International Journal of Enhanced Research in Science, Technology & Engineering
ISSN: 2319-7463, Vol. 5 Issue 4, April-2016

Experimental Analysis of Unit Commitment Problem by using a Hybrid Computing Technique

Gaurav Rohilla[1], Rajesh Dudi[2]

[1]M. Tech. Student (EE), Manav Institute of Technology and Management, Jevra, Hisar, India
[1]Head of Department (EE), Manav Institute of Technology and Management, Jevra, Hisar, India

ABSTRACT

An approach for solving unit commitment based on the modern soft computing techniques has been proposed. These soft computing techniques which might be quite helpful in the power system optimization include Quasi-Newton method, genetic algorithms, artificial neural networks/expert systems, fuzzy logic approach, tabu search method and any hybrid algorithm. It is demonstrated that these modern techniques are quite helpful in savings of units significantly in terms of memory used, calculation speed and lesser cost in comparison of other conventional methods like priority listing, stimulated annealing and exhaustive enumeration. The author has proposed a hybrid algorithm of Quasi-Newton method, Sequential Quadratic Programming and Line-Search method which has been compared with one of the conventional method i.e. Priority Listing method.

Keywords: unit commitment, soft computing, priority listing, quasi-newton method.

1. INTRODUCTION

In the modernistic age of the power system operation, one of the most stimulating interests is to decide which electrical generating units should run in each period so as to satisfy a varying demand for electricity. The problem is interesting because in a typical electrical system there are a variety of units available for generating electricity, and each unit has its own characteristics. Such type of decisions and actions are made under the section Unit Commitment.

Unit Commitment problem (UCP) brings up the task of finding an optimal schedule, and production level, for each generating unit over a given period of time. The unit commitment decision indicates which generating units are to be in use at each point in time over a scheduling horizon. An important criterion in power system operation is to meet the load demand at least possible fuel cost using mingle of different power plants. For such kind of problems, the load requirements, reserve requirements and the constraints of the generating units must be taken into considerations. Solving such type of problem may be computationally expensive in large electrical power systems.

Furthermore, in order to supply high quality electric power to customers in a fastened and economical manner, thermal unit commitment is considered to be one of the best available options. The planning of the committed generating units generally for a time period of 1 or 2 days to 2 weeks split down in a periods of 1 hour. The committed units should satisfy the forecasted system load and reserve requirements, at minimal operating cost, subject to a large set of other system, technological and environmental constraints. Also, the available and committed generating units should be able to supply the peak demands as well as the seasonal demands. At one extreme, a nuclear power unit can provide electricity at a very low incremental cost for each additional megawatt hour of energy, but it has both a high cost of starting up again once it has been shut down and it takes awhile to bring it back up to full power.

A typical nuclear unit may be shut down only in the Spring or Autumn, when there is very little heating or air-conditioning demand, so demand is lowest. At the other extreme, a gas turbine generator can be started up in a few minutes. However, its incremental cost per megawatt hour is much more expensive [5]. Similarly, the limited amount of hydro-electric energy stored in the dams and the system reservoirs may not prove to be sufficient to respond to high demands. Therefore, costly thermal generating-units are often used to make up for the supply shortage. Since generators cannot instantly turn on and produce power, unit commitment must be planned in advance so that enough generation is always available to handle system demand with an adequate reserve margin in the event that generators or transmission lines go out or load demand increases. The start up and shut down processes are considered in the post-processing step performed after the UC calculation. In case of the worse load forecast, the deviation of the conventional UC solution can be overcome with the lower load level and the more hourly reserve requirements. Several conventional methods are available to solve the UCP. But all these methods need the exact mathematical model of the system and there may be a chance of bog down at the local optimum.

