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Impact of Shunt FACTS Devices on Security Constrained Unit Commitment

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Benders Decomposition (BD),
Load Shedding (LS).

ABSTRACT

Shunt FACTS Devices (SFD) would play an important role in maintaining security and reduce total generation cost in the economical operation of power systems. The application of this device to the AC model of security-constrained unit commitment (SCUC) for the day ahead scheduling is presented in this paper. The proposed AC model of SCUC with SFD would include active and reactive power flow constraints which increase the network controllability at normal operation and contingency. A general SFD model is introduced for the reactive power management in SCUC which is based on the reactive power injection model (RPIM). The case studies demonstrate the effectiveness of the SFD application to SCUC with AC network constraints. Meanwhile simulation results demonstrate the combined use of these devices to SCUC have a significant impact on maintaining network security, preventing load shedding, lower total generation cost and increase using the maximum capacity of the existing transmission network.

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1. INTRODUCTION

In a restructured power market, the independent system operator (ISO) oversees the operation bulk electric power system, transmission lines, and electricity market generated and transmitted by its member utilities. The primary stated mission of the ISO is to operate the grid reliably and efficiently, provide fair and open transmission access, promote environmental stewardship, and facilitate effective markets and promote infrastructure development. The ISO has the authority and responsibility to commit and dispatch system generation units and curtail loads for maintaining the system security at normal operation and contingency (i.e., balance load demands and satisfy fuel, environmental aspects, and network security requirements) [1]-[3]. The ISO executes the SCUC program to plan a secure and economic scheduling of generating units start-ups and shut-downs over a given time horizon for serving the hourly load demand while satisfying temporal and operational limits of generation and transmission facilities in power systems [2]-[4]. The objective of SCUC is to maximize the social welfares based on energy and price bids submitted by market participants, generation suppliers, and load demanders. As a key decision-making component for the current power system operation, the modeling and solution of SCUC, especially for the large-scale power systems, should be seriously recognized and analyzed.

The restructuring of power utilities has increased the uncertainties in system operation. The regulatory constraints on the expansion of the transmission network has resulted in reduction of stability margins and increased the risks of cascading outages and blackouts. This problem can be effectively tackled by the introduction of high power electronic controllers for the regulation of power flows and voltages in AC transmission networks. This allows 'flexible' operation of AC transmission systems whereby the changes can be accommodated easily without stressing the system. Power electronic based systems and other static equipment that provide controllability of power flow and voltage are termed as Flexible AC Transmission Systems (FACTS) controllers [5].

The role of FACTS devices in power system performance enhancement becomes more important, since the main responsibility of generation units is to produce active, rather than reactive power compensation. Maximum power transmission (close to lines thermal limit) over a long distance in a power system, without adversely affecting the stability and security margin, can be achieved through a fast power flow control. Voltage stability depends on the ability of the power system to maintain acceptable voltage for the system buses under normal conditions, and, also, in the face of disturbances. In other words, after an incidence of disturbance, i.e. an increase in demand load and/or system characteristic changes, the system may face voltage instability, which may cause an uncontrollable deviation of voltage [4]. The failure of power systems to provide the required reactive power is the main cause of instability. Therefore, considering the reactive power security margin can increase the reliability of the system and prevent any possible blackouts. FACTS obtained a well-known reputation for higher controllability in power systems by means of power electronic devices. The first application of FACTS devices is a fast power flow control and voltage stability, which can help to improve the system security [5]-[8].

In this paper, an effective ac contingency dispatch over a day ahead period based on the security-constrained unit commitment (SCUC) model is proposed. A general model of SFD is incorporated in the proposed SCUC formulations. GENCOs will submit their bids to the ISO. The ISO will then use this model to minimize the bid-based system operating cost while maintaining the system security at both normal state and pre-defined contingency cases.

This paper is organized as follows. Section II provides an outline of the proposed model. Section III describes the formulations of SCUC and SCOPF based on ac network. Section IV presents and discusses test cases considering the prevailing constraints. The conclusion drawn from the study is provided in Section V.

2. MODEL OUTLINE

Figure 1 depicts the flowchart of the proposed SCUC model that encompasses NCOPF and SCOPF with ac contingency dispatch over the 24-h horizon. NCOPF utilizes the UC solution for calculating the optimal dispatch of resources, minimizing the bid-based operating cost at steady state. SCOPF utilizes the UC solution for calculating the optimal dispatch of units, minimizing the bid-based operating cost at preventing system violations when contingencies occur. Benders decomposition is utilized to decompose the SCUC problem into smaller and easier to solve subproblems [9]-[12]. The master problem uses the available market information to find the optimal hourly schedule of units (UC) by considering the prevailing UC constraints The hourly solution of UC is used in the subproblems to examine the AC network constraints at steady state and contingency [13]-[24]. The shunt FACTS devices are incorporated in the subproblems if violations are detected. Given the unit schedule by the UC solution, the Subproblem 1 will check the base case network feasibility. In this subproblem, slack variables for real and reactive power mismatches are minimized based on line flow and Shunt FACTS Devices adjustments. The proposed Benders cut incorporate slack variables for the real and reactive power mismatch that is mitigated by recalculating the unit schedules. If NCOPF cannot guarantee the system security at steady-state load shedding may be utilized for managing a feasible solution. A converged base case power flow will be achieved based on the UC results. The contingencies network check subproblem, i.e., subproblem 2, uses the UC solution for the base case to check the system security in case of contingencies. Using AC power flow equations, both real and reactive power mismatches are minimized in this subproblem. If SCOPF cannot guarantee the system security at critical contingencies, LS may be utilized for managing a feasible solution. In our approach, augmented Lagrangian relaxation (ALR) is applied to solve UC.

2.1. Ncopf

This section in Figure 2 consists of optimal power flow (OPF) for checking hourly network constraints. The OPF is optimized by applying primal/dual interior point method (PDIPM). The OPF checks hourly network constraints to find out whether the proposed UC solution can provide a converged ac power flow and meet network constraints (such as transmission flow and bus voltage limits). If the NCOPF is infeasible, the Benders cuts will be introduced into the next UC calculation. The iterative process between UC and the subproblem 1 will continue until ac violations are eliminated. If the maximum number of iterations of the NCOPF is reached before identifying a feasible solution, the load shedding (LS) is prescribed to find a converged NCOPF solution at steady state [25]-[30].

2.2. Scopf

At this stage the converged ncopf solution at steady state will be utilized for examining ac contingencies. Here we solve opf with additional constraints for each contingency in which represents a time-based permissible adjustment of real power generation. Once a contingency is introduced, if violations are not eliminated within the emergency time by applying control variables such as real power generation and shunt facts devices, the contingency will be labeled as uncontrollable contingency. Accordingly, a pre-contingency operating point is sought for the uncontrollable contingency by recalculating the uc. The new operating point that includes preventive control actions can prevent system violations in the event of the uncontrollable contingency. Meanwhile, possible corrective dispatch controls within the given emergency time will eliminate system violations for any controllable contingencies.

2.3. Ls

If violations resulting from uncontrollable contingencies cannot be mitigated by available control measures, ls will provide a feasible ncopf/ scopf solution based on decremental bids/contracts. The idea for applying ls is to add virtual generators at load buses where ls is allowed. The effect of a virtual generator is to shed local loads for removing any violations at steady state and contingencies. Ls at a substation could represent several curtailment contracts. We provide the following five assumptions for implementing ls.

- In this proposed algorithm, demand bids are inelastic. Ls is represented as an undesirable function, and ls contract prices are presumably higher than generating unit bids. Ls is treated as the last resort when all other options fail in seeking a feasible solution.
- Virtual units are considered for ncopf at steady state and scopf at contingency based on the hourly commitment of units.
- It is assumed that each load bus power factor is constant.
- The ratio of system spinning/ operating reserve requirement to the total load is assumed to remain constant for the entire time.

2.4. Solution Procedure

- Solve uc.
- Check the hourly ac power flow dispatch at steady state by opf. If the hourly opf is not converged and number of iteration between uc and the subproblem 1 (ncopf) is not reached, benders cuts go back to step 1 for recalculating uc. Otherwise, if the hourly opf converged, proceed to the step 5.
- If the maximum number of iteration between uc and the subproblem 1 (ncopf) is reached and the opf is not converged, use the feasible uc results at the previous iteration as the final and go to the next step for the ls solution.
- Add virtual generators to opf and obtain the ls solution at steady state.
- Solve scopf subproblem with additional constraints for each contingency. Check the hourly ac network for each contingency. If ac power flow is not converged or network (transmission flows and bus voltages) violations exist, and number of iteration between uc and the subproblem 2 (scopf) is not reached, form the corresponding benders cuts and return to step 1.
- If the scopf solution is infeasible and the maximum number of iterations is reached, label the contingency as uncontrollable. Use the feasible uc results at the previous iteration as the final and go to the next step for the ls solution.
- Add virtual generators to opf and obtain the ls solution at contingency state.

