International Journal of Engineering & Technology, 7 (2.6) (2018) 283-289

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research Paper



Security Constrained Unit Commitment in a Power System based on Benders Decomposition and Mixed Integer Non-linear Programming

Pranda Prasanta Gupta[1]*, Prerna Jain[2], Suman Sharma[3], Rohit Bhakar[4]

[1,3] Research Scholar Department of Electrical Engineering, Malaviya National Institute of Technology, Jaipur, India
[2,4]Assistant Professor Department of Electrical Engineering, Malaviya National Institute of Technology, Jaipur, India
**Corresponding author E-mail:prandaprasantagupta@gmail.com*

Abstract

In deregulated power markets, Independent System Operators (ISOs) maintains adequate reserve requirement in order to respond to generation and system security constraints. In order to estimate accurate reserve requirement and handling non-linearity and non-convexity of the problem, an efficient computational framework is required. In addition, ISO executes SCUC in order to reach the consistent operation. In this paper, a novel type of application which is Benders decomposition (BD) and Mixed integer non linear programming (MINLP) can be used to assess network security constraints by using AC optimal power flow (ACOPF) in a power system. It performs ACOPF in network security check evaluation with line outage contingency. The process of solving modified system would be close to optimal solution, the gap between the close to optimal and optimal solution is expected to determine whether a close to optimal solutionis accepetable for convenientpurpose. This approach drastically betters the fast computational requirement in practical power system .The numerical case studies are investigated in detail using an IEEE 118-bus system.

Keywords: *ACOPF; BD; SCUC; MINLP*

1. Introduction

Unit commitment (UC) is a multifaceted assessment making problem of determining which unit is on and how much produce power hourly. Its objective is to minimize total operating costs over a scheduling horizon (i.e. day-ahead) satisfying technical and operational constraints. Exhaustive research work has been performed in this area [1]. Conventional UC problem would not assure the sufficient power flow from generator to load due to indeterminate network security constraints [2]. The incorporation these constraints in traditional UC formulation is characterized as SCUC in the open-access market organization [3-5]. System Operator (SO) performs SCUC to provide the desired level of system security after market clearing and operation cost is obtained from the standard offer program [2]. Operation cost obtained from SCUC is analyzed by generation companies (GENCOs) and daily generator schedule is provided to power system operator [6-7]. Three elements are included in SCUC paradigm: supplying load reliability, maximizing security and minimizing costs. Therefore, well-organized explanations of SCUC problem canpromeniently effect modern power system.

A lot of work in this area deals with utility of optimization techniques to solve problem such as mixed integer linear programming (MILP)-based method, semi-definite programming-based method [2], Lagrangian relaxation method [8], Quadratic programming using branch and bound method [9], linear programming [10], dynamic programming [11], and BD method [12-13]). The optimization technique of BD based approach in this model is developed for optimal operation for solving SCUC problem obtainable, example in [14-15]. It is well-known that the result of MILP might need extensive computational time and huge memory obtain ability for big rangeprogram, modern developments in this solution method [16], have presented excessive position in enactment, on which inveterate by maximum ISOs previously using MILP formulation. As the SCUC formulation would be modeled as a MINLP solver. Since the SCUC problem is NP-hard and hard to solve this. The subordinate of the UC formulation is solved using MILP which is NP-hard [17], subordinate of the ACOPF formulation as a non-linear programming (NLP), non-convex need to solve also by NP-hard [18-20], the MINLP problem of ACOPF and SCUC combine the difficulty of mutually subordinate and is challenge to explain the problem [18].

The major role of the proposed SCUC model including network security constraints is to improve the computational performance of the existing SCUC formulation.The work for deterministic UC mechanism that signifies the network typically integrate DC power flow equation instead of AC ones. Intellectual benefit on the influential UC problem by [21], mainly approaches on MINLP with non-convex representation of thermal unit operator with undefined network constraints [22-25]; As UC problem have been comprehensive classically to incorporate a DC representation both with or without (e.g., [26-27]) real power losses are considered. Although, with DC power flow constraints relatively than AC problemmightguide to inaccuracy, as a DC model ignore reactive power and voltage. Moreover, an AC network model becomes more important in prudent way of power system scenario. In these framework N-1 contingency criteria, considering ACOPF to ensure system security is established for optimal operation of SCUC

Copyright © 2018Authors. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

problem. System operator wants to sufficient and consistent supply loads at single element outage at any assumed time [28].A new contingency measure, identified as N-1, system operator refers to be successive losing of twomechanismswith prevailing hours for adaptation of ACOPF model [29]. However, benefits of the quick response with N-1 contingency using ACOPF constraints have not yet been considered in the framework of SCUC.

