Indian Journal of Engineering

RESEARCH

ISSN 2319 – 7757 EISSN 2319 –7765

Proposing a New Model for Security Constraint Unit Commitment Problem, Considering Network

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Publication History
Received: 03 August 2015
Accepted: 25 August 2015
Published: 1 September 2015 (Special issue)

Citation
Ali Akbar Sayadi, Alireza Siadatan. Proposing a New Model for Security Constraint Unit Commitment Problem, Considering Network. *Indian Journal of Engineering*, 2015, 12(30), 169-175

ABSTRACT
In a restructured power market, the independent system operator (ISO) executes the security-constrained unit commitment (SCUC) program to plan a secure and economical hourly generation schedule for the day-ahead market. This paper introduces an efficient SCUC approach with ac constraints that obtains the minimum system operating cost while maintaining the security of power systems. In this paper, the problem of SCUC of heat units is considered. In such problems, usually transmission lines are neglected and considered to be completely reliable but in this paper, they are considered to make calculation more actual. Math model of this problem is a bi-level program which is calculated in n-k possible models. In first level (high level), total cost of load is optimized and in the second level (lower level), the worst incident with order k is considered. This problem is solved in GAMS software and lines which faced incident are taken out of network using math power software and after running load flow, lines with overload are identified.

Keywords: Unit Commitment, Day-Ahead Market, n-k Model, GAMS

1. INTRODUCTION
The generation business is rapidly becoming market driven. However, the system security is still the most important aspect of the power system operation and cannot be compromised in a market-driven approach. Market operators in various ISOs apply the standard market design (SMD) for scheduling a secure and economically viable power generation for the day-ahead market. One of the key components of SMD is security-constrained unit commitment (SCUC), which utilizes the detailed market information submitted by participants, such as the characteristics of generating units, availability of transmission capacity, generation offers and demand bids, scheduled transactions, curtailment

contracts, and so on (M. Shahidehpour et al., 2002,2000). SCUC provides a financially viable unit commitment (UC) that is physically feasible. The generation dispatch based on SCUC is made available to corresponding market participants. The market participants could use the available signals for reconsidering their proposed bids on generating resources, which includes signals on LMPs and transmission congestion (S. Wang et al., 1995; C. Wang et al., 1994). Normally, an acceptable SCUC solution could be reached in cooperation with market participants if the day-ahead market is healthy and robust.

The initial UC and economic dispatch (ED) of generating units are obtained in the optimal generation block based on the available market information (N. Deeb et al., 1991, 1993). Then, the ac network security block checks the constraints and tries to minimize any network security violations. However, if violations persist, certain constraints (Benders cuts) will be passed along to the optimal generation block for recalculating the UC solution (N. Alguacil et al., 2000). The iterative process will continue until all violations are eliminated and a converged optimal solution is found. In order to satisfy the network security constraints (H. Ma et al., 1998; H. Ma, 1999), replaced transmission constraints with penalty functions that appear directly in the Lagrangian function. In other words, all transmission constraints would be relaxed by using multipliers that are included in UC (G. W. Chang et al., 2001). The addition of multipliers could make it more difficult and even impossible to obtain the optimal UC solution as the number of constraints becomes larger.

In this paper, the problem of SCUC of heat units is considered. In such problems, usually transmission lines are neglected and considered to be completely reliable but in this paper, they are considered to make calculation more actual. Math model of this problem is a bi-level program which is calculated in n-k possible models. In first level (high level), total cost of load is optimized and in the second level (lower level), the worst incident with order k is considered. This problem is solved in GAMS software and lines which faced incident are taken out of network using math power software and after running load flow, lines with overload are identified.

2. MATHEMATICAL METHOD

To solve the problem, its exact model should be presented. In this part, exact mathematic model including objective function and all constraints are presented. Initial mode of problem is a bi-level model which is presented and is substituted with single-stage model.