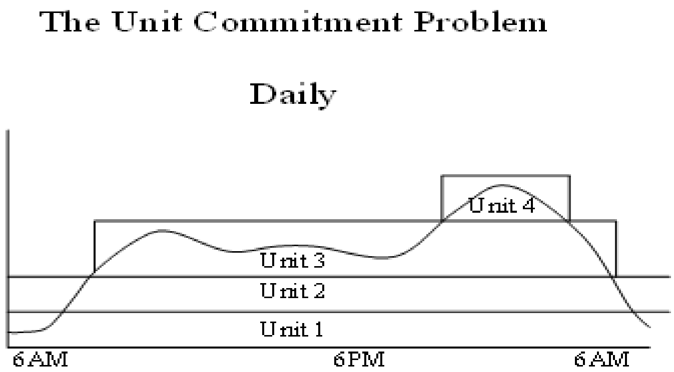

Fig.1: The example of daily unit commitment schedule [6].

In Power Systems, the investment is quite expensive, and the resources in running them are substantially becoming sparse of which the focus turns to optimizing the running cost of the power systems. In today's world, it becomes an extreme necessity to meet the demand as well as optimize the generation. In the UC problem, the decisions are the selection of the time for each unit to be on and/or offline (binary variables) as well as the unit's economic generation level (continuous variables). Unit commitment problem is a non-linear, large scale, mixed integer constrained optimization problem.

2. LITERATURE REVIEW

Unit commitment is a mixed-integer nonlinear optimization problem. It involves determining the economical operation schedule subject to all constraints. However, this problem has integer and continuous variables and moreover has many constraints. It is difficult to determine the economical operation schedule for that reason. The exact optimal solution can be obtained by complete enumeration which cannot be applied to realistic power systems due to its computational burdens. Adequate operating reserve is required in an electric power system to maintain a desired level of reliability through a given period of time. The traditional unit commitment is one of difficult scheduling problems for minimizing operation cost of units while satisfying the constraints on generators and system characteristics. However, in recent years, power systems become deregulated and competitive so that the power system operation requires the problem reformulation that reflects the changes under new environment. So attempts are being continuously made to solve this problem by reliable iterative and heuristic methods.

One of the algorithm proposed in [10], known as DP-SC, uses a strict priority list search sequence to reduce the possible combinations at every stage. Another method by the same authors employs a fixed search window to truncate the priority list, in which only the truncated combinations are evaluated. This method, known as DP-TC, performs much better than DP-SC as an optimizer; however it requires a much longer processing time.

S. Jalilzadeh and Y. Pirhayati presented (2009) an Improved Genetic Algorithm (IGA) for UCP with lowest cost. A modified approach to the solution of unit commitment problem using genetic algorithms is proposed in this paper. Improvement in cost and quality of solution is obtained [3].

In order to obtain a near optimal solution in low computational time and storage requirements, with respect to all specified constraints, Alma Ademovic et al.(2010) presented a Genetic Algorithm using real-coded chromosomes in opposite to the more commonly used binary coded scheme[1].

D. Simopoulos and G. Contaxis (2004) proposed some new rules concerning the cooling schedule and the random generation of the initial solution of the system. The results obtained in system studies show the effectiveness of the proposed model and indicate the need for further work in this area [4].

C. Christober and Asir Rajan (2004) presented a new approach to solve the short term unit commitment problem using an Evolutionary Programming Based Simulated Annealing Method with cooling and banking constraints. The objective of this paper was to find the generation scheduling such that the total operating cost can be minimized, when subjected to a variety of constraints [7].

P. Sriyanyong, and Y. H. Song (2005), proposed Particle Swarm Optimization (PSO) combined with Lagrange Relaxation method (LR) for solving UCP. The proposed approach employs PSO algorithm for optimal settings of

Lagrangian multipliers. The feasibility of the proposed method is demonstrated for four and ten unit systems, respectively [5].

In Feb. 1988, an expert system was developed based consultant to assist power system operators in scheduling the operation of generating units. In 1990, a unit commitment expert system consists of a commitment schedule database, a dynamic load pattern matching process, and an interface optimization process [6].

In Aug. 1991, an algorithm for unit commitment, uses priority list based heuristics in the form of interface rules to find a sub-optimal schedule for a given load pattern. An expert system has been developed in 1991, by M. S. Salam et al. and used as preprocessor as well as postprocessor to the truncated dynamic programming based unit commitment program to obtain an operationally feasible solution [7].

