The Nucleus **51**, No. 3 (2014) 335-343

www.thenucleuspak.org.pk

The Nucleus

ISSN 0029-5698 (Print)
ISSN 2306-6539 (Online)

A Review of Application of Genetic Algorithm in Solving Unit Commitment Problem

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(Received October 30,2013 and accepted in revised form August 25,2014)

Unit commitment (UC) is a non-linear, combinatorial, mixed integer constrained optimization problem. The aim of unit commitment problem (UCP) is obtained the most cost effective on/off schedule for generating units to meet the forecasted load demand and spinning reserve for a specified time horizon. UCP can be seen as a two combined optimization problem, the on/off scheduling problem of generating units and the real power allocation problem. A feasible UC schedule must satisfy various system and unit constraints. Various techniques have been developed to solve generator scheduling problem/ UCP. Natural Evolution based techniques are extensively applied to obtain global optimal solution. Genetic algorithm is one of the evolutionary method. This paper presents a comprehensive review on genetic algorithm based unit commitment problem solution. A survey of all of the research papers up to the year 2013 on this topic is given.

Keywords: Unit Commitment (UC), Optimization methods, Genetic algorithms (GA), Generation scheduling, Constraint satisfaction.

1. Introduction

Unit commitment problem (UCP) in the power system determine hourly on/off schedules for the generators with their power output over a specified time horizon. The objective of generator scheduling is to minimize the total operating cost of system while satisfying different system, environment and unit constraints. Mathematically it is a complex non-linear combinatorial optimization problem.

The exponential increase in search space with number of generating units and various system, environmental and unit constraint make the UCP a complex optimization problem. The optimal UCP schedule can be obtained by complete enumeration but this is not applicable to large system because it requires exhaustive computational time, so different techniques have been developed to solve this problem in reasonable amount of time.

These approaches which are used to solve the UCP can be classified into three groups: Deterministic approaches, Meta heuristic approaches and hybridized approaches. Deterministic approaches consist of dynamic programming (DP) [1] langrangian relaxation (LR) [2], mixed integer programming, priority list [3], branch and bound [4] etc.

Priority list method produces solution very fast but it convergences at sub optimal point. High dimensionality problem of dynamic programming makes it unsuitable for large systems. LR is a fast method but converges at local optima. Due to high computation time requirement, Branch and bound method fails to solve large system. In addition, deterministic approach are not proficient enough to handle minimum up time and minimum down time handling, so many intelligent techniques are being investigated to solve these problems.

To obtain a global optimal solution in reasonable computational time meta-heuristic techniques have been developed and most widely used for generator scheduling. Most widely used intelligent approaches include particle swarm optimization (PSO) [5], expert system (ES) [6], artificial bee algorithm [7], ant colony optimization (ACO) [8], gravitational search(GS) [9], genetic algorithm (GA), evolutionary programming (EP) [10], simulated annealing (SA) [11] and artificial neural networks [12]. These approaches produce near optimal solution for any type of system with an ease of handling all types of constraints. Recently meta-heuristic techniques are integrated with deterministic or other similar methods to solve the UCP more effectively. Various methods have been applied for UCP solution but none of them is considered as the best so far. Figure 1 shows complete list of techniques which have been developed to solve UCP.

Genetic algorithms are widely used to solve UCP because of its simplicity and function independency. Many operators have been developed to improve the performance of genetic algorithm. This paper discusses these improvements in detail.

2. Mathematical Formulation of UCP

The objective function of the UCP and various constraints associated with it are given below.

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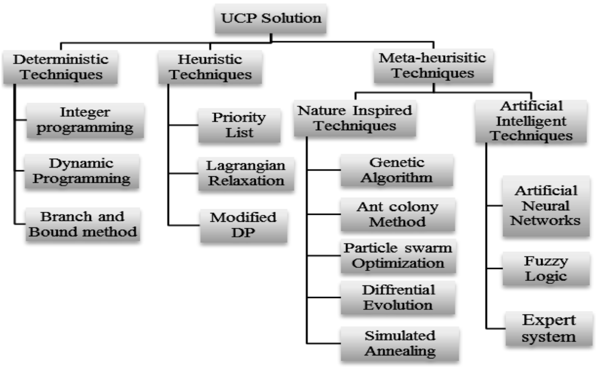

Figure 1. Categorized optimization techniques being used to solve UCP problem

2.1 Objective Function

The objective of the UCP is to minimize the total production cost and mathematically given as follow.

$$\text{Min TC} = \sum_{t=1}^{T}\sum_{i=1}^{N} u_i(t)\, F(p_i(t)) + u_i(t)\,(1-u_i(t-1))\, SC(t_i^{off}) \tag{1}$$

Here TC defines total cost, T defines the scheduling period, N defines no. of generating units, $u_i(t)$ is the status of unit at specified period, $SC(t_i^{off})$ represents the transition cost and F(Pi) is the operating cost of a unit for a specified time interval and it is given as follow.

$$F(P_i(t)) = A_i + B_i P_i(t) + C_i P_i^2(t) \tag{2}$$

Where A_i, B_i and C_i are cost coefficients.