3. OBJECTIVE FUNCTION AND CONSTRAINTS

The objective function of problem is presented in equation 1 and total cost is minimized in it.

$$\underbrace{Minimize}_{\substack{p_i(t), r_i^{NS}(t), \\ r_i^S(t), \\ v_i(t), v_i^{NS}(t)}} \sum_{t \in H} \sum_{i \in N} [C_{it}^P(p_i(t), v_i(t)) + C_i^S(t) r_i^S(t) + C_i^{NS}(t) r_i^{NS}(t)] \tag{1}$$

Where, the first component is cost of i_{th} generator in t_{th} time, the second component is cost of rotating reserve and the third component is non-rotating reserve. Constraints of this problem are presented in equations 2 to 15

$$\sum_{i \in N} p_i(t) = D(t);\ \forall t \in H \tag{2}$$

$$\sum_{i \in N} A_i^k(t) \left[p_i(t) + r_i^S(t) + r_i^{NS}(t) \right] \ge D(t);\ \forall k \in C, \forall t \in H \tag{3}$$

$$\underline{P}_i v_i(t) \le p_i(t) \le \overline{P}_i v_i(t); \forall i \in N, \forall t \in H \tag{4}$$

$$p_i(t) + r_i^S(t) \le \overline{P}_i v_i(t);\ \ \forall i \in N, \forall t \in H \tag{5}$$

$$0 \le r_i^S(t) \le \overline{R}_i^S v_i(t);\ \forall i \in N, \forall t \in H \tag{6}$$

$$\underline{P}_i v_i^{NS}(t) \le r_i^{NS}(t) \le \overline{R}_i^{NS} v_i^{NS}(t); \forall i \in N, \forall t \in H \tag{7}$$

$$v_i(t) + v_i^{NS}(t) \le 1; \forall i \in N, \forall t \in H \tag{8}$$

$$p_i(t-1) \le p_i(t) + RD_i v_i(t) \tag{9}$$

$$+SD_i[v_i(t-1) - v_i(t)] + \overline{P}_i[1 - v_i(t-1)]\ ;\ \forall i \in N, \forall t \in H$$

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$$p_i(t) \leq p_i(t-1) + RU_i v_i(t-1) \tag{10}$$

$$+SU_i[v_i(t) - v_i(t-1)] + \overline{P}_i[1 - v_i(t)]\ ;\ \forall i \in N, \forall t \in H$$

$$p_i(t) \leq r_i^S(t) + p_i(t-1) + RU_i v_i(t-1) \tag{11}$$

$$+SU_i[v_i(t) - v_i(t-1)] + \overline{P}_i[1 - v_i(t)]\ ;\ \forall i \in N, \forall t \in H$$

$$r_i^{NS}(t) \leq p_i(t-1) + RU_i v_i(t-1) + \overline{R}_i^{NS}[1 - v_i(t-1)]\ ; \tag{12}$$

$$\forall i \in N, \forall t \in H$$

$$r_i^{NS}(t) \leq SU_i\left[U_i^{NS}(t) - v_i(t-1)\right] \tag{13}$$

$$+\overline{R}_i^{NS}\left\{1 - \left[v_i^{NS}(t) - v_i(t-1)\right]\right\}\ ;\ \forall i \in N, \forall t \in H$$

$$v_i \epsilon \{0,1\}^{nH} \cap \vartheta_i ; \forall i \in N \tag{14}$$

$$v_i^{NS}(t) \epsilon \{0,1\} ; \forall i \in N, \forall t \in H \tag{15}$$

Now equations 2 to 15 are explained. These equations will provide security constraint of n-k considering all states of failure k generators from n generator. These states are presented by equation 16.

$$\sum_{i=1}^{k} \binom{n}{i} \tag{16}$$

In other words to justify n-k constraint, system must be able to supply load during outage of all single, double, triplek combinations. Therefore, total number of these states equals summation of these combinations.

4. CASE STUDY

Considered case study of this paper is IEEE 24 bus system. Information and analyzes of this network are presented in next part. Program of new method are written in GAMS and MATHPOWER software.