Ouyang et al. [4] studied a hybrid artificial neural network-dynamic programming approach to unit commitment. The proposed algorithm uses an artificial neural network to generate a pre-schedule according to the input load profile in the first step. Then a dynamic search is performed at those stages where the commitment states of some of the units are not certain.

The neural networks are used at the pre-processor and post-processor stages and the operating constraints are presented as heuristic rules in the system where feasible solution is obtained through inference. A new approach using genetic algorithms based neural networks and dynamic programming has been proposed by S. J. Huang [5].

A different approach was employed in determining SR. They formulate the UC problem in a different fashion and minimize the SR instead of the operating cost with respect to the usual UC constraints and a reliability constraint, which ensures that the system meets the required reliability level [9].

Caroe and Schultz [8] have a similar critique of the Birge and Takriti approach. The authors take advantage of two-stage stochastic programming and combine LR with branch and bound to solve the UC problem. In Caroe and Schultz's paper two-stage stochastic programming works in the following manner. They define the amount of power that will be generated by thermal generators in all time periods as first-stage variables and the amount of power that will be obtained using gas turbines, which take less time to turn on and off, as the second-stage variables. These results are used in committing generators.

A method provides an algorithm that calculates multivariate normal tail probabilities with up to 500 dimensions with a small error margin. In his paper, Genz uses three transformations so that the transformed form can be evaluated using a subregion adaptive numerical integration algorithm which is a variation of locally adaptive numerical integration. The first transformation performed is a Cholesky decomposition transformation. Cholesky decomposition is the transformation of a symmetric matrix to a product of a lower triangular matrix and its transpose [6].

3. METHODOLOGIES TO SOLVE UNIT COMMITMENT PROBLEM

Various methodologies used to solve the unit commitment problems are summarized and discussed as follows.

Unit Commitment Methodologies

Since unit commitment (UC) is a large, non-linear, non-convex, and mixed integer problem, the attempt to receive the optimal schedule of committing generating units is challenging. Various methods have been developed to solve the UC problem with the same intention of minimizing the cost in the reasonable computational time. Several conventional UC methodologies are summarized in the following sections.

PRIORITY LISTING

This unit commitment solution is to list all combinations of units on and off, as well as the corresponding total cost to create a rank list, and then make the decision according to the rank table. This method is called the priority list. The generation of initial solution is important, particularly, for the UC problem. The initial solution is usually generated at random. However this technique is difficult to get a feasible solution for the UC problem with many constraints, resulting in the quality of solution obtained being unsatisfactory. The priority list method is an efficient method to overcome this problem. This method is simple and requires short computing time and small computer memory. However, the UC solution obtained from the priority list method may not be the optimal schedule because start-up cost and ramp rate constraints are not included in determining the priority commitment order and AFLC does not adequately reflect the operating cost of generating units when they do not operate at the full load [6].

QUASI-NEWTON METHOD

Quasi-Newton algorithms are arguably the most popular class of nonlinear numerical optimization methods, used widely in numerical applications not just in machine learning. In optimization, quasi-Newton methods (a special case of variable metric methods) are algorithms for finding local maxima and minima of functions. Quasi-Newton methods are based on Newton's method to find the stationary point of a function, where the gradient is 0. Newton's method assumes that the function can be locally approximated as a quadratic in the region around the optimum, and uses the first and second derivatives to find the stationary point. In higher dimensions, Newton's method uses the gradient and Hessian matrix of second derivatives of the function to be minimized.

In quasi-Newton methods the Hessian matrix does not need to be computed. The Hessian is updated by analyzing successive gradient vectors instead. Quasi-Newton methods are a generalization of the secant method to find the root of the first derivative for multidimensional problems. In multi-dimensions the secant equation is under-determined, and quasi-Newton methods differ in how they constrain the solution, typically by adding a simple low-rank update to the current estimate of the Hessian.