2.2 Constraints

Two types of constraints are associated with UCP

- System constraints
- Unit constraints

2.2.1 System Constraint

These constraints are associated with whole system e.g. real power balance, and spinning reserve.

a. Real Power balance constraint

Total power generated at time t must be equal to the load demand at that time.

$$\forall\, t: \quad \sum_{i=1}^{N} u_i(t)\, P_i(t) = P_d(t) \tag{3}$$

Here $P_d(t)$ represents the demand at time t.

b. Spinning reserve

To increase reliability of system there must be some extra power available in the system for emergency conditions such as load forecast error, generator failure and generator shortage.

$$\forall\, t: \quad \sum_{i=1}^{N} u_i(t)\, P_i^{max} \geq P_d(t) + P_R(t) \tag{4}$$

Here P_i^{max} is the maximum power that a unit generate and $P_R(t)$ represents the spinning reserve at time t.

2.2.2 Unit Constraints

These are associated with single units and independent of the whole system. These constraints include minimum up time (MUT) and minimum down time (MDT) and output power limits of the units.

a. Generation Output Limits

$$P_i^{min} \leq P_i(t) \leq P_i^{max} \tag{5}$$

Here P_i^{min} and P_i^{max} are the minimum and maximum power generation limits.

b. Minimum up and down time constraints (MUT)

$$X_i^{on} \leq T_i^{on} \tag{6}$$

$$X_i^{off} \leq T_i^{off} \tag{7}$$

Here X_i^{off} represents the on time of i^{th} unit and X_i^{off} represents the off time of i^{th} unit.

3. Genetic Algorithm

Genetic algorithm is a random search stochastic technique based on natural evolution principle. Genetic algorithm is a peculiar class of evolutionary algorithms that use techniques inspired by evolutionary biology such as inheritance, mutation, selection, and recombination. A typical genetic algorithm requires two things to be defined:

- A genetic representation of the solution domain.
- A fitness function to evaluate the solution domain.

Genetic algorithm starts with the random production of individuals that makes the initial population. The value of objective function is evaluated for every individual in the population. After that individuals are selected to form mating pool population. Individuals having best fitness values have more probabilities of being selected for mating pool population. Once the mating pool is created crossover operator is applied for information exchange. To avoid the premature convergence a mutation operator is applied, that randomly changes the value at one or more places and is used to search the unexplored search space. Mutation is employed only on few of the individuals in the population obtained after crossover. The applications of genetic operators (crossover and mutation) produce new population that replaces the previous parent population. This GA process is repeated until a predefined stop criteria is satisfied.

The genetic algorithm is first introduced by Goldberg [13] for solving optimization problems. GA is widely used to solve optimization problems in engineering as well as in other fields. Although the work on genetic algorithm based optimization started in 80's but Research papers regarding genetic algorithm for solving unit commitment problem has been found from year 1993. Figure 2 indicates the number of research papers on unit commitment using GA from 1993 to 2014.

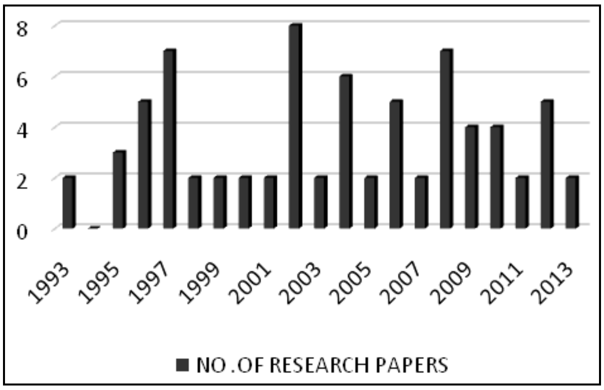

Figure 2. No. of papers published each year on UCP based on GA

Genetic algorithm techniques for solving unit commitment problem can be categorized in

- Traditional Genetic algorithm
- Hybridized genetic algorithm approaches (combination of genetic algorithm and other techniques)

3.1 Simple Genetic Algorithm for UCP

Dasgupta et al. [14] proposed simple genetic algorithm for determining the near optimal solution for the unit commitment planning. Penalty function is used in this approach for constraint violation. An elitism scheme is proposed so that the best solution are copied in a group and passed to next step. The scheme was implemented on 10 generators over time base of 24-hours. Crossover and mutation probabilities of 0.78 and 0.15 were taken and 500 generations were allowed for each independent run.

Ma et al. [15] updated the results of genetic algorithm to solve unit commitment problem by using two point crossover and forced mutation operator for reproduction and constraint handling respectively. Two types of coding schemes with different string length are used. The scheme having smaller string length was found best for 10 unit system. Tournament selection is used as a selection operator. FORTRON 77 was used for implementation. The introduction of forced mutation operator improves the performance of the algorithm.