5. NETWORK INFORMATION

Schematic of this network is presented in Fig. 1 and information about capacity and coefficients of generators cost functions are also presented in Table 1.

Table 1

Information about capacity and coefficients of generators cost functions

Unit	$\underline{P}_i$(MW)	$\overline{P}_i$(MW)	a_i(k$MW2)	b_i (k$/MW)	c_i (k$)	Bus No.
1	2.4	12	0.025	25.54	24.38	15
2	2.4	12	0.026	25.67	24.41	15
3	2.4	12	0.028	25.80	24.63	15
4	2.4	12	0.028	25.93	24.76	15
5	2.4	12	0.028	26.06	24.88	15
6	4.0	20	0.011	37.55	117.75	1
7	4.0	20	0.012	37.66	118.10	1
8	4.0	20	0.013	37.77	118.45	2
9	4.0	20	0.014	37.88	118.82	2
10	15.2	76	0.008	13.32	81.13	1

11	15.2	76	0.009	13.35	81.29	1
12	15.2	76	0.009	13.38	81.46	2
13	15.2	76	0.009	13.40	81.62	2
14	25.0	100	0.006	18.00	217.89	7
15	25.0	100	0.006	18.10	218.33	7
16	25.0	100	0.005	18.20	218.77	7
17	54.25	155	0.004	10.69	142.73	15
18	54.25	155	0.004	10.71	143.02	16
19	54.25	155	0.004	10.73	143.31	23
20	54.25	155	0.004	10.75	143.59	23
21	68.95	155	0.002	23.00	259.13	13
22	68.95	197	0.002	23.10	259.64	13
23	68.95	197	0.002	23.20	260.17	13
24	140.0	350	0.001	10.86	177.05	23
25	100.0	400	0.001	7.49	310.00	18
26	100.0	400	0.001	7.50	311.91	21

Table 2 presents least outage time, least operating time, initial situation and coefficients of cost function of hot starting.

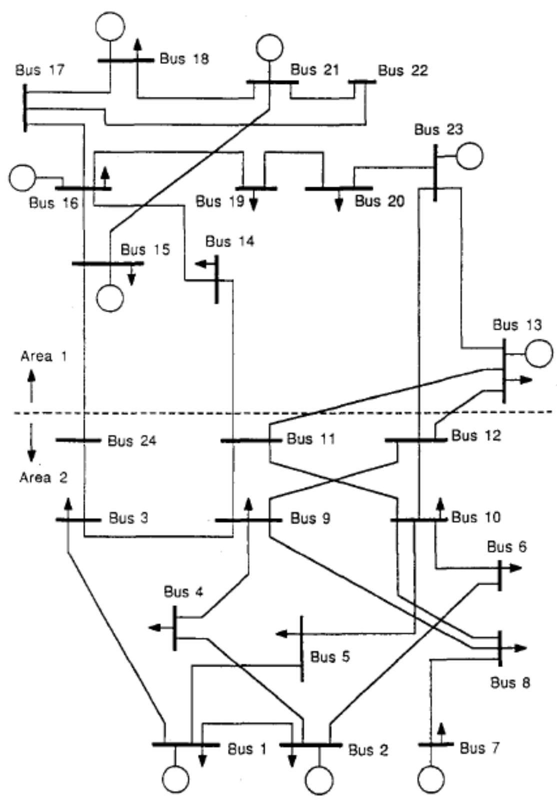

Figure 1
24 bus IEEE test network

Table 2
Least outage time, least operating time, initial situation and coefficients of cost function of hot starting

Unit	Min up (h)	Min down (h)	Init coned (h)	α_1 (\$)	β_1 (\$)	τ_1 (\$)
1--5	0	0	-1	0	0	1
6--9	0	0	-1	20	20	2
10--13	3	-2	3	50	50	3
14--16	4	-2	-3	70	70	4
17--20	5	-3	5	150	150	6
21--23	5	-4	-4	200	200	8
24	8	-5	10	300	200	8
25--26	8	-5	10	500	500	10

And finally, information of network loads for 24 hours is presented in Table 3.