The first quasi-Newton algorithm was proposed by W.C. Davidon, a physicist working at Argonne National Laboratory. He developed the first quasi-Newton algorithm in 1959: the DFP updating formula, which was later popularized by Fletcher and Powell in 1963, but is rarely used today. The most common quasi-Newton algorithms are currently the SR1 formula (for symmetric rank one), the BHHH method, the widespread BFGS method (suggested independently by Broyden, Fletcher, Goldfarb, and Shanno, in 1970), and its low-memory extension, L-BFGS. The Broyden's class is a linear combination of the DFP and BFGS methods [6].

SEQUENTIAL QUADRATIC PROGRAMMING (SQP)

Sequential quadratic programming (SQP) is an iterative method for nonlinear optimization. SQP methods are used on problems for which the objective function and the constraints are twice continuously differentiable.

SQP methods solve a sequence of optimization subproblems, each of which optimizes a quadratic model of the objective subject to a linearization of the constraints. If the problem is unconstrained, then the method reduces to Newton's method for finding a point where the gradient of the objective vanishes. If the problem has only equality constraints, then the method is equivalent to applying Newton's method to the first-order optimality conditions, or Karush–Kuhn–Tucker conditions, of the problem. SQP methods have been implemented in many packages, including NPSOL, NLPQL, OPSYC, OPTIMA, MATLAB, and SQP.

In its purest form, the sequential QP algorithm replaces the objective function with the quadratic approximation and replaces the constraint functions by linear approximations.

Since its popularization in the late 1970’s Sequential Quadratic Programming SQP has arguably become the most successful method for solving nonlinearly constrained optimization problems. As with most optimization methods, SQP is not a single algorithm but rather a conceptual method from which numerous special algorithms have evolved. Backed by a solid theoretical and computational foundation both commercial and public domain SQP algorithms have been developed and used to solve a remarkably large set of important practical problems. Recently large scale versions have been devised and tested with promising results [4].

LINE SEARCH METHOD

Line-search methods constitute a class of methods for solving unconstrained optimization problems. In optimization, the line search strategy is one of two basic iterative approaches to find a local minimum of an objective function. The other approach is trust region. The line search approach first finds a descent direction along which the objective function f will be reduced and then computes a step size that determines how far should move along that direction. The descent direction can be computed by various methods, such as gradient descent, Newton's method and Quasi-Newton method. The step size can be determined either exactly or inexactly.

Line search techniques are in essence optimization algorithms for one-dimensional minimization problems. They are often regarded as the backbones of nonlinear optimization algorithms. Typically, these techniques search a bracketed interval [8].

In this case, a simple three-generator, four-hour unit commitment schedule determined by the priority listing method is compared to that determined by the proposed hybrid algorithm of Quasi-Newton method, Sequential Quadratic Programming and Line-search method. The system unit data and the load demands are shown in Table I and II.

4. RESULTS AND DISCUSSIONS

This chapter is primarily concerned with more general aspects of the work and review described in the dissertation. The detailed aspects of the material contained in the thesis have been discussed in the respective chapters. The work proposed here is mainly software oriented and the main motivation has been to develop Unit Commitment optimal schedule using one of the traditional method and one of the hybrid algorithm of Quasi-Newton Method, Sequential Quadratic Programming and Line Search Method.

The proposed hybrid algorithm is one of the potential solution methodologies for UC problem, as it is fast in exploring the global minimum regions and also takes smaller time to converge the local minimum solution. The performance of the given 3-unit system has been improved by the proposed algorithms in terms of the computational time. It is quite significant in terms of the large scale systems and higher load demands.

In this case, a simple three-generator, four-hour unit commitment schedule determined by the priority listing method is compared to that determined by the proposed hybrid algorithm of Quasi-Newton method, Sequential Quadratic Programming and Line-search method. The system unit data and the load demands are shown in Table I and II.

The performance of the Priority list method is given in Table III. The CPU times of Priority Listing method goes on increasing as the load demand increases. It takes a lot of time for the high load demands. The performance of the proposed Hybrid algorithm is given in Table IV. The CPU times of this method is very low near about 1 second in case of larger load demands also.