3. PROBLEM FORMULATION

3.1. UC Formulation

The objective of the UC problem is to determine the set of generating units while minimizes the total production cost over the scheduling period. Therefore, the objective function is expressed as the sum of fuel, start-up and shut down costs of the generating units. The UC problem can be mathematically formulated as [17]:

$$\mathrm{Min.\,TGC} = \sum_{i=1}^{Nu}\sum_{h=1}^{Nh}\left\{\begin{matrix}\left[\, F_i(P_{ih}) + SU_{ih}\cdot\left(1 - Z_{i(h-1)}\right)\right]\cdot Z_{ih} \\ + SD_{ih}\cdot(1 - Z_{ih})\cdot Z_{i(h-1)}\end{matrix}\right\} \tag{1}$$

Due to the operational requirements, the minimization of the objective function is subjected to the following constraints:

(a) Power balance constraints

$$\sum_{i=1}^{Nu} P_{ih} \cdot Z_{ih} = P_{Dh} + P_{Lh} \quad (2)$$
$$\sum_{i=1}^{Nu} Q_{ih} \cdot Z_{ih} = Q_{Dh} + Q_{Lh}$$

(b) Spinning and operating reserve constraints

$$\sum_{i=1}^{Nu} \left[R_{S,ih} \cdot Z_{ih}\right] \geq R_{Sh} \quad (3)$$
$$\sum_{i=1}^{Nu} \left[R_{O,ih} \cdot Z_{ih}\right] \geq R_{Oh}$$

(c) Minimum up/down time constraints

$$\left[X_{i(h-1)}^{on} - T_i^{on}\right] \cdot \left[Z_{i(h-1)} - Z_{ih}\right] \geq 0 \quad (4)$$
$$\left[X_{i(h-1)}^{off} - T_i^{off}\right] \cdot \left[Z_{ih} - Z_{i(h-1)}\right] \geq 0$$

(d) Power generation limit constraints

$$\underline{P}_i \cdot Z_{ih} \leq P_{ih} \leq \overline{P}_i \cdot Z_{ih} \quad (5)$$
$$\underline{Q}_i \cdot Z_{ih} \leq Q_{ih} \leq \overline{Q}_i \cdot Z_{ih}$$

(e) Ramping Up/Down limits

$$P_{ih} - P_{i(h-1)} \leq \left[1 - Z_{ih} \cdot \left(1 - Z_{i(h-1)}\right)\right] \cdot RU_i + Z_{ih} \cdot \left(1 - Z_{i(h-1)}\right) \cdot \underline{P}_i$$
$$P_{i(h-1)} - P_{ih} \leq \left[1 - Z_{i(h-1)} \cdot (1 - Z_{ih})\right] \cdot RD_i + Z_{i(h-1)} \cdot (1 - Z_{ih}) \cdot \underline{P}_i \quad (6)$$

Also note that P_{Lh} and Q_{Lh} in (2) is originally the estimated system loss at time h. However, following the iterations between UC and the subproblem 1 NCOPF, the estimated will be updated by its exact value obtained from the subproblem of NCOPF.

In order to solve UC, the ALR method is employed for relaxing power system constraints (2), (3). The relaxed problem is decomposed into N subproblems for each unit. Dynamic programming (DP) including minimum up/down time limit (5), and ramp rate limits (6) is used to search for the optimal commitment of a single unit over the entire study period. Lagrangian multipliers are updated based on violations of system constraints. The convergence criterion is satisfied if the duality gap between primal and dual solutions is within a given limit. [13] – [15].

3.2 NCUC/SCOPF with Load Shedding

Based on UC results, the objective function (9) is to minimize OPF and LS costs at steady state and when considering contingencies. The second term in the objective function is for modeling virtual units that will be used if OPF is infeasible. Constraints (10) and (11) represent the power balance and system spinning/operating reserve requirement. Note that the ratio of system spinning/operating reserve requirement to the total load should be fixed based on the above assumption for LS.

$$\text{Min. } TGC = \sum_{i=1}^{Nu} \sum_{h=1}^{Nh} \{ F_i(P_{ih}) \cdot Z_{ih}\} + \sum_{k=1}^{Nvu} \sum_{h=1}^{Nh} F_{sk}(VP_{kh}) \quad (7)$$

(f) Power balance constraints

$$\sum_{i=1}^{Nu} P_{ih} \cdot Z_{ih} + \sum_{k=1}^{Nvu} VP_{kh} = P_{Dh} + P_{Lh} \quad (8)$$
$$\sum_{i=1}^{Nu} Q_{ih} \cdot Z_{ih} + \sum_{k=1}^{Nvu} VQ_{kh} = Q_{Dh} + Q_{Lh}$$

(g) Spinning and operating reserve constraints

$$\sum_{i=1}^{Nu}\left[R_{S,ih}\cdot Z_{ih}\right] \geq \frac{R_{Sh}}{P_{D,h}}\cdot\left(P_{D,h}-\sum_{k=1}^{Nvu}VP_{kh}\right) \quad (9)$$

$$\sum_{i=1}^{Nu}\left[R_{O,ih}\cdot Z_{ih}\right] \geq \frac{R_{Oh}}{P_{D,h}}\left(P_{D,h}-\sum_{k=1}^{Nvu}VP_{kh}\right)$$

(a) Generation limit constraints

$$\underline{P}_i\cdot Z_{ih} \leq P_{ih} \leq \overline{P}_i\cdot Z_{ih} \quad (10)$$

$$\underline{Q}_i\cdot Z_{ih} \leq Q_{ih} \leq \overline{Q}_i\cdot Z_{ih}$$

(b) Ramping Up/Down limits

$$P_{ih}-P_{i(h-1)} \leq \left[1-Z_{ih}\cdot\left(1-Z_{i(h-1)}\right)\right]\cdot RU_i + Z_{ih}\cdot\left(1-Z_{i(h-1)}\right)\cdot\underline{P_i} \quad (11)$$

$$P_{i(h-1)}-P_{ih} \leq \left[1-Z_{i(h-1)}\cdot(1-Z_{ih})\right]\cdot RD_i + Z_{i(h-1)}\cdot(1-Z_{ih})\cdot\underline{P_i}$$

(c) The power flow equations

$$G_b(X,U,C)=0 \qquad b=1,2,\dots,Nb \quad (12)$$

(d) The transmission line flows constraint

$$\underline{P_l} \leq P_{lh} \leq \overline{P}_l \qquad l=1,2,\dots,Nl \quad (13)$$

(a) The voltage of the buses

$$\underline{V_b} \leq V_b \leq \overline{V}_b \qquad b=1,2,\dots,Nb \quad (14)$$

(a) The Shunt FACTS Devices constraint

$$\underline{P}_{sf} \leq P_{sf} \leq \overline{P}_{sf} \qquad f=1,2,\dots,Nf \quad (15)$$

$$\underline{Q}_{sf} \leq Q_{sf} \leq \overline{Q}_{sf} \qquad f=1,2,\dots,Nf$$

The state vector X comprises of the bus voltage phase angles and magnitudes. The control vector U comprises of all the controllable system variables like real power generations and reactive power generated by Shunt FACTS Devices. The parameter vector C includes all the uncontrollable system parameters such as line parameters, loads, etc.

4. CASE STUDIES

The proposed model is applied to a thirty -bus test system to illustrate the performance of SCUC.

4.1. thirty -Bus test System

The thirty-bus system depicted in Figure 2 has five units, forty-one transmission lines. The characteristics of units, transmission lines, and the hourly load distribution over the 24-h horizon are given in Tables I–III, respectively. The magnitude of voltage at each bus must be between 0.95 and 1.05. In order to analyze the efficiency of the proposed method, the following five case studies with corresponding constraints is considered:

Case 1) UC (without network constraints);

Case 2) NCUC;

Case 2_1) NCUC without SFD.

Case 2_2) NCUC with SFD at bus 8 adjustment.

Case 2_3) NCUC with SFD at buses 7,8,21 and 30 adjustment.

Case 3) SFD device at bus 8 are used to;

Case 3_1) committed to minimizing total generation cost.

