1500	430	1607	30	274898	1	1	1	1	1	1	1	1	1	0
13	1400	410	1497	0	304264	1	1	1	1	1	1	1	0	0	0
14	1300	385	1412	0	330853	1	1	1	1	1	1	0	0	0	0
15	1200	365	1332	0	355003	1	1	1	1	1	0	0	0	0	0
16	1050	345	1202	0	375899	1	1	0	1	1	0	0	0	0	0
17	1000	345	1202	0	395919	1	1	0	1	1	0	0	0	0	0
18	1100	345	1202	0	417780	1	1	0	1	1	0	0	0	0	0
19	1200	365	1332	550	442480	1	1	1	1	1	0	0	0	0	0
20	1400	410	1497	430	472276	1	1	1	1	1	1	1	0	0	0
21	1300	385	1412	0	498865	1	1	1	1	1	1	0	0	0	0
22	1100	345	1202	0	520725	1	1	0	1	1	0	0	0	0	0
23	900	325	1072	0	538410	1	1	0	0	1	0	0	0	0	0
24	800	300	910	0	553837	1	1	0	0	0	0	0	0	0	0

Table-VI: Unit Commitment Schedule of IEEE 10- Unit System for 24-hours Using QP- PSO

Time (hrs)	1	2	3	4	5	6	7	8	9	10	11	12
G1	455	455	455	455	455	455	455	455	455	455	455	455
G2	245	295	370	455	390	360	410	455	455	455	455	455
G3	0	0	0	0	130	130	130	130	130	130	130	130
G4	0	0	0	0	0	130	130	130	130	130	130	130
G5	0	0	25	40	25	25	25	30	85	162	162	162
G6	0	0	0	0	0	0	0	0	20	33	73	80
G7	0	0	0	0	0	0	0	0	25	25	25	25
G8	0	0	0	0	0	0	0	0	0	0	10	43
G9	0	0	0	0	0	0	0	0	0	10	10	10
G10	0	0	0	0	0	0	0	0	0	0	0	10
Time (hrs)	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
G1	455	455	455	455	455	455	455	455	455	455	455	455
G2	455	455	455	440	390	455	455	455	455	455	315	215
G3	130	130	130	130	130	130	130	130	130	0	0	0
G4	130	130	0	0	0	0	0	130	130	130	130	130
G5	162	85	115	25	25	50	130	162	85	35	0	0
G6	33	20	20	0	0	0	20	33	20	0	0	0
G7	25	25	25	0	0	0	0	25	25	25	0	0
G8	10	0	0	0	0	0	10	10	0	0	0	0
G9	0	0	0	0	0	0	0	0	0	0	0	0
G10	0	0	0	0	0	10	0	0	0	0	0	0

TOTAL COST= 566960

7. CONCLUSION

In this paper, the solutions of IEEE 14-Bus System and IEEE 10- Unit System single area unit commitment problem for 24-hours load using Dynamic programming method and hybrid of Quadratic Programming and Particle Swarm Optimization technique have been presented. The results have been effectively evaluated using MATLAB 7.12.0(R2011a) software.

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