Field et al. [16] improved the search space and results of traditional genetic algorithm by using a new domain specific operator for flipping of a bit. Three different utility systems each having 9 generators were used to test the performance of algorithm. The scheduling was done over a time horizon of 24 and 48 hours with different spinning reserves. This multi scheduling with different reserve help the utility while choosing economical scheduling. Each UC schedule gave better performance as compared to LR in terms of cost and computer execution time.

Orero et al. [17] developed the genetic algorithm to handle unit startup/shut down ramps rate constraint while solving UCP. Quadratic loss factor for MUT or MDT handling and an absolute value penalty factor for the spinning reserve/load demand constraint violation were used in proposed strategy. The robustness of the algorithm was found dependent on the selection and grading of the penalty factors. The scheduling was obtained for 26 generators. The percentage improvement in results with no ramp was 3.96% as compared to ANN. While using ramp rate limits the improvement was 5.03%. The computer execution time with ramping was 7.5 minutes and without ramp limits was 6.3 minutes.

Kazarlis et al. [18] proposed different problem specific genetic operators. The proposed operators prevents the local optimal convergence of algorithm. A varying penalty function was used for constraint handling. Test system up to 100 units was used to test the performance of proposed scheme. The cost for 100 units was $5627437 which was less as compared to $5657277 (LR). The disadvantage of proposed scheme was its high computational time requirement

Yang et al. [19] modified the GA for solving real time UCP. A new coding scheme for GA in which MUT or MDT constraint are directly integrated in the binary string was presented. A fixed Penalty term is integrated in objective function to handle other constraint violation for which scaling factor was taken as 1000. Crossover and mutation rates of 0.6 and 0.001 were chosen respectively. The developed scheme was tested on 38-unit Tai-power system and total cost was M$196.06 which is less as compared to M$198.22 (SA) and M$202.37(LR).

Yang et al. [20] developed parallel implementation of genetic algorithm for economic scheduling of 38-units. MUT or MDT was directly nested in the binary string. Parallel structure reduces execution time of GA.

Schedule was obtained at three different utility factors. The strategy had better results as compared to sequential GA. The best solution was M$195.01in comparison with M$196.81(LR).

Hongwei et al. [21] made the fitness function varying by dynamic integration of problem's constraints of the problem. A model to automatically adjust the GA parameters based on evaluating population and chromosome was built in a stratagem to optimize the parameter and a new convergence rule was used. Comparison depicted that the cost for 10-unit system was $610646.5 by using varying fitness function which is less than $611758.1(non-varying fitness function). Also the computation time of proposed scheme was 258 seconds which is less than 262 seconds (non-varying fitness function).

The traditional genetic algorithm has weaknesses of slow convergence and solution inconsistency. Li [22] proposed a sequential technique for solving UCP to reduce above two problems. The proposed approach reduced computational time as well as the variance between different runs for genetic algorithm. Ramp rates were also taken into account in this scheme. Scheduling was obtained for 6-generators and the best solution produced a cost of $469,168.28.

Christiansen et al. [23] developed five new genetic operators to improve the performance of the genetic algorithm. The proposed method has a pliancy to model the limitation of unit. The scheme can model any size of problem. The approach was implemented on MATLAB. Ten generators are used for testing the effectiveness of the proposed approach and the best schedule had a cost of $568047.8. The only drawback of the scheme was its high execution time requirement.

Yuanda [24] developed an extended genetic algorithm application for short term UC. Different techniques including initial feasible generation, relating feasible and infeasible solution for feasibility checking, redundancy checking method for layoff some solutions and a boundary search method were proposed. As a result performance of GA was greatly improved.

The purpose of generator scheduling is to minimize total production cost or to maximize the profit. Richter et al. [25] updated the GA based unit commitment for price based operation. The author redefined the objective function in term of maximizing profit. Intelligent mutation and crossover operators are used to create off spring. UC Schedule for10-units over 48-hour was obtained and the profit obtained was $676,267.

Senjyu et al. [26] presented a new GA operator based on unit characteristics and intelligent technique for producing initial population. The initial population was produced base on load curve data for the feasible initial population generation. New shift, intelligent mutation and cross-over operator were introduced. Units were classified in different clusters based on MUT/MDT constraint. The scheduling is obtained up to 100-generators over a time of 24 hours. The cost for 10 unit system was $563,977 as compared to $565825 simple genetic algorithm (SGA). Time consumed for solving the problem was 85 seconds and is less than 221 seconds (SGA).

Arroyo et al. [27] addressed the suitability of parallel repair GA for generation planning. The approach gave a model framework that was less restrictive compared to DP and LR. A hybrid parallel model was developed to avoid local convergence and to minimize Computing time. A practical system of Spain having 45-units was used to test the performance of proposed algorithm. The cost obtained was $1029557, an improvement of 0.076% was achieved by using this scheme as compared to dynamic programming.

Currently the power market is going toward the deregulated environment. Energy contracts in deregulated power system makes the UCP more convoluted problem. Xing et al. [28] included the energy constraint while solving UCP by GA. The solution oscillation issue produced by fixed energy price was reduced by using changing lambda method in generation allocation step. Three cases were discussed i.e. without energy constraint, with one energy constraint and with two energy constraints.