Table 3
Information of network loads for 24 hours

HOUR	LOAD MW	HOUR	LOAD MW	HOUR	LOAD MW
1	2223.0	9	2280.0	17	2593.5
2	2052.0	10	2508.0	18	2850.0
3	1938.0	11	2565.0	19	2821.5
4	1881.0	12	2593.5	20	2764.5
5	1824.0	13	2565.0	21	2679.0
6	1825.5	14	2508.0	22	2622.0
7	1881.0	15	2479.5	23	2479.5
8	1995.0	16	2479.5	24	2308.5

6. SIMULATION RESULTS

In this part, results of applying presented method to case study are presented. Program outputs are hourly production of units and total generation cost.

- *Load distribution without considering transmission network*

In order to present impact of considering transmission line, the program is run in network without transmission line. Results are presented in Table 4.

- *Load distribution considering transmission line*

In this part, transmission part is considered. Total cost of load supplying in this situation is 434273.87 dollars. Supplied power of each unit is presented in Tables 5 and 6.

Table 4
Without transmission line

8	7	6	5	4	3	2	1	
19.08689								10
18.53287								11

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								12
17.51203								13
71.59455	68.15897		61.07447	54.25				17
69.72997	66.3736							18
68.22785	64.93396							19
67.04587		64.92301						20
208.27	198.0335	201.577	176.9255	152.1156	210	210	210	24
300	300	294.25	294.25	289.8347	252.0802	252.0802	252.0802	25
300	300	294.25	294.25	287.5497	250.4198	250.4198	250.4198	26

Table 5
Supplied power of each unit

16	15	14	13	12	11	10	9	
19.65374					20.5049	20.5049	28.50956	10
					19.91834	19.91835	27.73746	11
							27.11617	12
							26.31593	13
			68.15896	68.15895	74.9389	74.93905	93.81301	17
71.03645	65.75924	65.98372	66.37361	66.3736	72.997	72.99698	91.43509	18
	64.33102		64.93396	64.93398	71.43445	71.43424	89.52969	19
68.30981		63.4219			70.20641	70.20648	88.04308	20
210	196.1597	196.8444	198.0335	198.0335	210	210	210	24
300	300	300	300	300	300	300	300	25
300	300	300	300	300	300	300	300	26

Table 6
Supplied power of each unit

24	23	22	21	20	19	18	17	
			20.50488		19.05666		19.65374	10
			19.91831	24.26413	18.50464			11
				23.70691	18.05271			12
				22.99379				13
		68.15893	74.93896	85.42897	71.52434	68.15896		17
		66.3736	72.99734	83.24474	69.66115	66.37361	71.03646	18
		64.934	71.43413	81.4916	68.16053	64.93397		19
	64.92301		70.20638	80.11986	66.97946		68.30981	20
210	201.577	198.0335	210	210	208.0605	198.0335	210	24
252.0802	294.25	300	300	300	300	300	300	25
250.4198	294.25	300	300	300	300	300	300	26

Units' reservation summation is presented in Table 7.

Table 7

The amount of units' reservation summation

1	2	3	4	5	6	7	8
362.5	362.5	362.5	394.25	394.25	394.25	502.75	602.6
9	10	11	12	13	14	15	16
617.8	587.4	587.4	502.75	502.75	448.5	448.5	463.7
17	18	19	20	21	22	23	24
463.7	502.75	602.6	602.6	587.4	502.75	394.25	362.5

7. CONCLUSION

Results of this paper are as follow

1. To calculate n-k commitment, with increase in k, number of states to be analyzed gets too much and problem becomes un-solvable.
2. 2-to model worst case during problem of minimizing total cost of load supplying, it is required to add a new modeling problem as constraint which makes resulted model a two states model.
3. Analyzing lines outage, it is observed that some lines are overloaded in special incidents. To prevent their overloads, units' storages can be used.

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