2020 IEEE International Conference on Power Electronics, Smart Grid and Renewable Energy (PESGRE2020)

Security-Constrained Unit Commitment for Demand Response Provider - A Stochastic Approach

Pravat Kumar Ray
Senior Member, IEEE
Department of Eleectrical Engineering
National Institute of Technology
Rourkela, India
rayp@nitrkl.ac.in

Chinmaya Jagdev Jena
Department of Eleectrical Engineering
National Institute of Technology
Rourkela, India
cjjena.205@gmail.com

***Abstract*— Introduction of load flexibility is an important factor for achieving the demand Response. In demand response the load is also adjusted at almost all operational time along with adjusting the generation units. The demand response programs require the involvement of all retail customers, and also all the requirements of the independent system operators (ISOs) must be met. The proposed stochastic model is a long-term solution for security-constrained unit commitment (SCUC). The stochastic model for unit commitment is implemented by implementing different scenarios including random disturbances. This paper presents review on scheduling reserves by a market participant Demand Response Provider (DRP). The demand response provider has been found suitable for implementing of ancillary market and day-ahead market in the demand response implementation in the electricity market.**

Keywords—Security-constrained unit commitment, Demand response provider, Ancillary services demand response

I. Introduction

The power industry is advancing towards a distributed and ssophisticated one. The market forces are driving the cost of electricity and lessening net expense through expanded competition. An entity called independent system operator (ISO) ensures independent operation of grid. The ISO is used to establish rules for energy and ancillary services markets, operate transmission system in a reasonable manner and provide restricting measures against market risks.

The major purposes of any electricity market are ensuring security of the system and providing economic operation from both generating and user end. In power industry, unit commitment means optimization of resources from the generation side such that it meets the load demand satisfactorily with the minimum price. Maintaining security is important for all systems, and when the unit commitment solution maintains all the security parameters, it is known as security-constrained unit commitment.

The price-based control of electric utilities started in 1980s. The end-use consumers were allowed to manage their resources using penalties and incentives [2]. The various demand response programs implemented by several ISOs are broadly classified into time-based demand response programs and incentive-based demand response program [3]. Different users have different load curves. Thus, reducing the charges for each consumer will be different. It also depends on their energy utilization, technology of production and contrasts in their tariff levels for power at various occasions of day. The size and nature of the load also determines the efficiency of the program implemented, as studied in [4]. Demand Response is an important factor in the smart grid technology, whose policies were introduced by Federal Energy Regulatory Commission under US government [1][6].

The term security-constrained unit commitment (SCUC) was described as a method to commit generating units economically by J.D. Guy [9][10]. SCUC comes into picture when the security concerns are met satisfactorily and implemented in power network [11]. Before researchers used indirect methods to include such constraints. These methods did not involve the security condition in the dual optimization problem; however, it is abruptly added in the results. These leads to results where a few generating stations remain turned off the unnecessarily. John. J. Shaw introduced a direct method [12] where the algorithm schedules generation for the units for the specified time interval meeting the forecasted demand while satisfying security of the system and constraints regarding the power flow in transmission line. The solution obtained here showed better results compared to indirect methods.

The electricity market is becoming open and the necessity for the schedulers of power system to produce non-discriminatory and high-quality schedules, which can provide secure and consistent operation, is the necessity of the hours. Reference [16] implements the SCUC in open market and determines schedules for a more stable operation. Reference [18] provides a direct-current model algorithm which includes security. Shayesteh, M. Parsa Moghaddam ,S. Taherynejhad and M. K. Sheikh-EL-Eslami [20] implemented Emergency demand response programs to achieve congestion management in the deregulated environment of the operation of power systems.

The optimization techniques can be complex and time consuming. When these are applied for real-time solution, the efficiency in terms of lesser time consumed is more appreciable. Stochastic programming aims at calculating optimal solutions for uncertain data [22]. The random disturbances in the power system can also be optimized using the stochastic programming.

In this paper scheduling for stochastic security-constrained unit commitment method is developed. The methodology is explained and the demand response programs are implemented. The results are obtained for some given systems.

