ISSN 2348 – 9928
IJAICT Volume 4, Issue 10, October 2017 Doi:01.0401/ijaict.2015.09.04 Published on 05 (10) 2017

LAGRANGIAN RELAXATION BASED SECURITY CONSTRAINED UNIT COMMITMENT CONSIDERING VOLTAGE CONSTRAINT

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Abstract— Security is one of the important issues in power system. In this paper voltage constraint is incorporated with Security Constrained Unit Commitment formulation to maintain the voltage security. The objective is to minimize the total production cost considering the voltage security. Lagrangian Relaxation based approach is proposed to determine the Voltage Security Constrained Unit Commitment (SCUC) considering the thermal unit. Lagrangian formulations are applied to relax the constraints with objective function using multipliers. Lagrangian multiplier is adopted to deal with coupling constraints. Using Lagrangian Relaxation, the problem is decomposed into two problems. The master problem solves unit commitment with prevailing constraints. The sub problem minimizes the violations of voltage constraints. In order to maintain the voltage security when the voltage is high generation of reactive power is done and when the voltage is low absorption of reactive power is done. The simulation provides some analysis of the proposed method with IEEE 39 bus system with 10 generating units.

Keywords— Security constrained unit commitment (SCUC), Lagrangian relaxation (LR), Unit commitment problem (UCP).

I. INTRODUCTION

An Security-constrained unit commitment (SCUC) is a crucial problem in the power system scheduling of generation. The proposed paper provides a bibliographical survey, mathematical formulations, and general developments in the UC field. The methods proposed to solve the unit commitment problem include priority list, dynamic programming, branch and bound, Lagrange relaxation, and Benders decomposition. The proposed survey helps the researchers to overcome the difficulties while carrying out research in UC problem under deregulated and regulated industry of power [1]. Transmission Switching (TS) has been incorporated with Security Constrained Unit Commitment (SCUC) to check the flows in the transmission and voltages of the buses in the base case and contingency conditions to alleviate the transmission violations. The Transmission Switching sub problem analysis the contingencies and identifies the changes required to the UC master problem solution when the mitigation of the contingencies cannot be done in the Transmission Switching sub problem. For the management of congestion Transmission Switching model was proposed [2].

To model the wind generation stochastic techniques have been adopted. To solve the forecasted intermittent wind power generation the Bender's Decomposition method has been adopted. To eliminate the violation Benders cut has been generated. Benders cuts are created and added to the master problem to revise the solution of the unit commitment. To obtain the wind forecasting simulation, statistical method or combination of two had been proposed. The stochastic optimization compared with the deterministic methods would reduce the system cost by 0.25% in the unit commitment. The large integration of intermittent wind generation (WG) in power systems has necessitated the inclusion of more innovative and sophisticated approaches in the power system [3].

The mixed-integer programming (MIP) application presents the capacity to handle large-scale problems. The proposed Security Constrained Unit Commitment solution uses the Benders decomposition to decompose the problem into a master problem and two sub problems. To reduce the violation Benders cut has been created. Benders cuts are generated and added to the master problem to find the solution of the unit commitment. The method proposed applies a method of decomposition to separate the natural gas transmission and the power transmission as two separate subproblem from the unit commitment (UC) in the master problem. Gas contracts have been proposed, modeled and then incorporated in the master Unit Commitment Problem. The subproblem of natural gas transmission checks the feasibility of natural gas transmission and natural gas transmission security constraints for the unit commitment and for the gas-fired generating units dispatch. If any violations arose in the natural gas transmission, corresponding energy constraints would be created and added with the master problem for solving the UC next iteration [4].

ISSN 2348 – 9928
Doi:01.0401/ijaict.2015.09.04 Published on 05 (10) 2017

The method proposes a stochastic model to obtain the long term solution of security-constrained unit commitment (SCUC). The proposed model would be used very often by the vertically integrated market utilities as well as the Independent Standard Operators in the markets of electricity. In the proposed method the random disturbance which includes inaccuracies of load forecasting, generation unit outages and the transmission lines are designed as scenario trees considering the Monte Carlo simulation method. To consider the dual optimization, the coupling constraints from the scenarios are relaxed and the problem of optimization is decomposed into long term deterministic SCUC sub problems. For every deterministic long-term SCUC, the fuel and emission constraints represent the resource constraints in the vertically integrated markets. In order to decompose the sub problems along with the long-term SCUC into the tractable short-term MIP-based SCUC sub problems without considering the resource constraints the Lagrangian relaxation algorithm is used. To simulate random characteristics of power systems the Monte Carlo (MC) simulation method has been adopted. The proposed stochastic planning model uses multiple scenarios in the Monte Carlo simulation [5].