Case 3_2) regulate related magnitude voltage bus 8 at 1.0 (pu).

Case 4) SCUC by outage of line 6–8 (contingency dispatch);

Case 4_1) SCUC without SFD.

Case 4_2) SCUC with SFD at buses 7,8,21 and 30 adjustment.

Assume the LS contract is 500$/MWh for each load.

Case 5) failure in unit 3 (contingency dispatch);

Case 5_1) SCUC without SFD.

Case 5_2) SCUC with SFD at buses 7,8,21 and 30 adjustment.

Assume the LS contract is 500$/MWh for each load.

In some cases, according Table IV, SFD are considered. These devices are modeled using the proposed RPIM [18].

Case 1) In this case, UC will determine the base case schedule of units, when disregarding the network constraints. The commitment schedule is shown in Table IV in which 1 and 0 represent hourly on/off states of units, and hour 0 represents the initial condition. In addition, the daily bid-based generation dispatch cost given in Table IV is $ 142203.6145. The optimal generation dispatch given in Table V. In this case, the economical units 1, 2 and 4 supply the base load, which are committed at the entire scheduling horizon. The units 3 are committed at certain hours (11-21) to supply peak load and to minimize the total generation cost. More expensive units 4 and 5 are not committed at all hours.

Case 2) In case 2_1, the impact of ac network constrained at steady state on unit commitment (NCUC) is studied. If we use the UC results in Case 1 for NCOPF calculations, magnitude voltage violations will occur at buses 12-20. In order to considering the network constraints, we find that the other UC in Case 2_1. So, the commitment schedule is shown in Table IV and the optimal generation dispatch of NCOPF is changed as shown in Table V. The highlighted items in mentioned Table show differences between Case 1 and Case 2_1. In order to maintaining the magnitude voltage buses to their limits ($0.95 \leq V \leq 1.05$) and line capacity limits in accordance Table II, the generation dispatch of the economical units 1, 2, 3 and 4 is changed. The relatively expensive units 5 and 6 are dispatched to supply the system loads. Accordingly, the daily cost of bid-based generation dispatch increases to $ 169505.19.

In Cases 2_2-2_3, the SFD inject the controllable reactive power to the network and also manage reactive power flows and accordingly adjust bus voltage levels. The SFD decrease the reactive power flow on the network lines and therefore increase the transfer capability of the lines. In case 2_2-2_3 the voltage at all buses and the reactive power flow at network lines is changed by the SFD. In case 2_2, the reactive power generation by Shunt FACTS Device at bus 8 is shown in Table VII. In case 2_3, the reactive power generation by SFD is shown in Fig. 3.The commitment schedule is shown in Table VI and the optimal generation dispatch of NCOPF is changed as shown in Table VII. The highlighted items in Tables IV, VI show differences between all this section cases compared to case 1. Without the SFD the voltage drop occur at all buses mostly at peak hours. However, the reactive power injection to the network increases the bus voltages and prevents voltage and line capacity violations. Without the Shunt FACTS Devices, voltages are adjusted by the neighboring generating units. The reactive power generation of units is increased for adjusting the voltage level at buses, which would also increase the reactive power flow at network lines. So, the SFD could reduce the active and reactive power dispatch of units, decrease reactive power line flows, bus voltage support and minimize the total generation cost. In the whole cases are mentioned, case 2_3 has the minimum total generation cost and less committed more expensive units. Therefor distributed SFD in load buses is better choice for power system planning.

Case 3) In these cases (3_1 and 3_2), NCUC will determine schedule of units when SFD is committed to minimizing total generation cost (case 3_1) and regulate related bus voltage at 1 pu. The commitment schedule is shown in Table VIII and active power generation dispatch in Table IX. It is clear that when the SFD committed to regulating corresponding bus voltage is less effective on minimizing cost function. Therefore, it is desirable these controllable devices should be adjust based on NCUC planning. If contingency is occurred, the SCUC determines the setting of SFD. The capacity of this equipment should be determined based on long-term planning. The reactive power generation by SFD is shown in Table IX. The highlighted items in Tables VIII show differences between all this section cases compared to case 1.

Case 4) The outage of line 6–8, based on results of NCUC, will cause the line capacity 6-28, 8-28, 21-24 and 22-24 out of permissible range. The addition of Benders cuts to the SCOPF for a preventive dispatch control will provide a feasible dispatch solution. Then Benders cuts to UC for modifying the UC/SCOPF solution are generated. In Table X the modified UC solution is given. However, at hours 1-24, because of bus voltage and mentioned line capacity limits, if all of the units is committed still cannot satisfy the network constraints. Thus, virtual generator are added at load bus 8 for load curtailment. As a result, certain amount of load is curtailed at violated hours (1-24). Despite LS cost, the daily bid-based dispatch cost is more increased. The new generation dispatch in SCOPF is illustrated in Table XI. In case 4_2, the considering of SFD in the network has caused that magnitude voltage of the buses are not out of range. But because of line capacity limits or network congestion in this case, the SFD does not help to prevent load curtailment at hours 8-24. The highlighted items in Tables X show differences between all this section cases compared to case 1. In case 4_2, Because of entire reactive power injection controlling and reactive power flow managing in network, the SFD are the best option in optimizing cost, less load curtailment and maintaining network security. It is clear with distributed SFD in network and supporting of all bus voltages has the better result in NCUC/SCUC problems. The reactive power generation by SFD is shown in Fig. 4.

Case 5) In cases 5_1-5_2, the generating unit 2 out of service. According to the NCUC results, unit 3 fails to supply loads at hours 1 through 24. Thus, the SCOPF solution for this contingency will require Benders cut for recomputing UC. The commitment schedule is shown in Table XII and active power generation dispatch in Table XIII. The highlighted items in Tables XII show differences between all this section cases compared to case 1. By comparison optimal generation dispatch in Tables VII and XIII, it is clear that the expensive units 3, 5 and 6 replaces unit 2 to supply more loads. In case 5_2, by economic adjusting of SFD in the network has caused that magnitude voltage of the buses are not out of range. The reactive power generation by SFD is shown in Fig. 5.

5. CONCLUSIONS

The NCUC/SCUC results of numerical tests show the effectiveness of the proposed method for minimizing bid based generation cost and maintain network security in steady state and contingency. The proposed method could solve both NCUC and SCUC modules based on ac constraints and advice a good set of corrective and preventive control protocol for the secure and economical operation of power systems.

Impact of SFD adjustment was investigated into the NCUC/SCUC with AC network constraints at steady state and contingency. To enhance the proposed AC solution of SCUC, Shunt FACTS devices were considered. A RPIM was used to model the effect of SFD in the AC power flow, using reactive power injections to system load buses. We concluded that the incorporation of SFD would enhance the hourly SCUC solution when considering bus voltage and line capacity constraints.

If the SFD with the sufficient capacity at full load centers to be installed and utilized, more effective in the short-term power system planning will yield. Distributed fast controllable shunt reactive power resources will regulate bus voltage, less reactive power flow and reduce losses in the power system. Furthermore, the use of maximum capacity of the transmission system will be provided. Meanwhile, economic dispatch of load between power plants can provide. With turn off more expensive units in low and medium demand hours, the total production cost decreases. More expensive units may be used in terms of network emergency event if needed to maintain network security. Therefore proper operation of this equipment in the SCUC is necessary.