The paper has been organized as follows, section II describes on unit commitment in demand response, section III emphasizes the scheduling by Stochastic Security Constrained Unit Commitment, section IV shows the results and discussions and section V concludes the paper

II. Unit Commitment in Demand Response

Demand response is a program or tariff built up to inspire in changing the electric used by the end-user in response to the change in the cost of electricity after some time, or to give encouraging payment instalments intended to actuate lower electricity uses now and again of high market costs or when grid reliability is imperiled. Demand Side Management (DSM) has advanced from utility programs which have been referred to in the industry as energy protection and management of load. DSM is more extensive in degree than either preservation or load management, be that as it may, and incorporates extra innovations, for example, generation and electric storage, electrification, different advertising methodologies, equipment programs, and new employments. DSM hence incorporates options intended to construct load as well as lessen load. Few examples include valley filling, strategic energy conservation, peak shaving and load shifting. These can also be considered as load management.

In the managed power sector, unit commitment indicates to improving generation assets to fulfil load request at any rate cost. As the linked motive is to reduce operational cost, the unit commitment may also be referred to as cost-based unit commitment. When the motive is to maintain the security, it is a security-constrained unit commitment (SCUC). The economic dispatch coordination conditions reveal to us how to load the units that are running. Deciding the units to run or unit commitment planning is an intelligent augmentation of the dispatching capacity. Alongside the economic dispatching of units on line, the best possible assurance of the units to work is a significant factor in limiting framework fuel costs. The unit commitment program decides if progressing or deferring the beginning and halting occasions of any unit in the preliminary calendar will result in a system fuel cost decrease. In the event that a cost decrease is acquired, the calendar is changed and the checking proceeds until no further improvement can be accomplished. The basic unit commitment logic is as shown in Fig.1.

To achieve the unit commitment, the combinations are made such that either the load is being supplied by an individual unit or by a combination of units depending on the various factors and conditions. Thus, the number of combinations that are to be tested for each individual time interval with M number of time periods for the loading pattern and N number of units to be committed are

$$C_1^N + C_2^N + \ldots + C_{N-1}^N + C_N^N = 2^N - 1 \quad (1)$$

Where C_j^N is combination of N number of items while considering j number of items at that time. Thus for M periods the total number of combinations to be checked is $(2N - 1)^M$. This can be huge number in case of a system consisting of a large number of units and more time intervals. In this paper, stochastic model is used to for obtaining a long-term solution.

III. Scheduling By Stochastic Security-constrained Unit Commitment

The stochastics method is applicable to vertical electrical utilities and independent system operators (ISOs). The whole system is divided into various scenarios and the probability of occurrence of each scenario is estimated using Monte Carlo simulation method. The scenarios can be random disturbances, like the disruption of transmission lines and generating units, inaccuracy in forecasting load, etc. This leads to formation of sub-problems of a deterministic long-term security-constrained unit commitment problem. The demand response model is obtained for different types of demand response programs.

A. Problem Formulation

The ISO receives bids from demand response provider (DRP) and acknowledges them as reserve provided from load side. It is done in ancillary service market more than any other market comparatively. Thus, many ISOs have developed programs and use them as Ancillary Service Demand Response (ASDR) program. It can used as reserve during shortage of reserve. It can also be implemented for day-ahead market and provides incentives if used. ASDR program is implemented using the DRPs connected in the system.

Load reduction demand response (LRDR) program permits participants to avail load reduction offers in the day-ahead energy market. Fig.1 represents the interaction methodology in case of LRDR program being implemented by DRP. ISO introduces the LRDR program, and sends the program data to members, including aggregators and huge clients, and requests that they present their offer bundles to give load reduction in the program. On the off chance that these offers are chosen for task amid the ISO's market clearing process, at that point, members must give the planned load reduction on the following day. The hours wherein offers of a member are acknowledged by the ISO are called program occasions for that member.

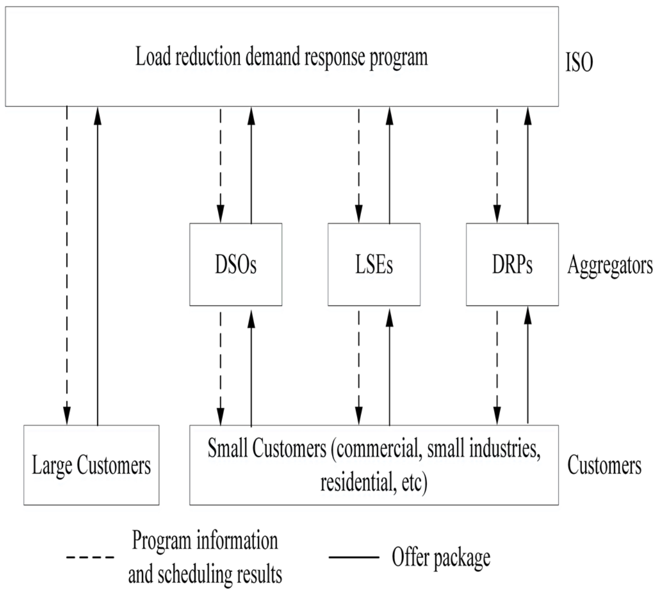

Fig 1. LRDR program's interaction among participants

LRDR resources can be provided by individual demand response provider. The DRP involved in providing actual load reduction should declare the energy response price in the offer package for the curtailment compensation from the ISO. LRDR act as a resource for reserve supplying. In the LRDR program, participants are allowed to for their load reduction offers in day-ahead market. The energy cost of DRP d at hour t is mathematically formulated as follows.