This paper proposes a model to obtain feasible solution for the security constrained unit commitment (SCUC) problems within the Lagrangian relaxation framework [6]. Gas contracts were modelled and incorporated in the master UC problem. The natural gas transmission sub problem checks the feasibility of natural gas transmission as well as natural gas transmission security constraints for the commitment [7]. Lagrangian Relaxation technique was applied to decompose the original optimization problem into sub problems for midterm generation and transmission maintenance scheduling and short-term SCUC. Mixed Integer Programming (MIP) has been proposed to solve SCUC [8]. A stochastic model was proposed to schedule reserves. Demand Response Providers (DRPS) provide Demand-side reserve. A mixed-integer representation of reserve provided by DRPs and its associated cost function were used in the proposed stochastic model [9]. The hourly Demand Response (DR) was incorporated into security-constrained unit commitment (SCUC) for economic and security purposes. At peak periods Demand-side participation may reduce the loads [10].

This paper is organized as follows: In Section 2**,** the problem formulation for security constrained unit commitment with voltage constraint is presented. Lagrangian method for security constrained unit commitment for master problem is given in Section 3. Section 4 discusses flowchart and algorithm for the proposed method. The results of the voltage security constrained unit commitment are presented in section 5. Section 6 summarizes the conclusions.

II. PROBLEM FORMULATION OF SCUC WITH VOLTAGE CONSTRAINTS

The objective of Security Constrained Unit Commitment (SCUC) is to obtain a unit commitment schedule at minimum production cost without compromising the system reliability. The traditional unit commitment algorithm determines the unit schedules to minimize the operating costs and satisfy the prevailing constraints such as load balance, system spinning reserve, ramp rate limits, fuel constraints, multiple emission requirements and minimum up and down time limits over a set of time periods. The scheduled units supply the load demands and possibly maintain transmission flows and bus voltages within their permissible limits. SCUC is treated as an optimization problem that minimizes perceived operating costs based on the incremental costs submitted by generating units.

The objective function for the SCUC is given as

$$\sum_{i=1}^{Ng} \sum_{t=1}^{N_t} [C_i(P(i,\ t))I(i,\ t) + S(i,\ t)] \qquad (1)$$

where

$C_{fi}(P(i,t))$ - Production Cost
$S(i,t)$ - Start Up Cost

Many constraints can be applied to the Security Constrained Unit Commitment problem. The constraint includes system real power balance, reactive power generation limits, system voltage limits, fuel constraints and start up cost.

2.1 System real power balance

The system real power balance constraint is the most important constraint in the SCUC. The generated power from all committed units must be equal to the load demand. This is formulated in the balance equation as

$$\sum_{t=1}^{Ng} (P(i,\ t))I(i,\ t) = PD\ (t) \qquad (2)$$

where

$P(i, t)$ - Generation of unit i at time t
$P_D(t)$ - Total system real power load demand at time t

ISSN 2348 – 9928
Doi:01.0401/ijaict.2015.09.04 Published on 05 (10) 2017

2.2 Reactive Power Generation Limit

The system reactive power operating reserve requirement is formulated as

$$Q^{\min} \leq Q \leq Q^{\max} \tag{3}$$

where

Q^{min} - System reactive power lower limit vector

Q^{max} - System reactive power upper limit vector

2.3 System Voltage Limits

The system voltage limits is formulated as

$$V^{\min} \leq V \leq V^{\max} \tag{4}$$

where

V^{min} - System voltage lower limit vector
V^{max} -System voltage upper limit vector

2.4 Start up Cost

The start- up cost is the cost incurred during the starting of the generating unit. Different units have different start up cost.
Start up Cost=0, if unit is stopped and started immediately.