The main contributions of this proposed framework in this area aresummarized as follows:

1) Proposed a new SCUC problem based on BD and MINLP method is formulated in this paper, computationally quick SCUC formulation framework with network security constraints and solved using CPLEX solver.Moreover, the variations of network constraints parameter on operational cost, LMP, and for computational and cost performance are calculated in this model.

2) Novel contribution of proposed work is inclusion of line contingency in SCUC model with network security and solved by using ACOPF equation is considered into this model. Solving the MINLP model of SCUC is extra complex than the obtainable (MILP) models based on DC power flow modeling. For such system it would be challenging task for solving this problem in practical power system scenario.

The rest of the paper organization is as follows: Section II explains a mathematical formulation of SCUC; section III describes the proposed SCUC algorithm; section IV describes the case study to show the impact of SCUC on both economical and technical feature and section V represents conclusion and future work

2. Mathematical Formulation of SCUC

The SCUC including network security model calculate line contingency at each bus in a system. In SCUC model, the problem is disintegrated with two subproblems. First problem is to calculate major SCUC optimizes the commitment and schedule of all units apart from network security constraints. On the other hand, second problem calculate branch outage contingency by performing ACOPF with network security to optimize hourly schedule of SCUC.

Notation

A. Indices and sets	
g	Index of thermal generating units
j,i	Index of security buses
t	Index of time periods
FT	Index for fuel type
N_G	Set of all thermal generating unit
N_B	Set of security buses
N_l	Set of security branches
N_G^i	Set of all thermal generating unit attached to bus i
N_l^i	Set of all branches attached to bus i
B. Variables	
$P_{g,t}$	Real power generation of unit g at hour t (MW).
$Q_{g,t}$	Reactive power generation of unit g at hour t (MW).
$FC_g(.)$	Production cost function of unit g
$F_g^e(.)$	Emission function of unit g
$F_g^f(.)$	Fuel consumption function of unit g
$SR_{g,t}$	Spinning reserve of unit g at hour t (MW).
$OR_{g,t}$	Operating reserve of unit g at hour t (MW).
$P_{ij,t}$	Real power flow of branch connecting bus i to j at hour t
$Q_{ij,t}$	Reactive power flow of branch connecting bus i to j at hour t
$FL_{ij,t}$	Line flow at node j and i at hour t
$V_{i,t}$	Voltage magnitude at bus i at hour t
T_t	Transformer tap limit at hour t
γ_t	Phase shifting transformer at hour t
C. Binary Variables	
$U_{g,t}$	Commitment status of unit g at hour t
$\hat{U}_{g,t}$	Vector are committed state of unit g at hour t
$y_{g,t}$	Startup indicator
$z_{g,t}$	Shutdown indicator
D. Parameters	
a_g, b_g, c_g	Cost coefficient parameter of unit g
$PD_{i,t}$	Real power load of bus i at hour t (MW).
$QD_{i,t}$	Reactive power load of bus i at hour t (MW).
$\bar{P}_g, \underline{P}_g$	Maximum and minimum limits of real power generation of thermal unit (MW).
$\underline{Q}_g, \bar{Q}_g$	Maximum and minimum limits of reactive power generation of thermal unit (MW)
$\underline{V}_i, \bar{V}_i$	Maximum and minimum voltage magnitude at bus i
UR_g, DR_g	Ramping up, down limit of a unit g
MUT_g^{on}, MDT_g^{off}	Minimum down and up time of a unit g
R_{st}, R_{ot}	Spinning and operating reserve requirements
$ST_{g,t}, SD_{g,t}$	Start-up, Shut down cost of unit g at hour t
$ST_{g,t}^e, SD_{g,t}^e$	Start-up, Shut down emission of unit g at hour t
$ST_{g,t}^f, SD_{g,t}^f$	Start-up, Shut down fuel consumption of unit g at hour t
$FL_{ij}^{\max}$	Maximum power flow limit of branch attached of bus i to j
$S_{FT}^{\min}, S_{FT}^{\max}$	Minimum / and Maximum fuel consumption of fuel type FT
$\bar{T}, \underline{T}$	Upper and lower limit vector of transformer tap
$\bar{\gamma}, \underline{\gamma}$	Upper and lower limit vector of phase shifter angle
λ	Multiplier ouput vector