$$CDRP_{d,t} = \sum_{k=1}^{NQ_d} l_k^d p_k^d \quad (2)$$

Where l_k^d is the scheduled load reduction associated with the block k for d^{th} participant at time interval t and p_k^d is the

978-1-7281-4251-7/20/$31.00 ©2020 IEEE

cost associated with block k for d[th] participant d at time interval t.

B. Stochastic Security-constrained Unit Commitment

The SCUC problem models the uncertainties along with various scenarios in the system. The Monte Carlo simulation method, scenario aggregation and scenario reduction techniques are discussed. To determine the frequency of operation and duration of generator and transmission line outages based on forced outage rates and rates to repair the Monte Carlo method is used. The advantage of this method is that to achieve a desired accuracy level number of samples needed is independent of system size. This makes it compatible for large scale simulation.

Scenario Aggregation: Considering NT time periods and ξ_h is a vector describing time h, then $\xi_0^s, \xi_1^s, \ldots, \xi_N$ T^s is the possible scenario. Monte Carlo simulation method creates a set of scenarios S where P_s is the probability of occurrence of s. Now for each of the scenario s, the formula for scenario aggregation is min $P_s \sum_{h=1}^{N} Tf(x_h^s, u_h^s, \xi_h^s)$. x_h^s and u_h^s are the sate variables, decision variables respectively. And ξ_h^s is the scenarios.

Scenario Reduction: The scenario reduction is used to reduce the number of scenarios for computational ease. The technique is a scenario-based approximation having less scenarios and with a justifiably good approximation of original system.

The objective function of the total cost given in equation (2) to be minimized. It consists of cost of energy production including starting up cost, shutting down cost and cost of scheduling DRP reserves.

$$Total\ cost = min \sum_{s=1}^{S} P_s \sum_{p=1}^{NP} \sum_{t=1}^{NT} \sum_{i=1}^{NG} \Big[F_{c,itp}(P_{itp}^s * I_{itp}^s) + SU_{itp}^s + SD_{itp}^s + \sum_{d=1}^{ND} CDRP_d^t \Big] \quad (3)$$

Few constraints which have to be met in obtaining an optimized solution are mentioned in equation (4) to equation (6). The DC Power flow equation is given as below equation. It specifies that the total power generated by all the generating units provides the loads and any transmission losses in the system.

$$\sum_{i=1}^{NG_b} P_{it} - P_{bt}^D = \sum_{l=1}^{L_b} F_{lt} \quad (4)$$

Each transmission line can allow a certain amount of power to pass through it for a certain interval of time. Transmission flow limits are given by equation (5).

$$-F_{lt}^{max} \le F_{lt} \le F_{lt}^{max} \quad (5)$$

The generating units have the limits of maximum power that can be produced at a given interval of time. It also has a lower limit of generation; below which it is not economical to run the unit. Real power generation constraints are mentioned in equation (6).

$$P_{it}^{max} \le P_{it} \le P_{it}^{max} \quad (6)$$

The stochastic long-term SCUC problem can be found by adding a set of constraints with the objective function (7). A Lagrangian multiplier μ_{itp}^s is associated with constraints on each commitment state of unit i. The corresponding penalty term $\mu_{itp}^s(I_{itp}^s - C_{itp})$ is added to objective function.

$$min\ P_s \left\{ \sum_{p=1}^{NP} \sum_{t=1}^{NT} \sum_{i=1}^{NG} \left[F_{c,itp}(P_{itp}^s * I_{itp}^s) + SU_{itp}^s + SD_{itp}^s \right] + \sum_{(s,p,t)\in\{B(S,P,\tau)\}} \sum_{i=1}^{NG} \mu_{itp}^s (I_{itp}^s - C_{itp}) \right\} \quad (7)$$

$$C_{itp} = \frac{\sum_{s\in\{B(S,P,\tau)\}} P_{itp}^s * I_{itp}^s}{\sum_{s\in\{B(S,P,\tau)\}} P_S}$$