From this result, it is shown that the performance by hybrid algorithm is better than that of priority listing method in terms of computational time.

From the given data in the reference manuscript [2], the objective function can be generally defined as:

$$\mathbf{Fi(P_{Gi}) = A_i.P_{Gi}^2 + B_i.P_{Gi} + C_i \quad , \qquad i = 1, 2, 3\ldots\ldots n} \qquad \textbf{(i)}$$

where,
$\mathbf{Fi(P_{Gi})}$ is production cost of unit i at a time t (Rs/hr),
$\mathbf{A_i}$, $\mathbf{B_i}$ and $\mathbf{C_i}$ are cost coefficients of unit i (Rs/MWh),
$\mathbf{P_{Gi}}$ is its power output during hour t (MW).

Similarly, the objective function for the given 3 units can be formulated respectively as;

$$\mathbf{F_1(P_{G1}) = 500.P_{G1}^2 + 10.P_{G1} + 0.0020} \qquad \textbf{(ii)}$$

$$\mathbf{F_2(P_{G2}) = 300.P_{G2}^2 + 8.P_{G2} + 0.0025} \qquad \textbf{(iii)}$$

$$\mathbf{F_3(P_{G3}) = 100.P_{G3}^2 + 6.P_{G3} + 0.0050} \qquad \textbf{(iv)}$$

The constraint function can be defined as:

$$\mathbf{P_G = P_D} \qquad \textbf{(v)}$$

where,
P_G = Power generated
P_D = Power demand

While performing the function, the constraint must be satisfied. Hence, it can be defined as:

$$\mathbf{c = P_D - P_{G1} - P_{G2} - P_{G3}} \qquad \textbf{(vi)}$$

The output shown in the command window by the hybrid algorithm:

Output:
iterations: 3
funcCount: 12
lssteplength: 1
stepsize: 2.8422e-014
algorithm: 'medium-scale: SQP, Quasi-Newton, line-search'
firstorderopt: 1.7053e-008
constrviolation: 2.8422e-014
message: [1x788 char]

The given tables show the unit data for 3 unit system and its load demand for consecutive 4 hours. The Table I shows the various parameters of the 3 units and the Table II shows the 4 hour load demand.

Table I: Unit data for 3-unit system [21]

Unit	P_{max}	P_{min}	a	b	c
1	600	100	500	10	0.0020
2	400	100	300	8	0.0025
3	200	50	100	6	0.0050

Table II: Load Demand for 4 hours [21]

Time (hr)	P_{load} (MW)
1	250
2	520
3	1100
4	330

Here, the Table III demonstrates the optimal load sharing obtained by the shut down algorithm of Priority Listing when executed in MATLAB. U1, U2, U3 are the three generating units which are scheduled for 4 hours respective to the load demand.

Table III: Optimal Load Scheduling by Priority Listing Method

Hour	U1	U2	U3	Load Demand (MW)	Comput. Time (sec)	Hourly Cost (Rs)
1	33	54	163	250	420	4.077×10^6
2	120	201	199	520	3120	2.32×10^7
3	502	399	199	1100	5220	1.77×10^8
4	49	82	199	330	1320	7.18×10^6

The same unit data when executed with the application of the proposed hybrid algorithm gives an alternate to the load sharing phenomenon. As it is clear from the given tables, the hourly cost for the generating units is large at low loads but decreases with the increase in the load demand. However, the computational time taken by this technique is significantly low than those required by the above discussed method i.e. Priority Listing.

Table IV: Optimal Load Scheduling by Proposed Hybrid Algorithm

Hour	U1	U2	U3	Load Demand (MW)	Comput. Time (sec)	Hourly Cost (Rs)
1	100	100	50	250	0.5	8.25×10^6
2	119.9	200.1	200	520	1	2.32×10^7
3	500	400	200	1100	1.6	1.77×10^8
4	100	100	130	330	0.8	9.69×10^6

The following graph (Fig. 2) demonstrates the given hourly load demand of the 3-unit system.