2.1. Objective function

In this objective function, ISO is composed to minimize fuel cost for producing electric power, shutdown and start-up costs of generator units.

$$\text{MIN OF} = \sum_{g=1}^{N_G}\sum_{t=1}^{N_T}\left[FC_g(P_{g,t})U_{g,t} + ST_{g,t} + SD_{g,t}\right] \quad (1)$$

In the first-stage OF includes shut-down, start-up, and fuel costs of thermal units. The fuel costs $FC_g(P_{g,t})$ are typically presumed to be a quadratic of thermal generator.

$$FC_g(P_{g,t}) = a_g(P_{g,t})^2 + b_g(P_{g,t}) + c_g \quad (2)$$

$$\sum_{g=1}^{N_G} OR_{g,t}U_{g,t} = R_{ot},\ \forall t \quad (3)$$

$$\sum_{g=1}^{N_G} SR_{g,t}U_{g,t} = R_{st},\ \forall t \quad (4)$$

Ramp rate constraint

$$P_{g,t} - P_{g,t+1} \le RD_g(1-y_{g,t}) + y_{g,t}\underline{P}_g, \forall g, \forall t \quad (5)$$

$$P_{g,t+1} - P_{g,t} \le RU_g(1-z_{g,t}) + z_{g,t}\underline{P}_g, \forall g, \forall t \quad (6)$$

Minimum ON/OFF times

$$\begin{aligned} &\sum_{t=1}^{UT_g}(1-U_{g,t}) = 0, \quad \forall g \\ &y_{g,t} + \sum_{j=t+1}^{t+MUT_g^{on}-1} z_{g,j} \le 1, \quad \forall g, \forall t = UT_g+1,...,T \end{aligned} \quad (7)$$

$$UT_g = \max\left\{0, \min\left[NT, (MUT_g^{on} - US_{g,0}^{on})U_{g,0}\right]\right\} \quad (8)$$

$$\begin{aligned} &\sum_{t=1}^{DT_g} U_{g,t} = 0, \quad \forall g \\ &y_{g,t} + \sum_{j=t+1}^{t+MDT_g^{off}-1} (1-z_{g,j}) \le 1, \quad \forall g, \forall t = DT_g+1,...,T \end{aligned} \quad (9)$$

$$DT_g = \max\left\{0, \min\left[NT, (MDT_g^{off} - US_{g,0}^{off})(1-U_{g,0})\right]\right\} \quad (10)$$

Fuel constraints

$$S_{FT}^{\min} \le \sum_{g=1}^{N_G}\sum_{t=1}^{N_T}\left[F_{g,t}^f(P_{g,t})U_{g,t} + ST_{g,t}^f + SD_{g,t}^f\right] \le S_{FT}^{\max} \quad (11)$$

Emission constraints

$$\sum_{g=1}^{N_G}\sum_{t=1}^{N_T}\left[F_g^e(P_{g,t})U_{g,t} + ST_{g,t}^e + SD_{g,t}^e\right] \le EM^{\max} \quad (12)$$

Active power constraints

$$\underline{P}_g U_{g,t} \le P_{g,t} \le \bar{P}_g U_{g,t}, \ \forall g, \forall t \quad (13)$$

2.2. SCUC model with network security evaluation

The purpose of the SCUC model is to allocate the value of each bus voltage, LMP and transmission congestion at each bus. Involvement in spinning and operating reserve needs optimal number solution and hourly dispatch to permit the energy delivery for a longer time. Due to limit of generation resources, the number of branch flow limits is introduced. Therefore, optimal capacities at each node needed to be identified such that the above discussed issues are mitigated. Network constraints are mentioned as follows:

Security constraints

$$-FL_{ij}^{\max} \le FL_{ij,t} \le FL_{ij}^{\max} \quad (14)$$

Real and reactive nodal power balance constraint

$$P_{ij,t} = \frac{V_{i,t}^2}{Z_{ij}}\cos(\theta_{ij}) - \frac{V_{i,t}V_{j,t}}{Z_{ij}}\cos(\delta_{i,t} - \delta_{j,t} + \theta_{ij}) \quad (15)$$

$$Q_{ij,t} = \frac{V_{i,t}^2}{Z_{ij}}\sin(\theta_{ij}) - \frac{V_{i,t}V_{j,t}}{Z_{ij}}\sin(\delta_{i,t} - \delta_{j,t} + \theta_{ij}) - \frac{bV_{i,t}^2}{2} \quad (16)$$

Real and reactive power balance at scheduling time at every node and for every hour period

$$\sum_{g=1}^{N_G^i} P_{g,t} - PD_{i,t} = \sum_{j=1}^{N_l^i} P_{ij,t} \quad (17)$$

$$\sum_{g=1}^{N_G^i} Q_{g,t} - QD_{i,t} = \sum_{j=1}^{N_l^i} Q_{ij,t} \quad (18)$$

Reactive power constraints

$$\underline{Q}_g U_{g,t} \le Q_{g,t} \le \bar{Q}_g U_{g,t}, \ \forall g, \forall t \quad (19)$$

Limits of voltage at each bus

$$\underline{V}_i \le V_{i,t} \le \bar{V}_i, \ \forall i, \forall t \quad (20)$$

Limits on phase shifting and tap changing transformer

$$\underline{T} \le T_t \le \bar{T}, \ \forall t \quad (21)$$

$$\underline{\gamma} \le \gamma_t \le \bar{\gamma}, \ \forall t \quad (22)$$

3. Proposed a Two-Stage SCUC Formulated as an BD and MINLP Approach

The proposed SCUC model is an MINLP and two-stage problem is difficult to solve directly. Altough its clear from the exceeding problem, the existing constraints are non-convex, so, solving this difficulty with the assist of famous solver such as (DICOPT) and SBB [20]. The simplymethod to explain a MINLP is decomposed it keen on integer and non-convexfragment. BD will be use to hole the master problem into MIPfragment, and a NLP one to check the network security subproblem and feasibility benders cut is used to connect these parts.In regulate to explain the proposed SCUC formulation in Section 2, a BD has been adopted to solve this problem.As shown in Figure 1, Stage I considered master problem applies to the basic UC problem excluding AC network constraints. It contains binary variables as the on-off status of the generating units and real integer as unit schedules. As such, it is a MINLP problem. On the other hand in Stage II, subproblem considered here, consists of two subproblem. First is the network security consideration and second contingency analysis. Network security constraints are checked by running ACOPF.In concern with BD algorithm, the unique significant optimization problem spirit is decomposed into a sub-problem and a master problem. The comprehensive conversation schedule is obtained using BD [30-31]. The UC master problem, which include constraints (2-13) and objective function (1), provide the dispatch and schedule solution to minimize operational cost excluding network security constraints. After the solution of master problem, the network security ISO verifies for each hour. The output of the vector in Equation (16) are current commitment and dispatch solution obtain from the master are checked with the violation of transmission constraints. Using these value $\hat{P}_{h,t}$ and $\hat{Z}_{h,t}$, lower sub-problem objective is formulated by checking new security constraints as in equation (16). If any network violation arises on any of the subproblem, the benders cuts would be created and connected to the master problem in the subsequently simulation of UC. Moreover benders cuts are created establish on subproblem results.

$$\begin{aligned} v(\hat{U}, \hat{P}_g) = \hat{v} &+ \sum_{g=1}^{N_G}\lambda_{g,t}^n(P_{g,t}U_{g,t} - \hat{P}_{g,t}\hat{U}_{g,t}) \\ &+ \sum_{g=1}^{N_G}\mu_{g,t}^n(Q_{g,t}U_{g,t} - \hat{Q}_{g,t}\hat{U}_{g,t}) \end{aligned} \quad (23)$$

In Equation (23), where $\hat{v}$, $\lambda_{g,t}^n$, $\hat{P}_{g,t}$, $\hat{Q}_{g,t}$ and $\hat{U}_{g,t}$ represents the optimal solution for the master problem, simplex multiplier vector, the output of vector which are obtained in commitment state and real and rective power generation of unit g at hour t of the master problem.