Where,

NG = Number of generating units

NT = Number of scheduling hours

NP = Number of weeks under study

Ps = Weight factor of scenario s

$F_{c,itp}()$ = generation cost function of i[th] unit at time t with weekly interval p

P_{itp}^s = Real power generation of i[th] unit at time t with weekly interval p for scenario s

I_{itp}^s= Commitment state of i[th] unit at time t with weekly interval p for scenario s

SU_{itp}^s= Starting up cost of i[th] unit at time t with weekly interval p for scenario s

SD_{itp}^s= Shutting down cost of i[th] unit at time t with weekly interval p for scenario s

P_{it} = Real power generation of i[th] unit at time t

P_{bt}^D = Load demand of b[th] bus at time t

F_{lt} = Real power flow of line l at time t

F_{lt}^{max} = Maximum capacity of line l

P_{it}^{max} = Upper limit of real production of i[th] unit

P_{it}^{min} = Lower limit of real production of i[th] unit

The flow-chart describing the algorithm is shown in Fig.2. The scenarios represent a possible system state which might include outages. Various constraints are checked simultaneously for each scenario. The bundle constraint or coupling constraint is verified.

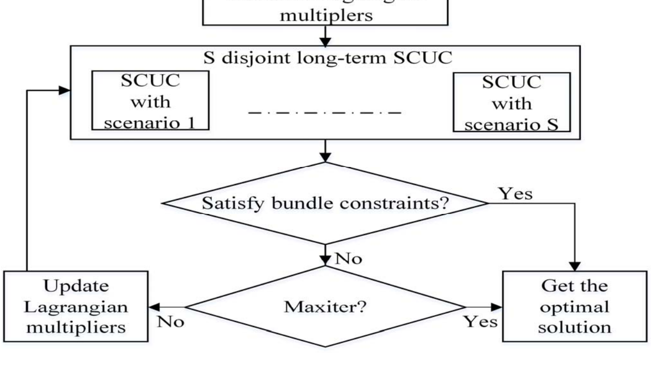

Fig 2: Flowchart for Stochastic Security Constrained Unit Commitment

IV. RESULTS AND DISCUSSIONS

The system considered for testing the proposed algorithms is a 6-bus system as illustrated in Fig.3. The system consist of three generating units, three loads, three DRPs and seven transmission lines. The load is considered for five time-intervals and shown in Table 1. The ramping rates for G1, G2 and G3 are considered to be 5.5 MW, 5.0 MW and 2.0 MW respectively. The curves for cost of generating units are given as quadratic functions with values mentioned in Table 2.

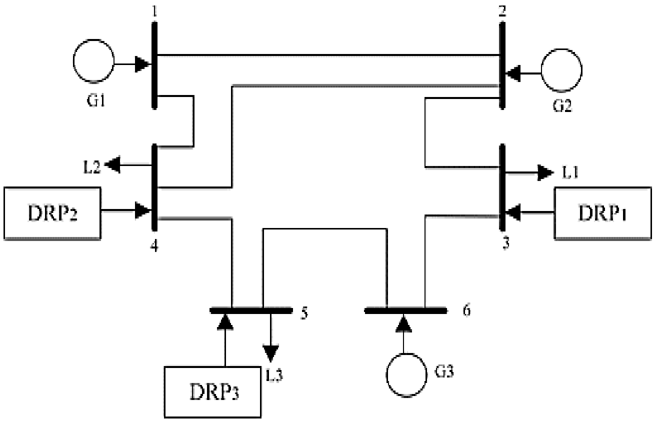

Fig 3: One line diagram of six-bus system considered for SCUC

TABLE 1 LOADING DATA FOR SCUC PROBLEM

HOUR	1	2	3	4	5
LOAD (MW)	150	225	250	200	125

A. ANCILLARY SERVICE DEMAND RESPONSE PROGRAM

The scheduling without considering the DRP's data is shown in Table 3. The stochastic method considers various scenarios and their probability of occurrence for determining the schedule for all the three generating units for the given five time-intervals. Here too the unit G2 is considered during peaks of loads, considering that this unit costs the maximum. G1 and G3 are committed for all the time-periods and power generation varies according to load.

The demand response reserves are considered where minimum 33% of the consumers agree to participate in the demand response program, i.e. k = 0. The offered package is assumed till k = 1, which is 66% of the consumers agree to provide spinning reserve in case of any outage. The total load is assumed to be distributed equally among all the loads connected in system. The scheduling is as shown in Table 4.