Swarup et al. [29] applied a novel scheme for chromosome representation and encoding the variable to solve large scale commitment schedule. To ensure the feasible solution, genetic operators were applied after the satisfaction of power balance constraint. Remaining constraints were handled by adding a penalty term in the objective function. C-programming environment was used to implement the proposed scheme. Best schedule for 10-generators had a cost of $603423.69. Important feature of the presented scheme was that it took only 73 seconds for 300 generations. Crossover and mutation rate were chosen as 0.8 and 0.03 respectively.

Senjyu et al. [30] combined genetic algorithm and Monte-Carlo tree search method for generation planning. An intelligent strategy for generating better initial population alongwith intelligent genetic operator and intelligent Monte-Carlo method was proposed. The best schedule obtained from proposed strategy had 0.33% less cost than the GA without Monte-Carlo search approach.

Damousis et al. [31] proposed a new solution for UCP based on the integer coded GA in which string size and computational time was reduced as compared to binary coded GA. To avert distortion in the search space created from the penalty function, MUT or MDT were directly coded in the chromosome. Unit swapping operator and Excessive-reserve elimination operator were proposed to improve the performance of ICGA. The cost for $1127244 as compared to $1130660(LR) and 1130291(binary coded GA). It took only 25 seconds and produced best solution within 300 generations.

Dudek [32] introduced new search operators in genetic algorithm to obtain generator scheduling. The proposed strategy used Production cost, Unit startup cost and load demand for defining mutation probability. Repair algorithm was used to handle different constraints. The algorithm was coded in MATLAB for 12 generators. Best cost obtained by presented scheme was $644951 which is much less than $702379 (simulated annealing) and $665634 (Monte-Carlo method). The drawback of this scheme was its high computer execution time.

Wei [33] updated the result of genetic algorithm by using adaptive crossover rate that varies with the maximum colony adaptation and the average colony adaptation degree of each generation. Rate of variation was adjusted by evolutionary generation and colony adaptation degree. The approach was found to be more precise and good convergent than simple GA.

In deregulated system there is a competition among different generation companies. The aim of power generating companies is to maximize profit so there is a need to change the objective function of UCP in deregulation environment. Solanki et al. [34] discussed the unit commitment problem in the deregulated environment. A profit based on/off schedule of three GENCO system were used to test the performance of proposed approach. The profit for these systems was $1540, $625 and $102.5. In deregulated environment profit is used as an objective function.

Kumar et al. [35] presented a two-layer strategy consisting of genetic algorithm and improved lambda iteration. Unit level and population level cross-over are introduced to increase the search space. A swap mutation operator is proposed committing the unit on/off based on unit’s full load average production cost. The proposed approach uses improved lambda iteration method to calculate the cost for obtained schedule. The operating cost was $564,367 compared to $565825 (LR, GA) for 10-unit system. Time consumed was 11 seconds compared with 67.75 second (GA).

Amjady et al. [36] applied a new integer coded GA for generation planning. A hybrid crossover based on average modified bound and swapped operator and a hybrid uniform and non-uniformed mutation operator were proposed. Test results for system up to 300-generators are given and justify the efficiency of proposed approach.

Jalilzadeh et al. [37] proposed an updated genetic algorithm to solve the generator scheduling problem. The approach used load data to create feasible initial population. A genetic operator based on the unit classification characterization method has been proposed. The proposed approach gives economical generator scheduling. The scheme was tested on 10-units and best UC schedule has a cost of $563931 which is less than $563942 (PSO), $564800 (LRGA).

Zhang et al. [38] developed a genetic algorithm based new model for generator scheduling including automatic generation control. A dynamic length binary encoding technique and an equal incremental rate based genetic operator was proposed for continues variables. A preferable efficiency was obtained in search space and CPU speed for 16-machine.

Kumar et al. [39] proposed a genetic algorithm based approach to solve the UCP in which optimal flow of power with line constraints was also included. In first step UC scheduling was obtained with prevailing constraint and in the second step line constraint violations were reduced using genetic algorithm based optimal power flow. An Indian utility system having 12-generators, 66 buses and 93 transmission lines was used to test the effectiveness of proposed approach.

Ma [40] proposed new solution for unit commitment problem. For global convergence quantum effect of superposition and entanglement were proposed for the genetic algorithm. The proposed approach work well for non-linear, non-convex and stochastic objective function.

Pavez-Lazo [41] developed deterministic genetic algorithm to solve unit commitment. A deterministic selection procedure and an annular crossover operator was proposed to avoid premature convergence. Increased possibility of genetic information exchange was achieved by proposed annular crossover operator. A repair algorithm was used for constraint handling. The approach was tested on 10, 38 and 45 unit system and cost obtained for these systems was $563987, $195042 and $1,029,557 respectively.

Abookazemi et al. [42] developed a parallel structure integrated with improved and optimized genetic algorithm. The proposed approach effectively handles the infeasibility of the solution. An intelligent mutation and a scaling function for selection in each generation was proposed. The strategy gave better economy, speedy GA performance and increased probability to find global optimal feasible solution. The solution gave better cost ($561,436) in comparison with LR ($565,825) and SGA ($591,715) for 10-unit system.