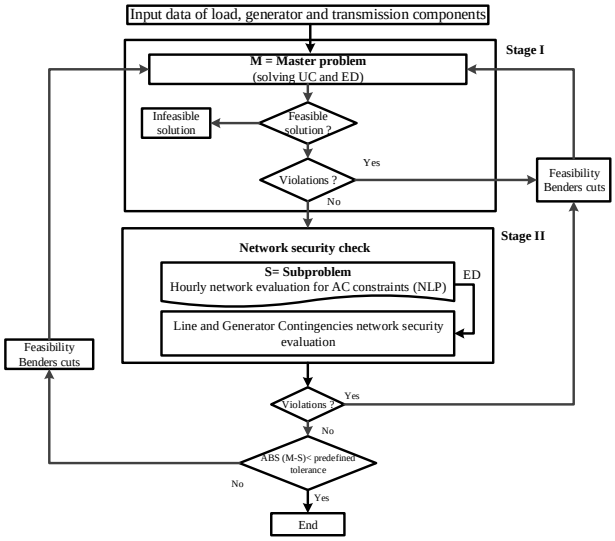


Fig. 1: Framework of SCUC Algorithm

4. Simulation Results

In order to focus a major issue, an improved IEEE 118-bus system is new to learn the BD and MINLP based on UC and SCUC problem. There are fifty four thermal units (G1….G54), and 186 transmission lines. The complete 118-bus system data are specified on website i.e. motor.iit.edu/data/SCUC_118. The peak load is6000 MW occur at Hour 21. Figure 2 shows the forecasted load demand. Different operational cases are discussed in this paper:I) Base case II) Dispatch with load demand on network security. III) Impact of SCUC on line contingency.

a) Base Case

In this case, UC is solved using MINLP and BD with daily operation costs of $1643854.51. The CPU time is about 597s. The proposed algorithm solved only the master problem. Consecutively the optimization problem with all generating units from Equation (1-13), is satisfied. Excluding network operating constraints, the problem SCUC verify the dispatch and commitment of units specified, u and P_g, real power generating units in MW are shown in Table 1 and 4 respectively.

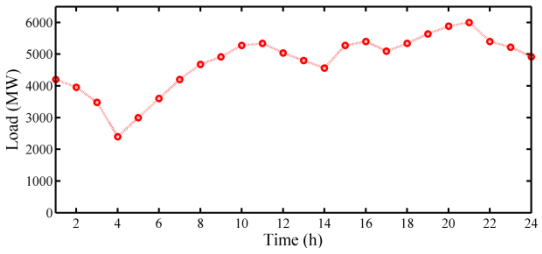


Fig. 2: Forecasted Load Profile

It can be seen that, the economical units (such as H4-H5, H10-H11, and H24-H25 etc.) are used as cheapest units and costly units (such as H6, H12-H13, H41-H42 and H46 etc.) are not committed for 24 h horizon. However, in some hours yet although the output of unit H7 and H14 is not met its ability so far, the H7 unit should be on due to lack of spinning reserve. The outstanding units are committed consequently to satisfy hourly load demand as shown in Figure 2.

Table 1: SCUC status without network security constraints

Unit	Hour (1-24)
H1-H2	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
H3	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
H4-H5	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
H6	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
H7	0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
H8-H9	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
H10	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
H11	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
H12-H13	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
H14	0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
H15	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
H16	0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
H17-H18	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
H19	0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
H20-H21	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
H22-H23	0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
H24-H25	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
H26	0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
H27-H28	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
H29	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
H30	0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
H31-H32	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
H33	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
H34-H35	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
H36	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
H37	0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
H38	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
H39-H40	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
H41-H42	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
H43-H44	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
H45	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
H46	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
H47-H48	0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
H49-H50	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
H51-H52	0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
H53	0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
H54	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

b) SCUC with network security

In Case 1 after the master problem has been solved, the subproblems are considered using the network security constraints are described in Section 2.2.

Moreover, in regulate to verify if there are some network violations, to charge the network hourly security verifysubproblem-based on original UC in Table 4.Although this system, there are transmission line violations on line 84-83 at time 10-14 and 22-24. In calculation, the voltage at bus 101 is more than its lower limits of 1.0 p.u. After simulation, the novel UC solution is accessible in Table 5 with a total production cost of $1723019.51. The implementation time is about 9742s. In Table 2 and 5, unit H37 in Zone 2 is not committed at hours 1-18 to alleviate the violations by droppingto deliver of power on Zone1.Likewise, units H22, H23, H26, H31-32, H33, H34 and H51 in Zone 2 is committed at positive hours (e.g., 1-2, 8-20, 10-24, and 9-24) to recompense for the concentrated supply from Zone 3.