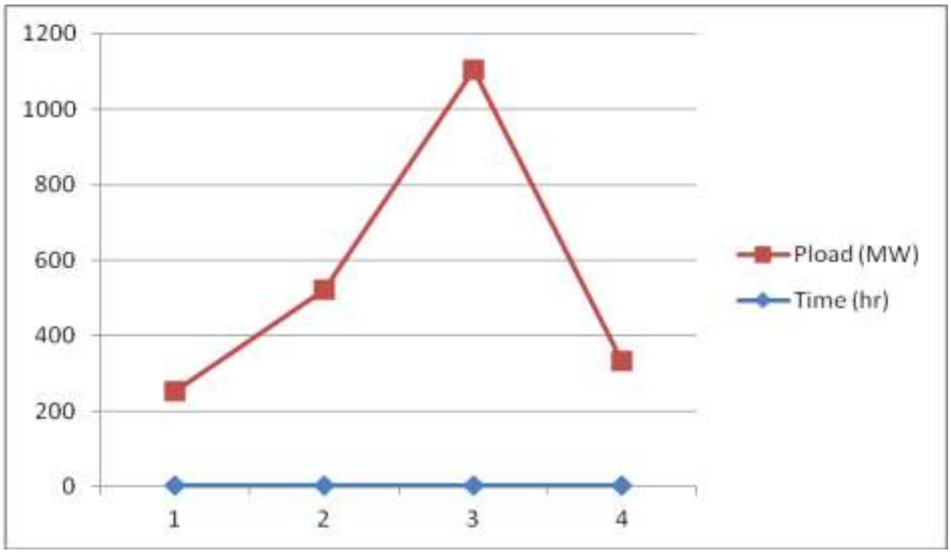

Fig. 2: Graph representing the 4-hour load schedule of the 3-unit system

Fig. 3 demonstrates the hourly cost of the units after evaluating the optimal load schedule for 4 hours by Priority Listing method.

Fig. 3: Graph representing hourly cost in ($\times 10^6$ Rs) for 4 hours demand by Priority Listing

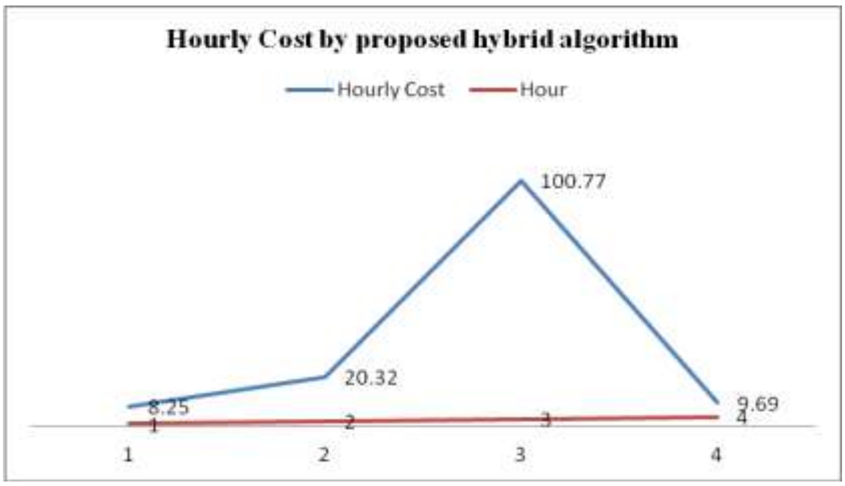

Fig.4: Graph representing hourly cost in ($\times 10^6$ Rs) for 4 hrs demand by proposed hybrid algorithm

The above graph (Fig. 4) demonstrates the hourly cost of the units after evaluating the optimal load schedule for 4 hours by the proposed hybrid algorithm.