Shobana et al. [43] applied genetic algorithm to solve multi objective function. Unit commitment problem along with constraint emission was discussed in the proposed strategy. To handle minimum up time and minimum down time constraints in genetic algorithm the integer base coding method was proposed for generating initial feasible solution. No penalty function was used for MUT or MDT constraints. Constrained Emission was also considered in proposed approach.24-hour commitment schedule is obtained for 10-generators and cost was $562892.

Dhanalakshmi et al. [44] developed an intelligent coding scheme for genetic algorithm to solve the scheduling problem. The Minimum up time and minimum down time constraint were handled by proposed intelligent coding scheme. Penalty parameter constraint handling technique is used to obtain a satisfactory balance of power constraint. Spinning reserve was not taken into account.

Dudek [45] represented the startup and shut down time in the binary strings. Penalty function method was used to handle other constraint. A new operator known as transportation operator is proposed. Exchange of information takes place between chromosomes of two randomly chosen units. The proposed approach helped in improving the computational efficiency genetic algorithm.

3.2 Binary-real coded GA.

Wen-Ping [46] presented a three dimensional matrix for representation of chromosome and unit commitment schedule. The strategy used Binary coded GA for UCP and real coded GA for EDP. To ensure the feasibility of solution power balance constraint was satisfied prior to genetic operation. Tests on 10-generators revealed the feasibility of proposed method.

Mantawy et al. [47] used a mixed binary and decimal coding scheme in genetic algorithm to solve UCP. Total operating cost based penalty less fitness function has been used in this strategy. The combinatorial problem was solved by GA and quadratic programming was used for generation allocation. Simulation results give more global optima in a reasonable CPU time.

Sun et al. [48] used matrix of real number for representing the chromosome. A new window mutation operator was proposed that was used. Novel repair schemes were presented for handling various constraints. IEEE standard test cases as well as real cases were considered. Ramp rate limits were also included in real time case studies. The proposed scheme produced better results for all cases. Only 3.6 seconds were consumed for 500 generations while solving 10-unit system.

Dang et al. [49] proposed a floating point representation for individuals in population based on anticipated load curve. Encoding and decoding methods were used to reduce the complications while handling MUT or MDT constraint. The floating point GA is also found felicitous for non-convex function. The obtained cost for 10 unit system was $564094 as compared to $565825 (DP, GA and LR).

Datta [50] developed an improved genetic algorithm with an approach to solve both real and integer parts of the UCP. Ramp rate constraints are also incorporated in the proposed strategy. Multi point variable crossover technique was used. For real GA simulated binary crossover and polynomial mutation were used. Time consumed was 4.91 seconds.

3.3 Hybrid Conventional Approaches and GA

Ohta [51] used a combined Langrangian relaxation and genetic algorithm approach to obtain the practical generator scheduling. The induction of heuristics string sequence enhanced the efficiency to solve the problem. An improvement of 0.05% was achieved in the cost compared to LR.

Cai et al. [52] developed a dynamic programming crossover operator to create off springs. The DP is included in place of crossover parameter without affecting the GA and DP algorithm. The proposed approach uses dynamic programming on genetic algorithm based parent population to produce new chromosome. The penalty function or repair algorithm is not used as DP crossover generates the feasible off springs if the initial population satisfy the constraints. The approach worked well for non-linear optimization problem. The improvement gained by the scheme was about 2% compared to DP.

Orero et al. [53] developed a hybrid GA combining the priority list for large scale UCP. FLAPC based priority is used for committing the units. Genetic operators are applied on priority list method based initial population. The proposed approach produced a solution of $3826 775 compared to $3834467 (Normal GA) and $3854821 (Priority list). The time consumed was 20 minutes as compared to 12 hours (normal GA).

Takata et al. [54] presented a hybrid genetic algorithm and lagrangian relaxation technique for solving unit commitment problem. To overcome the limitations of lagrangian relaxation in handling constraint genetic algorithm was employed. In Genetic algorithm constraint satisfaction can easily be obtained by simply adding penalty factor in the objective function. Moreover, the introduction of heuristics to facilitate genetic manipulation of the string improved the efficiency of the optimization. Simulation results had shown that this method was effective in solving practical UCP.

Yamin et al. [55] used an embedded genetic algorithm with langrangian relaxation.LR multiplier was revised by using genetic algorithm. Optimal bidding curves were obtained from scheduling results. The profit obtained from proposed approach was almost twice than traditional approaches.118-bus system was used to elaborate the proposed strategy. The operating cost was $876,523.6 as compared to $889,871.7(LR) and the profit was $230,321.5 in comparison with $243,669.6(LR). The scheme took about 5% more time than LR.

Huang et al. [56] proposed a genetic based neural network and dynamic programming (DP) strategy for UCP solution.. At initial phase a genetic-enhanced neural network is applied to generate the initial commitment schedule and then DP is used to ameliorate this schedule. Experiments for 43-units were carried out. The best solution has M$192.18 as compared to M$192.19(NN-DP), M$ 196.47 (LR) and M$193.87(SA).