Table 2: SCUC status with network security constraints

Unit	Hour (1-24)
H1	1 1 1 0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 1 1 1
H2	1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1
H3	1 1 0 0 0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0 0 0 0 0
H4	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0
H5	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1
H6	1 1 0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 1 1
H7	0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
H8	1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1
H9	1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
H10	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
H11	0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0
H12	1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0
H13	1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
H14	1 1 0 0 0 1 1 1 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
H15	1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
H16	1 1 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
H17	1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 0 0
H18	1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
H19	1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 1 1 1 1 1 1 1 1
H20	0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
H21	0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0
H22	1 1 0 0 0 1 1 1 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
H23	1 1 1 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
H24	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
H25	1 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0

H26	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H27	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H28	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
H30	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1
H31-H32	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
H33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
H34	1	1	1	0	1	1	0	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1
H35	1	1	1	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	1	1	1	1	1	1	1
H36	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1
H38	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
H39	1	1	1	0	1	0	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	0
H40	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
H41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H42	1	1	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
H43	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H44	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H45	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
H47	1	1	0	0	0	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H48	1	0	0	0	1	1	0	1	1	1	1	0	1	1	1	1	0	1	1	1	1	1	1	1	1
H49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H50	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
H51	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
H52	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0
H53	1	1	0	0	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H54	1	1	1	1	1	0	0	1	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0

Table 4 and 5 shows the dispatch result with and without network security constraints. When a network constraint is measured, the costly thermal units H10, H27-H28, H39-H40 and H43-H44 ought to be committed in regulate to persuade the demand at peak hour. The extra committed would be essential in the case cheaper generating units cannot be completely utilized, due to the network security constraints. The dispatch result of unit H7, H14, H16, H19, H26, H34-H35, H47-48, H51-52 and H53 in Table 4, considering without network constraint committed from 8 to 24 hours. With network constraint the unit is committed H14, H16, H20, H21 and H26 from from 6 to 24 hours. At hour 6, H14 and H16 are generating 50 MW that is within security power flow constraints.

By considering network security, H26 jumps to lower limits, H27-H28 is maximum power generating unit (420 MW), H31-H32 requirements be committed to stability the energy production and utilization. H14 and H26 is minimum power generating unit (25MW), since energy require decreasing the generation stage of H24 to equilibrium the stage of reserve. Since reserve zone of H22-H23, quite generate 100 MW. However, observed that H22-H23 is an economical unit, but it cannot be utilize cost-effectively because of reserve requirement.

c) SCUC effect on branch contingency

In this context, an AC-OPF study is used for mathematical analysis of deterministic SCOPF method as the load vary and the result of ranking scheme is demonstrated on the basis of operational costs. In Table 3 shows that the highly critical contingency rank selects on line 19-34 outages to show the special consequence on the production values and operation cost to secure the network. Zone B, units P13 was oblige to take the phase of the misplaced line because the residual line adding point the particular resources P15 is incapable to deliver the area excluding violation. Moreover at 4-6 and 12-14 h, all units are committed. In Zone 2, P50-P54 is committed for 24 horizons as compare to Case 2 which is more cheapest unit because it dispatch on 1-3, and 7-24 hour. Contingency which proves to be incredibly costly and the operational cost of network security turn to be $1910836.51. Incorporation of the loss of interact line 19-34 contingency occurs to be high-priced $187817, which is ~ 20% more than the Case 2.The CPU time on this case is 1043s.