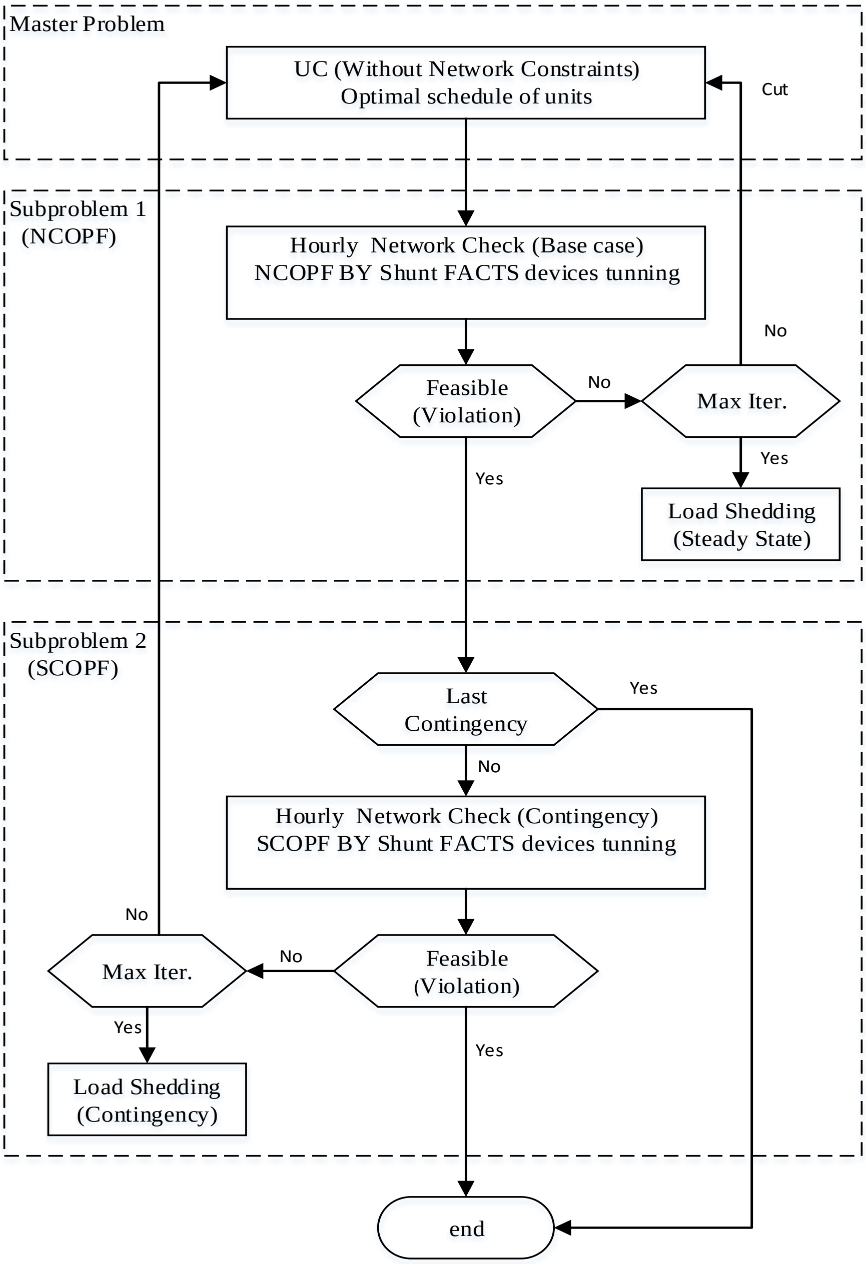

Figure 1. Flowchart of SCUC with Shunt FACTS Devices for reactive power management

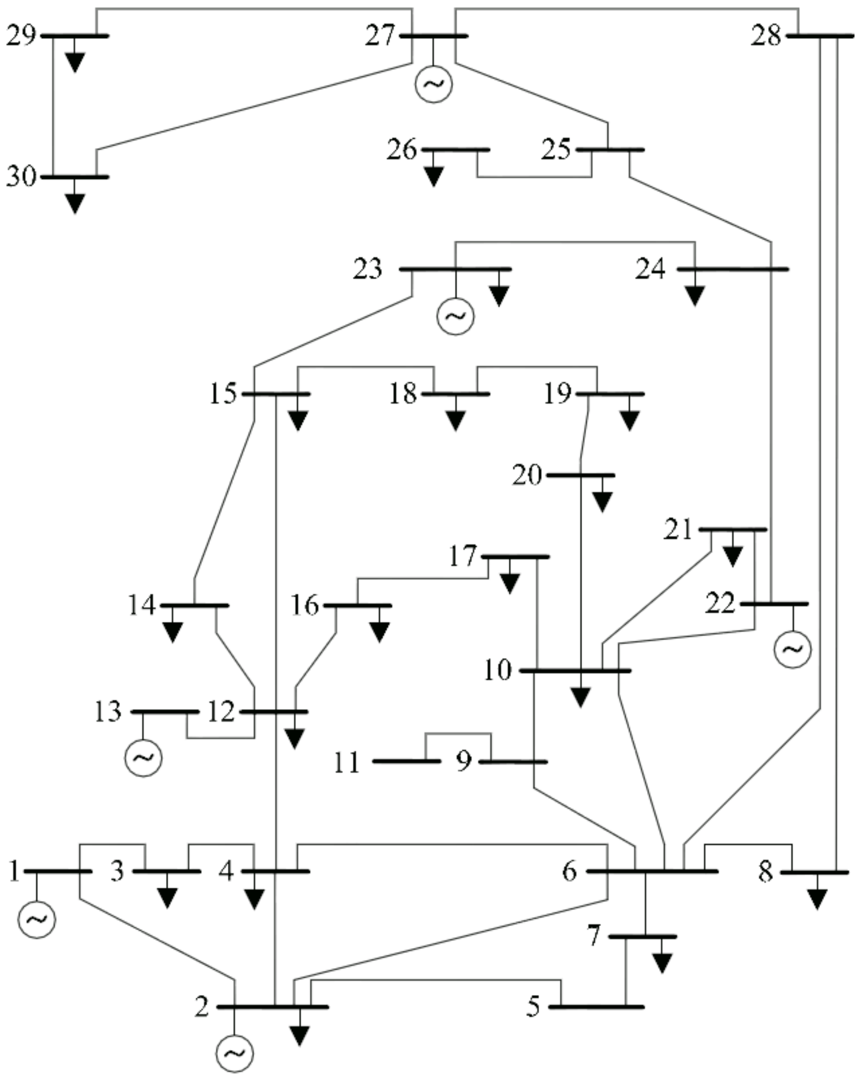

Figure 2. The 30-bus system

Table I. Unit Data

Unit No.		1	2	3	4	5	6
Bus No.		1	2	13	22	23	27
Unit Cost coefficients	a (MBtu)	150	180	125	200	90	75
	b (MBtu/MWh)	30	20.75	36.3	12.9	42.6	45.8
	c (MBtu/MW^{2}h)	0.02	0.0175	0.0125	0.00625	0.0135	0.0124
P_{min} (MW)		10	10	10	10	10	10
P_{max}(MW)		90	80	70	80	90	90
Q_{min}(Mvar)		-20	-15	-10	-15	-20	-20
Q_{max}(Mvar)		70	60	50	60	70	70
Start Up cost ($)		20	30	10	40	10	10
Shut down cost ($)		40	60	20	80	20	20
Fuel Cost ($/MBtu)		1.00	1.00	1.00	1.00	1.00	1.00
Initial Hour State (h)		2	4	1	4	1	1
Minimum Up Time (h)		2	4	1	4	1	1
Minimum Down Time (h)		-1	-2	-1	-2	-1	-1
Ramp Up Rate (MW/h)		50	40	30	40	20	30
Ramp Down Rate (MW/h)		60	45	25	50	25	40

Table 2. Transmission Line Data

Line No.	From Bus	To Bus	R (pu)	X (pu)	B (pu)	Flow Limit (MW)	Line No.	From Bus	To Bus	R (pu)	X (pu)	B (pu)	Flow Limit (MW)
1	1	2	0.02	0.06	0.03	130	22	15	18	0.11	0.22	0	16
2	1	3	0.05	0.19	0.02	130	23	18	19	0.06	0.13	0	16
3	2	4	0.06	0.17	0.02	65	24	19	20	0.03	0.07	0	32
4	3	4	0.01	0.04	0	130	25	10	20	0.09	0.21	0	32
5	2	5	0.05	0.2	0.02	130	26	10	17	0.03	0.08	0	32
6	2	6	0.06	0.18	0.02	65	27	10	21	0.03	0.07	0	32
7	4	6	0.01	0.04	0	90	28	10	22	0.07	0.15	0	32
8	5	7	0.05	0.12	0.01	70	29	21	22	0.01	0.02	0	32
9	6	7	0.03	0.08	0.01	130	30	15	23	0.1	0.2	0	16
10	6	8	0.01	0.04	0	40	31	22	24	0.12	0.18	0	16
11	6	9	0	0.21	0	65	32	23	24	0.13	0.27	0	16
12	6	10	0	0.56	0	32	33	24	25	0.19	0.33	0	16
13	9	11	0	0.21	0	65	34	25	26	0.25	0.38	0	16
14	9	10	0	0.11	0	65	35	25	27	0.11	0.21	0	16
15	4	12	0	0.26	0	65	36	28	27	0	0.4	0	65
16	12	13	0	0.14	0	65	37	27	29	0.22	0.42	0	16
17	12	14	0.12	0.26	0	32	38	27	30	0.32	0.6	0	16
18	12	15	0.07	0.13	0	32	39	29	30	0.24	0.45	0	16
19	12	16	0.09	0.2	0	32	40	8	28	0.06	0.2	0.02	32
20	14	15	0.22	0.2	0	16	41	6	28	0.02	0.06	0.01	32
21	16	17	0.08	0.19	0	16							