III. LAGRANGIAN RELAXATION

The Lagrangian Relaxation is based on the idea of relaxing the explicit linear constraints by bringing them into the objective function with associated Lagrangian Multiplier. The Lagrangian Relaxation resembles the dual optimization approach. The method punishes the violation of inequality constraints using a Lagrangian Multiplier. Lagrangian Relaxation is the most commonly adopted algorithm for solving constrained optimization problem. The relaxed problem can be solved as the original problem. A solution to the relaxed problem is an estimated solution to the original problem. Lagrangian Relaxation problem can be used in place of linear programming relaxation. Lagrangian Relaxation is used to provide good possible solution. Since 1970 LR has been the bounding decomposition technique until the beginning of the 1990. Relaxation method approximates a hard problem of constrained optimization into a simpler problem. The Lagrangian Relaxation optimization technique decomposes the unit commitment problem into a master problem and sub problem that are solved iteratively until a near best solution is obtained. The sub problems are solved autonomously. Each sub problem determines the commitment of a single unit. The problems are allied by Lagrangian Multiplier that is added to master problem to give up a dual problem. The dual problem has inferior dimensions than the primal problem. For the Unit Commitment problem, the primal function is forever superior than or equal to the function which is defined as fragile duality. The difference between the two functions yields the duality gap for which the primal function is an upper bound. The duality gap provides near optimality of the solution. The Lagrangian Multipliers are computed at the master problem level. Once computed Lagrangian Multiplier are passed to the sub problem. The solution of the sub problem by Forward Dynamic Programming is fed back to the master problem and updated multipliers are obtained and used by sub problem again. This process is repeated until the solution converges. For the short term unit commitment problem the multipliers are updated through a sub gradient method with a scaling factor and timing constants that are determined heuristically. Lagrangian Relaxation is a classical method for combinational optimization. Reduce the original problem based on the solution to the relaxed problem. The Lagrangian Relaxation method transforms the solutions of the relaxed problem into feasible solutions of the original problem. The optimal value of the relaxed problem is a lower bound of the optimal objective of the original problem.

IV. PROPOSED ALGORITHM

4.1 Algorithm of Lagrangian Relaxation

Lagrangian Relaxation algorithm is the best algorithm to solve the dual optimization problem. Relaxation refers to relaxation the coupling constraints. The algorithm of proposed technique is as follows:

1. Start the problem
2. Initialize the Lagrangian Multipliers according to the constraints considered. The total number of the multipliers depends on the number of the constraints.
3. Satisfy the constraints such as Real Power Balance, Reactive Power Generation Limits, Voltage Limits, Fuel Cost and Start up Cost.
4. Calculate the Primal Objective Function. The primal objective here is the fuel Cost. The fuel cost can be calculated from the cost coefficients
5. Calculate the Reactive Power from the reactance and the voltage of the corresponding units.
6. Calculate the Production Cost as the production cost is the product of the heat rate and the fuel cost added along with the start up cost.

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IJAICT Volume 4, Issue 10, October 2017

ISSN 2348 – 9928
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7. Check whether the reactive power is greater than or smaller than zero. If it is greater than zero go to the next step otherwise go to step 10.
8. If the reactive power is smaller than zero go to the next step.
9. Voltage is high and then Absorption of Reactive Power takes place to maintain the Voltage Security.
10. Voltage is low and then Production of Reactive power takes place to maintain the Voltage Security.
11. Check for Voltage Security. If the voltage is within the limit go to the step 12. Otherwise go to the next step.
12. Update the Lagrangian Multipliers and go to step 2 until the voltage security is attained.
13. Stop

4.2 Flowchart for Lagrangian Relaxation

The flowchart for the proposed algorithm is shown below:

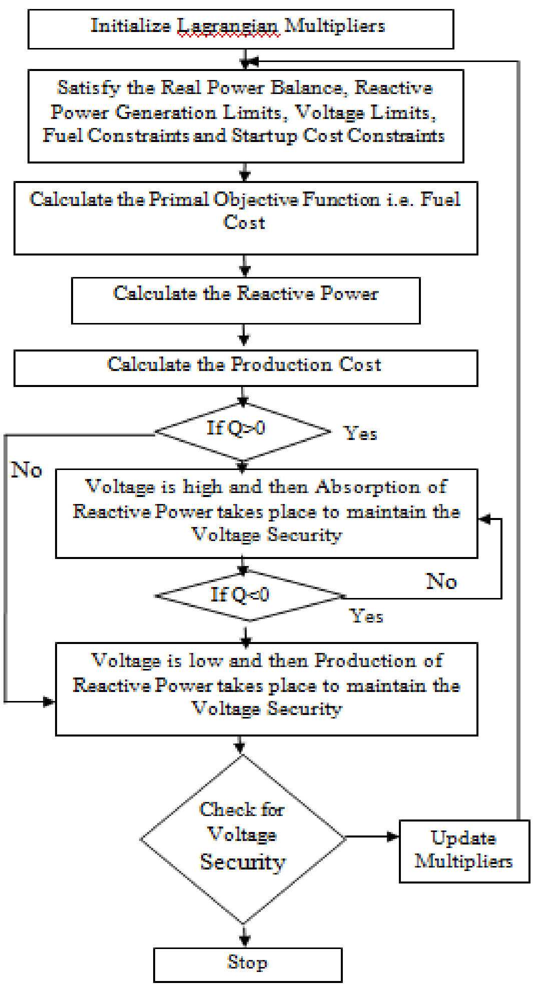

Fig. 1. Flowchart for Lagrangian Relaation Algorithm

V. SIMULATION RESULTS

In this paper, the production cost is calculated and the voltage security is maintained. The production cost of the 10 generating units are calculated by considering the heat rate, fuel cost and start up cost.. The total production cost of the 10 generating units is calculated as ₹ 69,401.33. When the voltage in the system is high absorption of reactive power is made. When the voltage in the system is low generation of reactive power is done in order to maintain the security The production cost of the units increases with the increase in size of the number of the units and decreases with the reduction in the number of the units. Unit data and load demand for IEEE Standard 39 Bus system and 10 generating units are given below:

TABLE I SYSTEM DATA FOR 39-BUS SYSTEM

Unit	Pmax (MW)	Pmin (MW)	a	B	c	MU
1	455	150	1000	16.19	0.00048	8
2	455	150	100	17.26	0.00031	8
3	130	20	100	16.60	0.00200	5
4	130	20	180	16.50	0.00211	5
5	162	25	100	19.70	0.00398	6
6	80	20	370	22.26	0.00712	3
7	85	25	480	27.74	0.00079	3
8	55	10	660	25.92	0.00413	1
9	55	10	665	27.27	0.00222	1
10	55	10	670	27.29	0.00173	1

TABLE II LOAD DATA FOR 39-BUS SYSTEM

MD	H_{cost}	C_{cost}	C_{hour}	Ini.St.	X	V
8	4500	9000	5	8	0.0411	1.02
8	5000	10000	5	8	0.0250	1.06
5	550	1100	4	-5	0.0151	1.09
5	560	1120	4	-5	0.0086	1.09
6	900	1800	4	-6	0.0213	1.06
3	170	340	-3	-3	0.0128	1.06
3	260	520	-3	-3	0.0129	1.05
1	30	60	-1	-1	0.0026	1.04
1	30	60	-1	-1	0.0012	1.00
1	30	60	-1	-1	0.0092	1.00

VI. CONCLUSION

Voltage security is the capability of a power system to keep the steady adequate voltages in the system at standard operating environment and after being subjected to a disturbance. Voltage security is a problem in power systems operation which results due to the occurrence of faulted or have a shortage of reactive

ISSN 2348 – 9928
Doi:01.0401/ijaict.2015.09.04 Published on 05 (10) 2017

power. The nature of voltage security can be analyzed by examining the manufacture, transmission and use of reactive power. The problem of voltage security affects the whole system, although it typically has a large participation in one of the critical areas of the power system. The insertion of voltage limits constraints assists the method to achieve a minimal amount of control while maintaining a sufficient voltage profile. The reduced aspect of the optimization problem makes the approach fit for real time crisis management. As future work, Voltage Security Constrained Unit Commitment schedule can be formulated for units like hydro power generation plants, nuclear power plants, wind power generation plants and solar power plants etc.

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