Table 3: SCUC with line 19-34 outage

Unit	Hour (1-24)																							
H1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H4	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H5	1	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H10	1	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H11	1	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H14	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H16	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H17	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H18	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H19	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H20	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H21	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H22	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H23	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H24	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H25	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H26	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H27	0	0	1	0	0	1	0	0	0	1	1	0	0	0	1	1	0	0	1	1	1	0	0	0
H28	0	0	1	0	0	1	0	0	0	1	1	0	0	0	1	1	0	0	1	1	1	0	0	0
H29	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H30	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H31	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H32	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H33	0	1	0	1	1	0	0	0	1	0	0	1	1	0	0	0	1	1	0	0	1	1	1	0
H34	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H35	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H37	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H38	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H41	0	1	0	1	1	0	0	1	1	0	0	1	1	0	0	0	1	1	0	1	1	1	1	0
H42	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H43	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	1	1	1
H44	1	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H45	1	1	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H47	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H48	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H50	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H51	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H52	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H53	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H54	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Impact of SCUC on system operational cost

Figure (3) indicates the sensitivity analysis of operational cost with respect to case consider. Although generating units it can provide reduction in system dispatch cost. Case 1 is showing minimum cost when network security constraints are neglected; Cost of $1723019.51in Case 2 is higher as compared to $1643854.51for Case 1 due to consideration of security constraints; Whereas in Case 3, incorporation of line contingency increases the cost of $1910836.51to maximum of three Cases.

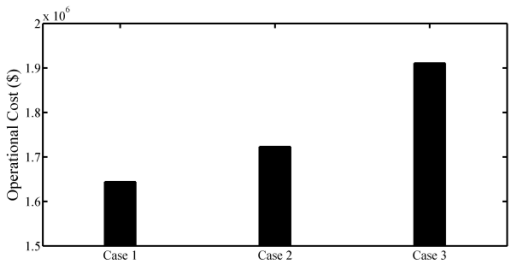


Fig. 3: System dispatch cost ($)

5. Conclusion and Future Work

This paper proposed SCUC with network security constraints using MINLP method. Recommended technique is measure on modified IEEE-118 bus transmission system and simulation results are create to be inspiring. A major enhancement in the computational time can be obtained by using the CPLEX solver in General algebraic modeling systems (GAMS). Moreover three different cases are considered, validate the realistic situation and to obtain better optimal solution. Results also shows that when contingency occur on branch 19-34, congestion cost at each node increase as compared to network security case extensively. Although, this techniqueobtainable can be beneficial for individuals SCUC problem to facilitate this modeled to DC power flow equation, for that case the use of AC constraint is manadatory, an additional sophistacted method is necessary in practical power system. However, having a new approach BD and MINLP process that can be used as ainitial point to findnear optimal solution would potentially assist the NLP solvers to locate the global solution efficiently. In future, the anticipated work can be potentially extended to investigate AC-based SCUC problems considering uncertainty behavior of renewable power generation and load demand.

References

[1] N. P. Padhy, "Unit commitment-a bibliographical survey," *IEEE Transaction on Power System*, Vol.19, No. 2, (2004), pp. 1196-1205.

[2] Bai X & Wei H, "Semi-Definite Programming-Based Method For Security-Constrained Unit Commitment with Operational and Optimal Power Flow Constraints", *IET Generation, Transmission andDistribution*,Vol.3, No.2, (2009), pp.182–197

[3] N. Amjady and H. Nasiri-Rad. "Security constrained unit commitment by a new adaptive hybrid stochastic search technique". *Energy Conversion and Management*; Vol.52, No.2, (2011), pp.1097–106

[4] QiaozhuZhai and Xiaohong Guan, "The Conditions for Obtaining Feasible Solutions to Security-Constrained Unit Commitment Problems" *IEEE Transaction on Power System*, Vol. 20, No.4, (2005)

[5] J. J. Shaw, "A direct method for security-constrained unit commitment," *IEEE Transaction on Power System*, Vol. 10, No. 3, (1995), pp. 1329–1342

[6] Zhu, J, "Optimization of power system operation," New Jersey, Wiley & Sons, Inc, (2009), p. 251.

[7] M. Shahidehpour, H. Yamin, Z. Li, Market Operations in Electric Power Systems, John Wiley & Sons, (2002).