Table 3. Hourly Load Distribution Data

Hour	Pd (MW)	Qd (Mvar)	Hour	Pd (MW)	Qd (Mvar)
1	191.9610	108.7893	13	272.8550	154.6341
2	181.1370	102.6551	14	274.5930	155.6190
3	177.0450	100.3360	15	276.1000	156.4731
4	174.1740	98.7090	16	277.3320	157.1713
5	175.1420	99.2575	17	278.3770	157.7635
6	181.9730	103.1289	18	279.4000	158.3433
7	197.8020	112.0996	19	274.8240	155.7499
8	214.8410	121.7560	20	267.4870	151.5919
9	230.6920	130.7392	21	258.5660	146.5361
10	244.8930	138.7873	22	244.7940	138.7312
11	253.2640	143.5313	23	228.2390	129.3490
12	264.9350	150.1456	24	221.8590	125.7333

Table 4. Uc (Case 1), Ncuc (Case 2_1)

THE DAILY COST OF BID BASED GENERATION DISPATCH ($)												
	142203.6145						169505.19					
	CASE 1						CASE 2_1					
Hour	U1	U2	U3	U4	U5	U6	U1	U2	U3	U4	U5	U6
0	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	0	1	0	0	1	1	0	1	0	1
2	1	1	0	1	0	0	1	1	0	1	0	1
3	1	1	0	1	0	0	1	1	0	1	0	1
4	1	1	0	1	0	0	1	1	0	1	0	1
5	1	1	0	1	0	0	1	1	0	1	0	1
6	1	1	0	1	0	0	1	1	0	1	0	1
7	1	1	0	1	0	0	1	1	1	1	0	1
8	1	1	0	1	0	0	1	1	1	1	0	1
9	1	1	0	1	0	0	1	1	1	1	0	1
10	1	1	0	1	0	0	1	1	1	1	0	1
11	1	1	1	1	0	0	1	1	1	1	0	1
12	1	1	1	1	0	0	1	1	1	1	1	1
13	1	1	1	1	0	0	1	1	1	1	1	1
14	1	1	1	1	0	0	1	1	1	1	1	1
15	1	1	1	1	0	0	1	1	1	1	1	1
16	1	1	1	1	0	0	1	1	1	1	1	1
17	1	1	1	1	0	0	1	1	1	1	1	1
18	1	1	1	1	0	0	1	1	1	1	1	1
19	1	1	1	1	0	0	1	1	1	1	1	1
20	1	1	1	1	0	0	1	1	1	1	1	1
21	1	1	1	1	0	0	1	1	1	1	1	1
22	1	1	0	1	0	0	1	1	1	1	0	1
23	1	1	0	1	0	0	1	1	1	1	0	1
24	1	1	0	1	0	0	1	1	1	1	0	1

Table 5. Active Power (Mw) Generation Dispatch (Case 1), Ncuc (Case 2_1)

Hour	CASE 1						CASE 2_1					
	U1	U2	U3	U4	U5	U6	U1	U2	U3	U4	U5	U6
1	31.961	80	0	80	0	0	57.56	80	0	48.95	0	10
2	21.137	80	0	80	0	0	42.88	80	0	52.21	0	10
3	17.045	80	0	80	0	0	37.69	80	0	53.06	0	10
4	14.174	80	0	80	0	0	34.09	80	0	53.62	0	10
5	15.142	80	0	80	0	0	35.30	80	0	53.44	0	10
6	21.973	80	0	80	0	0	43.97	80	0	52	0	10
7	37.802	80	0	80	0	0	46.27	80	10	55.82	0	10
8	54.841	80	0	80	0	0	65.96	80	10	54.07	0	10
9	70.692	80	0	80	0	0	86.27	80	10	50.74	0	10
10	84.893	80	0	80	0	0	90	80	24.99	46.58	0	10
11	83.264	80	10	80	0	0	90	80	36.98	43.10	0	10
12	90	80	14.935	80	0	0	90	80	37.42	44.80	10	10
13	90	80	22.855	80	0	0	90	80	48.46	41.87	10	10
14	90	80	24.593	80	0	0	90	80	51.02	41.08	10	10
15	90	80	26.1	80	0	0	90	80	53.30	40.34	10	10
16	90	80	27.332	80	0	0	90	80	55.21	39.69	10	10
17	90	80	28.377	80	0	0	90	80	56.86	39.11	10	10
18	90	80	29.4	80	0	0	90	80	57.37	38.35	10.93	10.33
19	90	80	24.824	80	0	0	90	80	51.37	40.97	10	10
20	90	80	17.487	80	0	0	90	80	40.92	43.90	10	10
21	88.566	80	10	80	0	0	90	80	45.20	40.34	10	10
22	84.794	80	0	80	0	0	90	80	24.85	46.62	0	10
23	68.239	80	0	80	0	0	83.03	80	10	51.31	0	10
24	61.859	80	0	80	0	0	74.75	80	10	52.72	0	10

Table 6. Ncuc (Case 2_2, Case 2_3)

Hour	THE DAILY COST OF BID BASED GENERATION DISPATCH ($)											
	164063.2						159658.89					
	CASE 2_2						CASE 2_3					
	U1	U2	U3	U4	U5	U6	U1	U2	U3	U4	U5	U6
0	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	0	1	0	1	1	1	0	1	0	0
2	1	1	0	1	0	1	1	1	0	1	0	0
3	1	1	0	1	1	0	1	1	0	1	0	0
4	1	1	0	1	1	0	1	1	0	1	0	0
5	1	1	0	1	1	0	1	1	0	1	0	0
6	1	1	0	1	0	1	1	1	0	1	0	0
7	1	1	0	1	0	1	1	1	0	1	0	0
8	1	1	0	1	0	1	1	1	0	1	0	0
9	1	1	1	1	0	1	1	1	0	1	1	0
10	1	1	1	1	0	1	1	1	1	1	1	1
11	1	1	1	1	0	1	1	1	1	1	0	0
12	1	1	1	1	0	1	1	1	1	1	0	0
13	1	1	1	1	0	1	1	1	1	1	0	0
14	1	1	1	1	0	1	1	1	1	1	0	0
15	1	1	1	1	0	1	1	1	1	1	0	0
16	1	1	1	1	0	1	1	1	1	1	0	0
17	1	1	1	1	0	1	1	1	1	1	1	0
18	1	1	1	1	0	1	1	1	1	1	1	0
19	1	1	1	1	0	1	1	1	1	1	0	0
20	1	1	1	1	0	1	1	1	1	1	0	0
21	1	1	1	1	0	1	1	1	1	1	0	0
22	1	1	1	1	0	1	1	1	1	1	1	1
23	1	1	1	1	0	1	1	1	0	1	1	0
24	1	1	0	1	0	1	1	1	0	1	1	0

Table 7. Active Power (Mw) Generation Dispatch, Ncuc (Case 2_2, Case 2_3)

Hour	CASE 2_2							CASE 2_3					
	U1	U2	U3	U4	U5	U6	Q_{SF}	U1	U2	U3	U4	U5	U6
1	48.85	80	0	57.15	0	10	77.97	61.13	80	0	55.69	0	0
2	36.80	80	0	57.85	0	10	74.87	48.55	80	0	56.74	0	0
3	23.13	80	0	57.34	10	0	64.33	43.83	80	0	57.12	0	0
4	29.99	80	0	57.42	10	0	64.06	40.53	80	0	57.40	0	0
5	31.05	80	0	57.40	10	0	64.15	41.64	80	0	57.31	0	0
6	37.72	80	0	57.82	0	10	75.27	49.52	80	0	56.66	0	0
7	55.59	80	0	56.55	0	10	79.27	68.09	80	0	54.94	0	0
8	76.44	80	0	53.85	0	10	83.05	89.52	80	0	51.71	0	0
9	81.02	80	10	55.59	0	10	81.78	89.15	80	0	57.28	10	0
10	90	80	16.92	54.64	0	10	86.64	84.31	80	10	56.15	10	10
11	90	80	26.42	53.59	0	10	87.31	79.42	80	44.25	56.02	0	0
12	90	80	40.29	51.55	0	10	87.73	86.95	80	49.51	55.58	0	0
13	90	80	50.22	49.73	0	10	88.02	90	80	54.99	55.32	0	0
14	90	80	52.47	49.27	0	10	88.09	90	80	56.81	55.27	0	0
15	90	80	54.44	48.85	0	10	88.15	90	80	58.46	55.22	0	0
16	90	80	56.07	48.50	0	10	88.20	90	80	60.07	54.91	0	0
17	90	80	56.98	48.09	0	10.55	88.22	90	80	49.72	55.16	10	0
18	90	80	56.98	47.51	0	12.14	88.18	90	80	50.83	55.10	10	0
19	90	80	52.77	49.21	0	10	88.10	90	80	57.06	55.26	0	0
20	90	80	43.44	51.01	0	10	87.82	88.67	80	50.61	55.48	0	0
21	90	80	32.62	52.75	0	10	87.50	82.69	80	46.77	55.81	0	0
22	90	80	16.81	54.65	0	10	86.62	84.20	80	10	56.16	10	10
23	78.27	80	10	55.69	0	10	80.72	86.41	80	0	57.39	10	0
24	85.59	80	0	52.27	0	10	84.47	79.30	80	0	57.67	10	0