Chen [57] applied and hybrid Taguchi GA method to solve the UCP. The Taguchi technique was used to enhance the offspring's quality created from crossover and mutation operation. The proposed strategy not only enhances search space but also search optimal solution with enhanced convergence. Results indicated that the HTGA had improved efficiency as compared real genetic algorithm.

3.4 Hybrid GA and Tabu Search Method

Mantawy et al. [58] developed hybrid method using genetic algorithm and tabu search method. The solution was coded as combination of binary number and decimal number to save memory and to reduce the computation time for the GA. The approach uses genetic algorithm for generation of initial population and tabu search algorithm in the reproduction phase. The proposed method reduces the probability of premature convergence of genetic algorithm. 2.16% better results were obtained for 10-unit system as compared to integer programming.

Rajan [59] used genetic algorithm which is embedded with tabu search to obtain the scheduling for practical system. Tabu search method is applied to create the initial population of genetic algorithm. The strategy deals with cooling and banking constraints along with other constraints. Operating cost for 34-units in p.u was 0.93710 compared to 1.00(DP), 0.99(LR) and 0.941 (GA).

3.5 Simulated Annealing Based GA

Cheng et al. [60] developed a hybrid approach containing genetic algorithm and simulated annealing to obtain the unit on/off scheduling. The proposed approach increases the speed of SA and improves the performance of genetic algorithm. Scheduling was obtained for a practical system of 40-generators. The scheme produced best schedule with a cost of $2734402 and consumed 1800 seconds.

Integration of renewable energy sources with conventional sources makes the unit commitment one of the challenging problem. Liang et al. [61] integrated simulated annealing to improve the performance of genetic algorithm in micro grid environment. The simulated annealing integrated in the genetic algorithm as one of its operator to abandon the bad individuals. Wind turbine and solar cells were integrated with thermal units. Convergence and computation time of GA was improved by the proposed approach. An improvement of $38.5 in objective function was noticed compared to traditional GA. Time consumed by proposed algorithm was 163 seconds as compared to 3011 seconds (Traditional GA).

3.6 Fuzzy Logic Based GA for UCP Solution

Liao et al. [62] developed a mixed approach based on GA, fuzzy logic and tabu search. Fuzzy logic was proposed to evaluate the chromosome information exchange rate and mutation probability. The proposed approach improved results by regulating fitness function and importing local optimum search in the method. The strategy had global optimal schedule with increased speed and performance. For 30-generators the cost was $1999645 as compared to $2130347 (DP), $2113462(SGA) and $2013468(Tabu search).

Liao et al. [63] proposed a chaos search immune algorithm that was embedded in the genetic algorithm for UCP. Initially immune and genetic algorithms were nested then the fuzzy logic and chaos search was implemented to solve the UC problem. Cross-over and mutation probability are changed from constant value to changing value and calculated by using fuzzy logic. The proposed strategy guaranteed Global optimal convergence of solution. Operating cost for 10 units in per unit was 0.92426compared to 0.97261(DP), 0.97483 (LR) and 1.000 (TS).

Mantawy [64] presented fuzzy logic to make the fuzzy based unit commitment model and genetic based approach for scheduling was proposed by. The model takes the uncertainty in the expected load demand and spinning reserve in the framework of fuzzy. A penalty term is calculated by using the proposed fuzzy model to converge the solution to more optimal solution. The economic dispatch part of problem was solved by dynamic programming. The cost saving was 0.65% of traditional GA while the spinning reserve was almost two time GA.

3.7 Hybrid GA and PSO

Zhang et al. [65] developed a hybrid genetic algorithm and particle swarm optimization. The approach uses genetic algorithm for optimizing unit commitment problem and particle swarm optimization for economic load dispatch problem. Probability of Local optimal convergence is prevented by using PSO. Feasible UC scheduling is obtained for 10-generator over a time horizon of 24hours.

Hosseini et al. [66] applied combined PSO and genetic algorithm to solve the UCP. In the proposed strategy genetic algorithm was used to solve generation allocation problem for the PSO based generator scheduling. Time fluctuating weight was used to improve the search space. MATLAB 2010 environment was used for implementation. Test results indicated that the performance of proposed algorithm is satisfactory. The results obtained for 10-unit system was $568960.

4. Future Directions

Genetic algorithm is widely used to solve UCP in different aspects while meeting different constraints. But following aspects are not addressed completely in literature.

1. Multi-area unit commitment.
2. Emission-constrained unit commitment.
3. Security-constrained unit commitment.
4. Multi-objective unit commitment schedule.
5. Unit commitment in micro grid envoirment.

A few of papers are available addressing these issues, therefore these issues can be addressed using genetic algorithm.

5. Conclusion

Generation scheduling is very critical in daily operation of power system. The optimal scheduling of generating units gives significant production cost savings. This paper presents a review on application of Genetic Algorithm to solve the thermal unit commitment problem. The GA approach has been found very effective to find an optimal UC schedule. It does not only provide a near optimal solution but also reduces the computing time and search effort. It is found that genetic algorithm with intelligent coding, parallel structure genetic algorithm and hybrid GA techniques appear to be best among all proposed GA strategies.