The generating unit G2 is a high cost unit, thus it is not considered in scheduling. The spinning reserve will be provided by the load as they are participant in the ASDR program. The load in first and last hour is less, thus outage of G1 generator also will not cause problem to load. However, for peak loads as in second- and third-time interval, DRP will provide the necessary reserve. The fourth hour has required spinning reserve value, but outage of any other unit will make the system unstable, thus a minimum reserve is provided by DRP.

Table 2: Generator Data for system considered in SCUC

Unit		G1	G2	G3
Unit Cost Coefficients	a_{i1} (MBtu/MW^{2}h)	0.00045	0.001	0.005
	a_{i2} (Mbtu/MWh)	13.51	32.63	17.69
	a_{i3} (Mbtu)	176.95	129.97	137.41
P_{max} (MW)		220	100	100
P_{min} (MW)		100	10	10
Initial State (h)		4	2	1
Min Down Time (h)		-4	-3	-1
Min Up Time (h)		4	2	1
Fuel Price (Rs/MBtu)		1.2469	1.2461	1.2462

Table 3: Scheduling Results without considering DR Reserves for Stochastic SCUC

Hour	Unit Status (on/off)			P_i (MW)			Production Cost (Rs/hour)
	G1	G2	G3	G1	G2	G3	
1	1	0	1	100	0	50	3362.3
2	1	1	1	130	10	85	5079.4
3	1	1	1	154	10	86	5510.7
4	1	0	1	145	0	55	4240.2
5	1	0	1	100	0	25	2799.5

Table 4: Scheduling Results with considering DR Reserves for Stochastic SCUC

Hour	Unit Status (on/off)			P_i (MW)			DRP Reserve (MW)
	G1	G2	G3	G1	G2	G3	
1	1	0	1	100	0	50	0
2	1	0	1	155	0	70	16.5
3	1	0	1	155	0	95	33
4	1	0	1	133	0	67	10
5	1	0	1	100	0	25	0

B. LOAD REDUCTION RESPONSE PROGRAM

The DRP offers package for participation in load reduction demand response is mentioned in Table 5. The program is implemented on the same load data as shown in Table 1. The reserves required is calculated as the previous method. Two cases are considered where 5% and 10% of participants, respectively agrees to reduce the load in day-ahead market. The allowable limits for load reduction initiation cost and load reduction duration are not taken into account. The related costs for different participation level in LRDR program are mentioned in Table 6. LRDR program does not provide extra generation in case of peak load, instead it provides compensation to the consumers to reduce the load in the peak hours. It is visible that the total cost for the system for given scheduling decreases. The model's effectiveness can be observed at the reserve costs cause the participants in load reduction demand response programs can participate in reserve market only.

Table 5: Offer package of participants in LRDR program

K	0	1	2
l_a^k	25% of total response	75% of total response	100% of total response
p_a^k**(Rs/MWh)**	12	14	17

Table 6: Offer package of participants in LRDR program

Participation level (%)	**Energy Cost (Rs)**	**Reserve Cost (Rs)**	**LRDR Cost (Rs)**	**Total Cost (Rs)**
5	20553.9	2104.3	137.25	22658.2
10	20553.9	2028.29	274.5	22585.2

V. CONCLUSION

In this paper, the stochastic model is used for schedule reserves provided by DRP for the wholesale power market is presented. DRP models the reserve resources on demand side. A mixed integer representation is used to model the energy and cost associated with the reserve provided. The DRP can be used to model any demand response program. However, ancillary market and day-ahead markets are easier to schedule along with unit commitment in the ISO. The whole algorithm has two stages. The first one consists of network constraints, while the security constraints are considered in the second one. The Monte Carlo simulation is considered to generate outages in the system. The number of scenarios is reduced according to the possibility of occurrence.

The proposed model is applied on a given system and satisfactory results was found. The demand response programs implemented were Ancillary services demand response and load reduction demand response. The two programs were modelled as mixed integer functions and the cost was taken as a factor for the scheduling of generation and reserves in the system. When the demand side is asked to provide reserve, the utility pays the customer the energy price calculated.

ACKNOWLEDGEMENT

The authors would like to thank DST, Govt. of India for supporting the research vide no. DST/INT/Thai/P-12/2019.

REFERENCES

[1] R. M. Delgado, "Demand-side management alternatives," Proceedings of the IEEE, vol. 73, no. 10, pp. 1471–1488, Oct 1985.