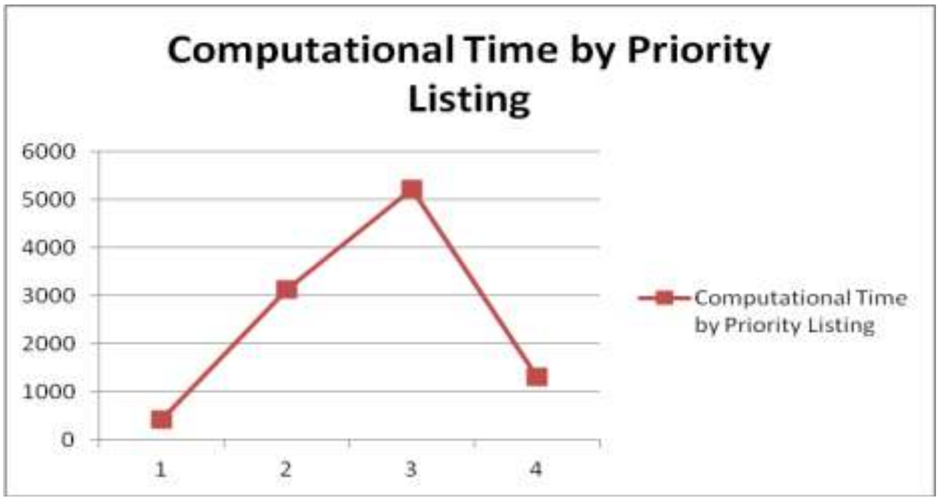

Fig. 5: Graph representing the computational time taken by Priority Listing

The above graph represents the computational time taken to evaluate the optimal load schedule per hour by the Priority listing method.

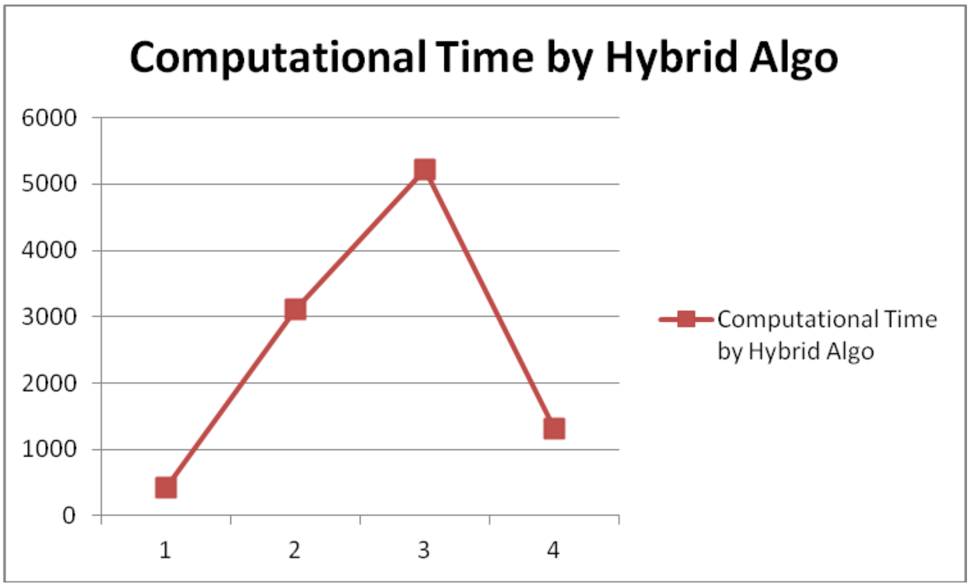

Fig. 6: Graph representing the computational time taken by Hybrid Algorithm

Figure 6 represents the computational time taken to evaluate the optimal load schedule per hour by the hybrid algorithm of Quasi-Newton method, Sequential Quadratic Programming and Line-Search method.

From the above graphs, it can be easily estimated that the computational time taken to taken to evaluate the optimal load schedule per hour by Priority Listing method is very large in compare to that taken by the hybrid algorithm of Quasi-Newton method, Sequential Quadratic Programming and Line-Search method which takes very less time to compute the optimal load sharing among the generating units.