Table 8. Ncuc with (Case 3_1, Case 3_2)

Hour	THE DAILY COST OF BID BASED GENERATION DISPATCH ($)											
	164063.2						167852.04					
	CASE 3_1						CASE 3_2					
	U1	U2	U3	U4	U5	U6	U1	U2	U3	U4	U5	U6
0	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	0	1	0	1	1	1	0	1	0	1
2	1	1	0	1	0	1	1	1	0	1	0	1
3	1	1	0	1	1	0	1	1	0	1	0	1
4	1	1	0	1	1	0	1	1	0	1	0	1
5	1	1	0	1	1	0	1	1	0	1	0	1
6	1	1	0	1	0	1	1	1	0	1	0	1
7	1	1	0	1	0	1	1	1	1	1	0	1
8	1	1	0	1	0	1	1	1	1	1	0	1
9	1	1	1	1	0	1	1	1	1	1	0	1
10	1	1	1	1	0	1	1	1	1	1	0	1
11	1	1	1	1	0	1	1	1	1	1	0	1
12	1	1	1	1	0	1	1	1	1	1	1	1
13	1	1	1	1	0	1	1	1	1	1	1	1
14	1	1	1	1	0	1	1	1	1	1	1	1
15	1	1	1	1	0	1	1	1	1	1	1	1
16	1	1	1	1	0	1	1	1	1	1	1	1
17	1	1	1	1	0	1	1	1	1	1	1	1
18	1	1	1	1	0	1	1	1	1	1	1	1
19	1	1	1	1	0	1	1	1	1	1	1	1
20	1	1	1	1	0	1	1	1	1	1	1	1
21	1	1	1	1	0	1	1	1	1	1	0	1
22	1	1	1	1	0	1	1	1	1	1	0	1
23	1	1	1	1	0	1	1	1	1	1	0	1
24	1	1	0	1	0	1	1	1	1	1	0	1

Table 9. Active Power (Mw)

Hour	CASE 3_1							CASE 3_2						
	U1	U2	U3	U4	U5	U6	Q_{SF}	U1	U2	U3	U4	U5	U6	Q_{SF}
1	48.85	80	0	57.15	0	10	77.97	57.01	80	0	49.35	0	10	4.62
2	36.80	80	0	57.85	0	10	74.87	42.67	80	0	52.19	0	10	5.6
3	33.13	80	0	57.34	10	0	64.33	37.40	80	0	53.19	0	10	5.71
4	29.99	80	0	57.42	10	0	64.06	33.76	80	0	53.83	0	10	5.05
5	31.05	80	0	57.40	10	0	64.15	34.98	80	0	53.62	0	10	5.27
6	37.72	80	0	57.82	0	10	75.27	43.76	80	0	51.99	0	10	5.54
7	55.59	80	0	56.55	0	10	79.27	45.98	80	10	55.87	0	10	18.71
8	76.44	80	0	53.85	0	10	83.05	64.99	80	10	54.87	0	10	13.18
9	81.02	80	10	55.59	0	10	81.78	83.88	80	10	52.81	0	10	16.28
10	90	80	16.92	54.64	0	10	86.64	90	80	21.91	49.37	0	10	18.38
11	90	80	26.42	53.59	0	10	87.31	90	80	33.24	46.53	0	10	18.83
12	90	80	40.29	51.55	0	10	87.73	90	80	34.11	48.02	10	10	23.04
13	90	80	50.22	49.73	0	10	88.02	90	80	44.07	46.02	10	10	23.36
14	90	80	52.47	49.27	0	10	88.09	90	80	46.34	45.49	10	10	23.43
15	90	80	54.44	48.85	0	10	88.15	90	80	48.35	45.01	10	10	23.49
16	90	80	56.07	48.50	0	10	88.20	90	80	50.02	44.59	10	10	23.54
17	90	80	56.98	48.09	0	10.55	88.22	90	80	51.45	44.22	10	10	23.58
18	90	80	56.98	47.51	0	12.14	88.18	90	80	52.86	43.84	10	10	23.62
19	90	80	52.77	49.21	0	10	88.10	90	80	46.65	45.42	10	10	23.44
20	90	80	43.44	51.01	0	10	87.82	90	80	37.25	47.44	10	10	23.14
21	90	80	32.62	52.75	0	10	87.50	90	80	40.83	44.36	0	10	19.06
22	90	80	16.81	54.65	0	10	86.62	90	80	21.78	49.40	0	10	18.37
23	78.27	80	10	55.69	0	10	80.72	80.86	80	10	53.22	0	10	15.49
24	85.59	80	0	52.27	0	10	84.47	73.17	80	10	54.140	0	10	13.59

Table 9. Active Power (Mw))

Hour	Case 3_1 U1	U2	U3	U4	U5	U6	Q_{SF}	Case 3_2 U1	U2	U3	U4	U5	U6	Q_{SF}
1	48.85	80	0	57.15	0	10	77.97	57.01	80	0	49.35	0	10	4.62
2	36.80	80	0	57.85	0	10	74.87	42.67	80	0	52.19	0	10	5.6
3	33.13	80	0	57.34	10	0	64.33	37.40	80	0	53.19	0	10	5.71
4	29.99	80	0	57.42	10	0	64.06	33.76	80	0	53.83	0	10	5.05
5	31.05	80	0	57.40	10	0	64.15	34.98	80	0	53.62	0	10	5.27
6	37.72	80	0	57.82	0	10	75.27	43.76	80	0	51.99	0	10	5.54
7	55.59	80	0	56.55	0	10	79.27	45.98	80	10	55.87	0	10	18.71
8	76.44	80	0	53.85	0	10	83.05	64.99	80	10	54.87	0	10	13.18
9	81.02	80	10	55.59	0	10	81.78	83.88	80	10	52.81	0	10	16.28
10	90	80	16.92	54.64	0	10	86.64	90	80	21.91	49.37	0	10	18.38
11	90	80	26.42	53.59	0	10	87.31	90	80	33.24	46.53	0	10	18.83
12	90	80	40.29	51.55	0	10	87.73	90	80	34.11	48.02	10	10	23.04
13	90	80	50.22	49.73	0	10	88.02	90	80	44.07	46.02	10	10	23.36
14	90	80	52.47	49.27	0	10	88.09	90	80	46.34	45.49	10	10	23.43
15	90	80	54.44	48.85	0	10	88.15	90	80	48.35	45.01	10	10	23.49
16	90	80	56.07	48.50	0	10	88.20	90	80	50.02	44.59	10	10	23.54
17	90	80	56.98	48.09	0	10.55	88.22	90	80	51.45	44.22	10	10	23.58
18	90	80	56.98	47.51	0	12.14	88.18	90	80	52.86	43.84	10	10	23.62
19	90	80	52.77	49.21	0	10	88.10	90	80	46.65	45.42	10	10	23.44
20	90	80	43.44	51.01	0	10	87.82	90	80	37.25	47.44	10	10	23.14
21	90	80	32.62	52.75	0	10	87.50	90	80	40.83	44.36	0	10	19.06
22	90	80	16.81	54.65	0	10	86.62	90	80	21.78	49.40	0	10	18.37
23	78.27	80	10	55.69	0	10	80.72	80.86	80	10	53.22	0	10	15.49
24	85.59	80	0	52.27	0	10	84.47	73.17	80	10	54.140	0	10	13.59

Generation Dispatch, Ncuc (Case 3_1, Case 3_2

Table 10. Scuc (Case 4_1, Case 4_2)