[2] Q. Qdr, "Benefits of demand response in electricity markets and recommendations for achieving them," US Dept. Energy, Washington, DC, USA, Tech. Rep, 2006.

[3] Q. B. Dam, S. Mohagheghi, and J. Stoupis, "Intelligent demand response scheme for customer side load management," in 2008 IEEE Energy 2030 Conference, Nov 2008, pp. 1–7.

[4] V. Stepanov, K. Suslov, E. Stashkevich, Z. Styczynski, and N. Voropai, "Demand response for different power supply systems," in IEEE PES Innovative Smart Grid Technologies, Europe, Oct 2014, pp. 1–5.

[5] K. Moslehi and R. Kumar, "A reliability perspective of the smart grid," IEEE Transactions on Smart Grid, vol. 1, no. 1, pp. 57–64, June 2010.

[6] F. E. R. Commission et al., "Demand response compensation in organized wholesale energy markets," Washington DC, March, vol. 15, p. 2, 2011.

[7] M. Shahidehpour, F. Tinney, and Yong Fu, "Impact of security on power systems operation," Proceedings of the IEEE, vol. 93, no. 11, pp. 2013–2025, Nov 2005.

[8] R. Azami and A. F. Fard, "Impact of demand response programs on system and nodal reliability of a deregulated power system," in 2008 IEEE International Conference on Sustainable Energy Technologies, Nov 2008, pp. 1262–1266.

[9] J. D. Guy, "Security constrained unit commitment," IEEE Transactions on Power Apparatus and Systems, vol. PAS-90, no. 3, pp. 1385–1390, May 1971.

[10] S. Takriti, J. R. Birge, and E. Long, "A stochastic model for the unit commitment problem," IEEE Transactions on Power Systems, vol. 11, no. 3, pp. 1497–1508, Aug 1996.

[11] M. Shahidehpour, H. Yamin, and Z. Li, "Market operations in electric power systems: forecasting, scheduling, and risk management." John Wiley & Sons, 2003.

[12] J. J. Shaw, "A direct method for security-constrained unit commitment," IEEE Transactions on Power Systems, vol. 10, no. 3, pp. 1329–1342, Aug 1995.

[13] A. J. Wood, B. F. Wollenberg, and G. B. Sheblé, "Power generation, operation, and control." John Wiley & Sons, 2013.

[14] L. Wu, M. Shahidehpour, and T. Li, "Stochastic security-constrained unit commitment," IEEE Transactions on Power Systems, vol. 22, no. 2, pp. 800–811, May 2007.

[15] H. Ma and S. M. Shahidehpour, "Unit commitment with transmission security and voltage constraints," IEEE Transactions on Power Systems, vol. 14, no. 2, pp. 757–764, May 1999.

[16] A. I. Cohen, V. Brandwahjn, and Show-Kan Chang, "Security constrained unit commitment for open markets," in Proceedings of the 21st International Conference on Power Industry Computer Applications. Connecting Utilities. PICA 99. To the Millennium and Beyond (Cat. No.99CH36351), May 1999, pp. 39–44.

[17] F. Bouffard, F. D. Galiana, and A. J. Conejo, "Market-clearing with stochastic security-part i: formulation," IEEE Transactions on Power Systems, vol. 20, no. 4, pp. 1818–1826, Nov 2005.

[18] M. Madrigal and V. H. Quintana, "A security-constrained energy and spinning reserve markets clearing system using an interior-point method," IEEE Transactions on Power Systems, vol. 15, no. 4, pp. 1410–1416, Nov 2000.

[19] M. Parvania and M. Fotuhi-Firuzabad, "Demand response scheduling by stochastic scuc," IEEE Transactions on Smart Grid, vol. 1, no. 1, pp. 89–98, June 2010.

[20] E. Shayesteh, M. Parsa Moghaddam, S. Taherynejhad, and M. K. Sheikh-EL-Eslami, "Congestion management using demand response programs in power market," in 2008 IEEE Power and Energy Society General Meeting - Conversion and Delivery of Electrical Energy in the 21st Century, July 2008, pp. 1–8.

[21] E. Heydarian-Forushani, M. P. Moghaddam, and M. K. Sheikh-El-Eslami, "A comprehensive load reduction demand response program for spinning reserve provision," in 2013 21st Iranian Conference on Electrical Engineering (ICEE), May 2013, pp. 1–6.

[22] P. Kall, S. W. Wallace, and P. Kall, Stochastic programming. Springer, 1994.