References

[1] W.L. Snyder, H.D. Powell and J.C. Rayburn, IEEE Transactions on Power Systems **2** (1987) 339.

[2] C.-P. Cheng, C.-W. Liu and C.-C. Liu, IEEE Transactions on Power Systems **15** (2000) 707.

[3] T. Senjyu, K. Shimabukuro, K. Uezato and T. Funabashi, IEEE Transactions on Power Systems **18** (2003) 882.

[4] C.-L. Chen and S.-C. Wang, IEEE Transactions on Energy Conversion **8** (1993) 184.

[5] B. Zhao C.X. Guo, B.R. Bai and Y.J. Cao, International Journal of Electrical Power & Energy Systems **28** (2006) 482.

[6] D. Kothari and A. Ahmad, Energy Conversion and Management **36** (1995) 257.

[7] K. Chandrasekaran, S. Hemamalini, S.P. Simon and N.P. Padhy, Electric Power Systems Research **84** (2012) 109.

[8] K. Vaisakh and L.R. Srinivas, Applied Soft Computing **11** (2011) 2863.

[9] E. Rashedi, H. Nezamabadi-Pour and S. Saryazdi, Natural Computing **9** (2010) 727.

[10] C.C.A. Rajan and M. Mohan, IEEE Transactions on Power Systems **19** (2004) 577.

[11] A. Mantawy, Y.L. Abdel-Magid and S.Z. Selim, IEEE Transactions on Power Systems **13** (1998) 197.

[12] R. Nayak and J.D. Sharma, Computers & Electrical Engineering **26** (2000) 461.

[13] D.E. Goldberg, Genetic Algorithms in Search, Optimization and Machine Learning, Addison-Wesley (1989).

[14] D. Dasgupta, Proceedings., Fifth International Conference on Short Term Unit-Commitment Using Genetic Algorithms, Tools with Artificial Intelligence (1993) pp. 240-247.

[15] X. Ma, A. El-Keib, R. Smith and H. Ma, Electric Power Systems Research **34** (1995) 29.

[16] T.T. Maifeld and G.B. Sheble, IEEE Transactions on Power Systems **11** (1996) 1359.

[17] S. Orero and M. Irving, International Journal of Electrical Power & Energy Systems **18** (1996) 19.

[18] S.A. Kazarlis, A. Bakirtzis and V. Petridis, IEEE Transactions on Power Systems **11** (1996) 83.

[19] H.-T. Yang, P.-C. Yang and C.-L. Huang, Applications of the Genetic Algorithm to the Unit Commitment Problem in Power Generation Industry, Fuzzy Systems, 1995. International Joint Conference of the Fourth IEEE International Conference on Fuzzy Systems and The Second International Fuzzy Engineering Symposium., Proceedings of IEEE International Conference (1995) p. 267-274.

[20] H.-T. Yang P.-C. Yang and C.-L. Huang, IEEE Transactions on Power Systems **12** (1997) 661.

[21] Z. Hongwei, Y. Liangting, W. Buyun, C. Gang and Y. Haiping, A New Genetic Algorithm for Unit Commitment, IEEE International Conference on Intelligent Processing Systems (1997) 606.

[22] F. Li,Genetic Algorithm Approach to More Consistent and Cost Effective Unit Commitment, Proceedings of the 3rd World Congress on Intelligent Control and Automation (2000) 581.

[23] J. C. Christiansen, C. A. Dortolina and J. Bermudez,An Approach to Solve the Unit Commitment Problem Using Genetic Algorithm, IEEE Power Engineering Society Summer Meeting IEEE, (2000)p. 261-266.

[24] G.S.S. Yuanda, Journal of Southeast University (Natural Science Edition) **3** (2000) 10.

[25] C.W. Richter Jr and G.B. Sheble, IEEE Transactions on Power Systems **15** (2000) 715.

[26] T Senjyu, H Yamashiro and K Uezato, A Unit Commitment Problem by Using Genetic Algorithm Based on Unit Characteristic Classification, IEEE Power Engineering Society Winter Meeting IEEE (2002) 58-63.

[27] J.M. Arroyo and A.J. Conejo, IEEE Transactions on Power Systems **17** (2002) 1216.

[28] W. Xing and F.F. Wu, International Journal of Electrical Power & Energy Systems **24** (2002) 329.

[29] K. Swarup and S. Yamashiro, IEEE Transactions on Power Systems **17** (2002) 87.

[30] T. Senjyu, H. Yamashiro, K. Shimabukuro, K. Uezato and T. Funabashi, Transactions Institute of Electrical Engineers of Japan C **122** (2002) 1360.

[31] I.G. Damousis, A.G. Bakirtzis and P.S. Dokopoulos, IEEE Transactions on Power Systems **19** (2004) 1165.

[32] G. Dudek, Electric Power Systems Research **72** (2004)299.