Hour														
	THE DAILY COST OF BID BASED GENERATION DISPATCH ($)													
	287742.43							239067.86						
	THE DAILY COST OF BID BASED GENERATION DISPATCH WITHOUT SHEDDING COST ($)													
	166345.63							160032.86						
	THE DAILY SHEDDING COST ($)													
	121396.8							79035						
	CASE 4_1						LC_8 (MW)	CASE 4_2						LC_8 (MW)
	U1	U2	U3	U4	U5	U6		U1	U2	U3	U4	U5	U6	
0	1	1	1	1	1	1	-	1	1	1	1	1	1	-
1	1	1	0	1	0	1	3.3490	1	1	0	1	0	1	-
2	1	1	1	1	0	1	1.4364	1	1	0	1	0	1	-
3	1	1	0	1	0	1	0.8424	1	1	0	1	0	0	-
4	1	1	1	1	0	1	0.2762	1	1	0	1	0	0	-
5	1	1	0	1	0	1	0.5556	1	1	0	1	0	0	-
6	1	1	0	1	0	1	1.7317	1	1	0	1	0	1	-
7	1	1	1	1	0	1	4.0783	1	1	0	1	0	1	-
8	1	1	1	1	0	1	6.8148	1	1	0	1	0	1	2.66
9	1	1	1	1	0	1	9.5128	1	1	0	1	0	1	5.18
10	1	1	1	1	0	1	11.6520	1	1	0	1	0	1	7.43
11	1	1	1	1	1	1	12.8537	1	1	0	1	0	1	8.76
12	1	1	1	1	1	1	14.7065	1	1	1	1	0	1	10.61
13	1	1	1	1	0	1	16.0117	1	1	1	1	0	1	11.87
14	1	1	1	1	1	1	16.5492	1	1	1	1	0	1	12.15
15	1	1	1	1	1	1	16.64	1	1	1	1	0	1	12.39
16	1	1	1	1	1	1	16.7142	1	1	1	1	0	1	12.58
17	1	1	1	1	1	1	17.2187	1	1	1	1	0	1	12.75
18	1	1	1	1	1	1	17.2820	1	1	1	1	0	1	12.91
19	1	1	1	1	1	1	16.5631	1	1	1	1	0	1	12.18
20	1	1	1	1	0	1	15.2724	1	1	1	1	0	1	11.01
21	1	1	1	1	0	1	13.9429	1	1	0	1	0	1	9.60
22	1	1	1	1	0	1	11.6473	1	1	0	1	0	1	7.42
23	1	1	1	1	0	1	9.0497	1	1	0	1	0	1	4.79
24	1	1	1	1	0	1	8.093	1	1	0	1	0	1	3.78

Table 11. Active Power (Mw) Generation Dispatch, Scuc (Case 4_1, Case 4_2)

Hour	Case 4_1 Unit No.						Case 4_2 Unit No.					
	1	2	3	4	5	6	1	2	3	4	5	6
1	46.71	80	0	48.62	0	18.01	41.01	80	0	58.03	0	17.09
2	24.43	80	10	55.01	0	14.07	32.98	80	0	58.92	0	13.03
3	32.31	80	0	52.77	0	15.35	29.88	80	0	59.22	0	11.59
4	23.18	80	10	42.28	0	21.51	27.71	80	0	59.41	0	10.60
5	30.56	80	0	53.22	0	14.98	28.44	80	0	59.35	0	10.93
6	36.98	80	0	51.57	0	16.06	33.62	80	0	58.86	0	13.33
7	38.10	80	10	52.98	0	17	44.94	80	0	57.39	0	19.77
8	51.17	80	10	52.01	0	19.97	57.88	80	0	56.24	0	23.05
9	64.34	80	10	49.98	0	22.73	70.14	80	0	55.22	0	25.92
10	69.23	80	18.65	46.71	0	24.74	80.85	80	0	54.18	0	28.90
11	31.64	80	61.75	32.28	10	28.31	87.07	80	0	53.51	0	30.84
12	35.39	80	61.26	29.89	10	38.61	88.29	80	10	53.48	0	29.15
13	70.72	80	49.05	35.74	0	27.87	89.96	80	14.84	52.90	0	30.05
14	68.02	80	39.33	41.21	10	26.04	89.99	80	16.26	52.76	0	30.22
15	66.33	80	42.84	40.55	10	26.24	90	80	17.52	52.65	0	30.36
16	62.17	80	49.35	39.34	10	26.08	90	80	18.55	52.55	0	30.47
17	67.19	80	43.92	40.38	10	26.24	90	80	19.42	52.47	0	30.57
18	66.04	80	46.34	39.91	10	26.38	90	80	20.28	52.39	0	30.67
19	67.76	80	39.87	41.11	10	26.07	89.99	80	16.45	52.75	0	30.24
20	72.03	80	40.83	38.58	0	27.21	90	80	10	53.19	0	29.95
21	72.53	80	29.84	42.38	0	26.19	90	80	0	52.79	0	33.28
22	69.39	80	18.38	46.74	0	24.73	90	80	0	54.19	0	28.88
23	62.15	80	10	50.38	0	22.43	68.23	80	0	55.38	0	25.47
24	56.93	80	10	51.27	0	21.02	63.29	80	0	55.79	0	24.31

Table 12. Scuc (case 5_1, case 5_2)

Hour	Case 5_1							Case 5_2						
The daily cost of bid based generation dispatch ($)	262955.52							202171.96						
The daily cost of bid based generation dispatch without curtailment cost ($)	198946.17							198096.96						
The daily curtailment cost ($)	64009.35							4075						
	Unit No.						LC_{21}	Unit No.						LC_{21}
	1	2	3	4	5	6		1	2	3	4	5	6	
0	1	1	1	1	1	1	-	1	1	1	1	1	1	-
1	1	0	1	1	0	1	-	1	0	1	1	0	0	-
2	1	0	1	1	0	1	-	1	0	1	1	0	0	-
3	1	0	1	1	0	1	-	1	0	1	1	0	0	-
4	1	0	1	1	0	1	-	1	0	1	1	0	0	-
5	1	0	1	1	0	1	-	1	0	1	1	0	0	-
6	1	0	1	1	0	1	-	1	0	1	1	0	0	-
7	1	0	1	1	0	1	-	1	0	1	1	0	0	-
8	1	0	1	1	1	1	-	1	0	1	1	1	0	-
9	1	0	1	1	1	1	-	1	0	1	1	1	1	-
10	1	0	1	1	1	1	-	1	0	1	1	1	1	-
11	1	0	1	1	1	1	2.5770	1	0	1	1	1	1	-
12	1	0	1	1	1	1	8.5773	1	0	1	1	1	1	-
13	1	0	1	1	1	1	12.8719	1	0	1	1	1	1	-
14	1	0	1	1	1	1	13.7159	1	0	1	1	1	1	0.21
15	1	0	1	1	1	1	14.4552	1	0	1	1	1	1	1
16	1	0	1	1	1	1	15.1123	1	0	1	1	1	1	1.65
17	1	0	1	1	1	1	15.6765	1	0	1	1	1	1	2.21
18	1	0	1	1	1	1	16.2278	1	0	1	1	1	1	2.75
19	1	0	1	1	1	1	13.7783	1	0	1	1	1	1	0.33
20	1	0	1	1	1	1	9.8723	1	0	1	1	1	1	-
21	1	0	1	1	1	1	5.1542	1	0	1	1	1	1	-
22	1	0	1	1	1	1	-	1	0	1	1	0	1	-
23	1	0	1	1	1	1	-	1	0	1	1	0	1	-
24	1	0	1	1	1	1	-	1	0	1	1	0	1	-

Table13. Active Power (Mw) Generation Dispatch, Scuc (Case 5_1, Case 5_2)