However, in concept of hourly operating cost, it is less in case of Priority Listing method only at low loads. But as there is an increment in the hourly load demand, the hourly cost also starts increasing to the higher values which is opposite in case of the Hybrid Algorithm method. The hourly cost in case of hybrid algorithm is higher than priority listing method at lower loads but same or less at higher loads which have also an additional advantage of less computational time to evaluate the optimal load sharing of the generating units.

CONCLUSION

The proposed work concludes that the hybrid algorithm involving Sequential Quadratic Programming, Quasi-Newton Method and Line-search method is quite tremendous in computing the optimal load schedule of the generating units and found to be quite significant for higher load demands in compare with the other conventional method like Priority Listing. The hourly cost of operation of the generating units may however differ or some expensive at low loads but the overall cost at some significant load levels will be always minimum and satisfactory to the generating plants. This hybrid algorithm will be most effective at the regions of higher load demands and where the computational time requirement is low. This method could be feasible and fast if implemented or adopted by the generating power plants or the power generation companies. The computational time of evaluation the optimal load demands is very low which will be very helpful in further improving the overall efficiency of the power system in future.

REFERENCES

[1]. Calvin Jin San C., “Development of a Profit Maximisation Unit Commitment Program”, September 2000.

[2]. Carlos Murillo-Sánchez, Robert J., “Thomas, Thermal Unit Commitment Including Optimal AC Power Flow Constraints”, Proceedings of the Hawaii International Conference On System Sciences, January 6-9, 1997, Kona, Hawaii.

[3]. Chao-an Li, Raymond B. Johnson, Alva J. Svoboda, “A New Unit Commitment Method”, Vol. 12, No. 1, February 1997.

[4]. Chitra Y., “Multi-Area Unit Commitment and Economic Dispatch with Market Operation Components”, Arlington, May 2006.

[5]. Christober C. and Asir R., “An Evolutionary Programming Based Simulated Annealing Method for Unit Commitment Problem with Cooling - Banking Constraints”, 2004.

[6]. Christober Asir R., Mohan M. R., Manivannan K., “Neural Based Tabu Search Method for Solving Unit Commitment Problem”, Power System Management and Control, 17-19 April 2002.

[7]. Christober C. Asir R., “Genetic Algorithm Based Simulated Annealing Method for Solving Unit Commitment Problem in Utility System”, IEEE, 2010, pp. 1-6.

[8]. Christober C. Asir R., Mohan M. R., K. Manivannan, “Improved Genetic Algorithm Solution to Unit Commitment Problem”, IEEE, 2002, pp. 255-260.

[9]. Alma A., Smajo B., Mensur H., “A Genetic Algorithm Solution to the Unit Commitment Problem Based on Real-Coded Chromosomes and Fuzzy Optimization”, 2010.

[10]. Ana V., Jorge Pinho de S., Manuel M., “Simulated Annealing for the unit commitment Problem”, IEEE Porto Power Tech Conference 10th -13th September, 2001.

[11]. Anders G. J., “Generation Planning Model with Reliability Constraints,” IEEE Transactions on Power Apparatus and Systems, Vol. PAS-100, No. 12, (December 1981), pp. 4901-4908.

[12]. Bavafa M., Monsef H. and Navidi N., “A New Hybrid Approach for Unit Commitment Using Lagrangian Relaxation Combined with Evolutionary and Quadratic Programming”, 2009.

[13]. Bhardwaj A., Kamboj V. K., Shukla V. K., Singh B., Khurana P., “Unit Commitment in Electrical Power System – A Literature Review”, IEEE International Conference on Power Engineering and Optimization Conference (PEOCO 2012), Malaysia, 2012.

[14]. Bhardwaj A., Kamboj V.K., Tung N.S., Shukla V.K., “The important impacts of unit commitment constraints in power system planning”, July 2012.

[15]. Billinton R. and N.A. Chowdhury, “Operating Reserve Assessment in Interconnected Generating Systems,” IEEE Transactions on Power Systems, Vol. 3, No. 4, pp. 1479-87, (November 1988).