[33] T. Wei, Electrotechnical Application **1** (2006) p. 023.

[34] J. Solanki, S. Khushalani and A. Srivastava, A Genetic Algorithm Approach to Price-Based Uni. Commitment, 38th North American Power Symposium (2006) pp. 425-429.

[35] V.S. Kumar and M. Mohan, Proc. of Int. J. Electrical and Power Engg. **2** (2008) 85.

[36] N. Amjady and A. Shirzadi, European Transactions on Electrical Power **19** (2009) 1161.

[37] S. Jalilzadeh and Y. Pirhayati, An Improved Genetic Algorithm for Unit Commitment Problem with Lowest Cost, IEEE International Conference on Intelligent Computing and Intelligent Systems (2009) p. 571-575.

[38] J.-f. Zhang, H.-x. Qin, J. Jia and J.-j. WU, Journal of Nanjing University of Science and Technology **6** (2009) 019.

[39] V. S. Kumar and M. Mohan, International Journal of Electrical Power & Energy Systems **32** (2010) 117.

[40] X. Ma, Power System Unit Commitment Based on Quantum Genetic Algorithm, Springer (2011).

[41] B. Pavez-Lazo and J. Soto-Cartes, Expert Systems with Applications **38** (2011) 6523.

[42] K. Abookazemi, H. Ahmad, A. Tavakolpour and M.Y. Hassan, International Journal of Electrical Power & Energy Systems **33** (2011) 969.

[43] S. Shobana and R. Janani, Int. J. of Emerg. Tech. and Adv. Engg. **3** (2013) 367.

[44] S. Dhanalakshmi, S. Baskar, S. Kannan and K. Mahadevan, Computers &Electrical Engineering **39** (2013) 79.

[45] G. Dudek, Expert Systems with Applications **40** (2013) 6080.

[46] C. Wen-Ping and L. Xian-Jue, Application of Double Matrix Hybrid Coded Genetic Algorithm in Unit Commitment, International Conference on Electricity Distribution, China (2008) p. 1-6.

[47] A. Mantawy, Y.L. Abdel-Magid and S.Z. Selim, Proc. Int. Conf. on Genetic Algorithms in Engineering Systems (1997) p.215–220.

[48] L. Sun, Y. Zhang and C. Jiang, Electric Power Systems Research **76** (2006) 716.

[49] C. Dang and M. Li, European Journal of Operational Research **181** (2007) 1370.

[50] D. Datta, Applied Soft Computing **13** (2013) 3873.

[51] T. Matsui; T. Takata, M. Kato, M. Aoyagi, M. Kunugi, K. Shimada and J. Nagata, Practical Approach to Unit Commitment Problem Using Genetic Algorithm and Lagrangian Relaxation Method, Proceedings of International Conference on Intelligent Systems Applications to Power Systems (1996) p. 434-440.

[52] X.-Q. Cai and K.-M. Lo, Methods & Applications **30** (1997) 4279.

[53] S. Orero and M. Irving, International Journal of Electrical Power & Energy Systems **19** (1997) 45.

[54] T. Takata, J. Takahashi, H. Yokoi, H. Nakano, M. Aoyagi, M. Kato, K. Shimada and J. Arai, Transactions-Institute of Electrical Engineers of Japan B **119** (1999) 654.

[55] H.Y. Yamin and S.M. Shahidehpour, Electric Power Systems Research **68** (2003) 83.

[56] C.-L. Huang, , IEEE Transactions on Power Systems **12** (1997) 654.

[57] C.Y. Chen, Integration of Genetic Algorithm and Taguchi Method for Thermal Unit Commitment, Ph D. Thesis (2006) 93.

[58] A. Mantawy, Y. L Abdel-Magid and S. Z Selim, Electric Power Systems Research **49** (1999) 71.

[59] C.C. Rajan, Journal of Electrical Engineering-Elektrotechnicky Casopis **60** (2009) 69.

[60] C.-P. Cheng, C.-W. Liu and C.-C. Liu, International Journal of Electrical Power & Energy Systems **24** (2002) 149.

[61] H.Z. Liang and H.B Gooi, Unit Commitment in Microgrids by Improved Genetic Algorithm, Conference Proceedings International Power Electronics Conference (IPEC) (2010) p. 842-847.

[62] G.-C. Liao and T.-P. Tsao, The Use of Genetic Algorithm/Fuzzy System and Tabu Search for Short-Term Unit Commitment, Proceedings of International Conference on Power System Technology (2002) p. 2302-2307.

[63] G.-C. Liao and T.-P. Tsao, Electric Power Systems Research **71** (2004) 135.

[64] A. Mantawy, Electric Power Systems Research **72** (2004) 171.

[65] J. Zhang, T.-Q. Liu, P. Su and X. Zhang, Power System Protection and Control **9** (2009) 135.

[66] S. Hosseini, H. Siahkali, and Y. Ghalandaran,Thermal Unit Commitment Using Hybrid Binary Particle Swarm Optimization and Genetic Algorithm, Power and Energy Engineering Conference (APPEEC), Asia-Pacific (2012) p. 1-5.