Hour	Case 5_1 Unit No.						Case 5_2 Unit No.					
	1	2	3	4	5	6	1	2	3	4	5	6
1	90	0	42.75	53.24	0	10	90	0	46.66	58.73	0	0
2	90	0	30.08	55	0	10	90	0	35.10	59.29	0	0
3	90	0	25.46	55.42	0	10	90	0	30.76	59.48	0	0
4	90	0	22.24	55.72	0	10	90	0	27.74	59.61	0	0
5	90	0	23.32	55.62	0	10	90	0	28.76	59.57	0	0
6	90	0	31.03	54.89	0	10	90	0	35.98	59.25	0	0
7	90	0	49.93	51.99	0	10	90	0	52.95	58.41	0	0
8	90	0	59.80	47.56	10	12.39	90	0	62.56	56.26	10	0
9	90	0	57.72	40.67	10.01	37.35	90	0	64.94	51.51	18.69	10
10	90	0	56.21	31.72	19.04	53.33	90	0	64.94	47.24	11.51	35.70
11	90	0	55.33	28.73	26.08	55.93	90	0	64.94	43.69	15.63	43.78
12	90	0	55.39	32.78	25.54	58.08	90	0	64.84	38.50	21.18	55.65
13	90	0	55.30	37.20	23.67	55.93	90	0	64.68	33.42	28.78	61.41
14	90	0	55.55	37.10	24.06	59.70	90	0	64.32	31.96	30.85	62.77
15	90	0	56.08	36.25	24.82	60.06	90	0	64.32	32.60	30.65	63.05
16	90	0	56.19	36.56	24.78	60.28	90	0	64.32	33.13	30.48	63.28
17	90	0	56.15	37.19	24.52	60.44	90	0	64.32	33.58	30.33	63.47
18	90	0	56.12	37.77	24.29	60.61	90	0	64.32	34.02	30.19	63.66
19	90	0	55.94	36.03	24.81	59.82	90	0	64.32	32.06	30.82	62.82
20	90	0	55.77	32.87	25.86	58.58	90	0	64.84	36.98	23.54	57.40
21	90	0	55.78	28.41	27.52	57.12	90	0	64.93	41.74	10	56.89
22	90	0	56.22	31.82	18.87	53.28	90	0	64.78	46.77	0	47.82
23	90	0	58.07	41.75	10	33.39	90	0	64.74	52.44	0	25.07
24	90	0	58.94	44.53	10	23.25	90	0	64.70	54.34	0	16.72

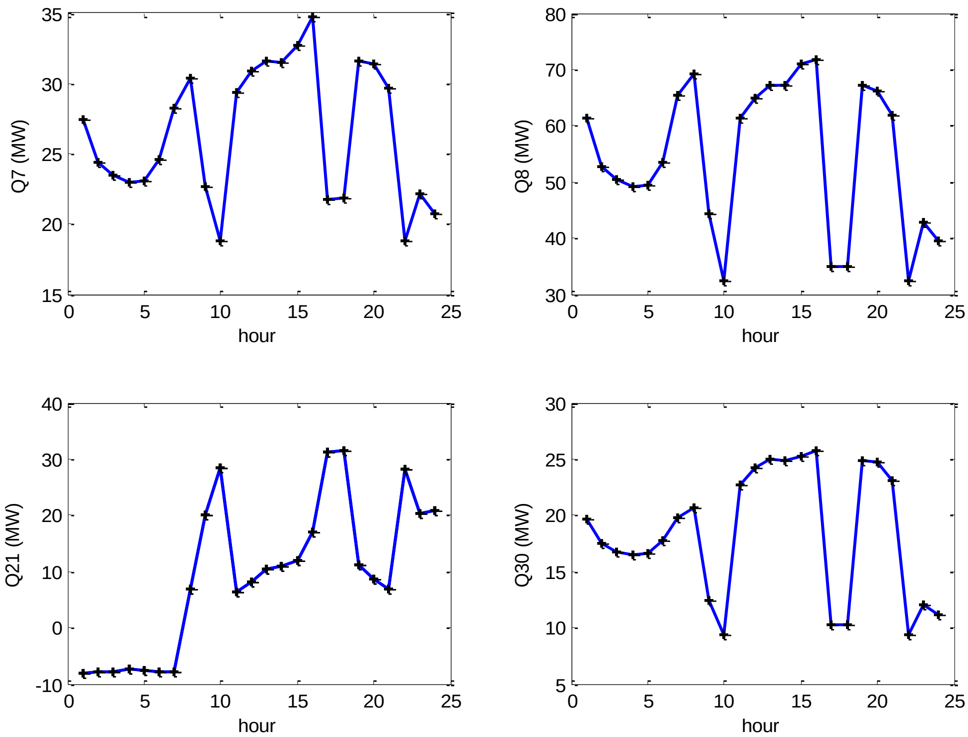

Figure 3. Reactive Power generation by SFD (cases 2_3)

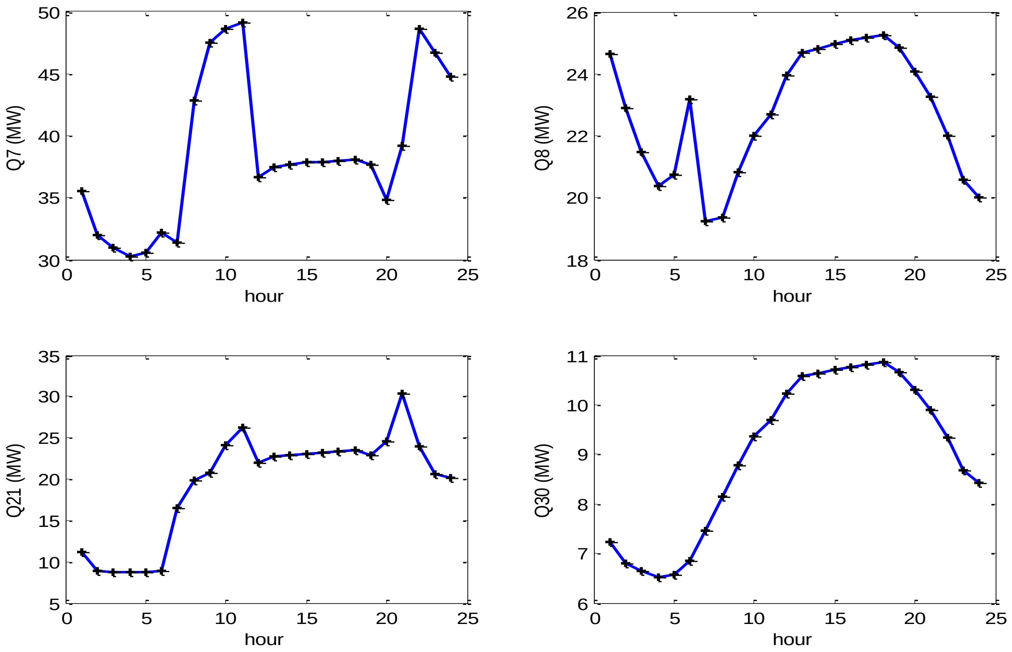

Figure 4. Reactive Power generation by SFD (cases 4_2)

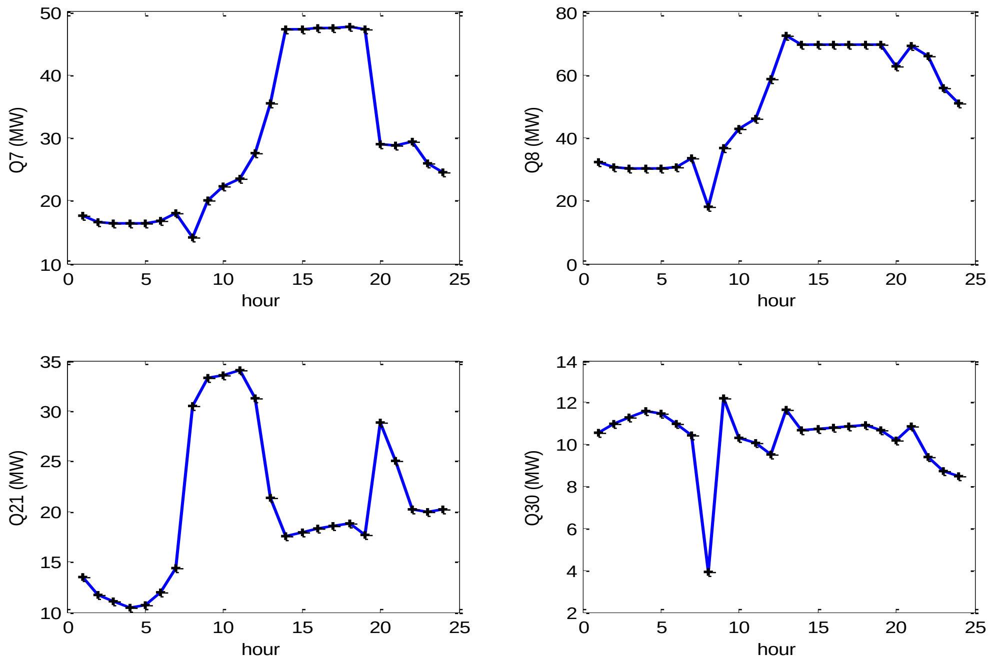

Figure 5. Reactive Power generation by SFD (cases 5_2)

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