[8] Y. Sun, Z. Li, W. Tian and M. Shahidehpour," A Lagrangian Decomposition Approach to Energy Stoarge Transportation Scheduling in Power Systems,"*IEEE Transaction on Power System,*Vol.31, No.6, (2016)

[9] Shafie-khah, M., Moghaddam, M.P., Sheikh-El-Eslami, M.K.: 'Unified solution of a non-convex SCUC problem using combination of modified branch-and-bound method with quadratic programming',*Energy Conversion and Management*, (2011), Vol.52, No.12, pp. 3425–3432

[10] Grey, A., Sekar, A.: 'Unified solution of security-constrained unit commitment problem using a linear programming methodology', *IETGeneration, Transmission and Distribution*, (2008), Vol.2, No.6, pp. 856–867

[11] Hobbs WJ et al. ,"An enhanced dynamic programming approach for unit commitment," *IEEE Transaction on Power System*, Vol.3 No.3, (1988), pp:1201–5

[12] Lyu, J.K., Kim, M.K., Yoon, Y.T., Park, J.K.: 'A new approach to security-constrained generation scheduling of large-scale power systems with a piecewise linear ramping model', *International Journal Electrical Power Energy System*, (2012), Vol. 34, pp. 121–131

[13] P.P. Gupta, P. Jain, S. Sharma and R.Bhakar,'' Reliability-Security Constrained Unit Commitment Based on Benders Decomposition and Mixed Integer NonLinear Programming," *International Conference on Computer,Communication, and Electronics (Comptelix)*,(2017).

[14] A. Nasri, S.J. Kazempour, A.J. Conejo and M. Ghandhari, "NetworkConstrained AC unit commitment under uncertainty: A Benders Decomposition Approach," *IEEE Transaction on Power System*, Vol. 31, No. 1, (2016), pp. 0085-8950.

[15] N. Amjady, S. Dehghan, A. Attarha and A.J. Conejo," Adaptive Robust network-constrained AC unit commitment," *IEEE Transaction on Power System*, Vol. 32, No. 1, (2017), pp. 0085-8950.

[16] IBM Ilog CPLEX. Available at http://www.ilog.com/products/cplex

[17] K. Lehmann, A. Grastien, and P. V.Hentenryck, "AC-feasibility on tree networks is NP-hard," *IEEE Transaction on Power System*, Vol. 31, No. 1, (2016), pp. 1–4.

[18] L. Wu and M. Shahidehpour, "Accelerating Benders decomposition for network-constrained unit commitment problems," *Energy Syste*m, Vol. 1, No. 3, (2010), pp. 339–376.

[19] M. J. Feizollahi, M. Costley, S. Ahmed, and S. Grijalva, "Large-scale decentralized unit commitment," *Electral Power and Energy Syste*m, Vol. 73, (2015), pp. 97–106.

[20] C. Tseng, "On power system generation unit commitment problems," Ph.D. dissertation, Dept. Ind. Eng. Oper. Res., Univ. California, Berkeley, CA, USA, (2010)

[21] H. Ma and M. Shahidehpour, "Unit commitment with transmission security and voltage constraints," *IEEE Transaction on Power System*, Vol. 14, No. 2, (1999), pp. 757–764.

[22] Q. P. Zheng, J. Wang, and A. L. Liu, "Stochastic optimization for unit commitment—A review," *IEEE Transaction on Power System*, Vol. 30, No. 4, (2015), pp. 1913–1924.

[23] M. Carrión and J. Arroyo, "A computationally efficient mixed-integer linear formulation for the thermal unit commitment problem," *IEEE Transaction on Power System*, Vol. 2, No. 1, (2011), pp. 69–77.

[24] J. Ostrowski, M. F. Anjos, and A. Vannelli, "Tight mixed integer linear programming formulations for the unit commitment problem," *IEEE Transaction on Power System*, vol. 27, no. 1, (2012), pp. 39–46.

[25] G. Morales-España, J. M. Latorre, and A. Ramos, "Tight and compact MILP formulation for the thermal unit commitment problem," *IEEE Transaction on Power System*, vol. 28, no. 4, pp. (2013), 4897–4908.

[26] T. Ding, R. Bo, Y. Yang and F. Blaabjerg, "Impact of negative reactance on defectiveness of B-Matrix and feasibility of DC power flow," ," *IEEE Transaction on Power System*, Vol.31, No.1, (2017), pp. 1949-3053.

[27] R. A. Jabr, "Tight polyhedral approximation for mixed-integer linear programming unit commitment formulations,"*IET Generation, Transmission andDistribution*, Vol. 6, No. 11, (2012), pp. 1104–1111

[28] R. F-Blanco, Y. Dvorkin, M A. O-Vazquez," Probabilistic security constrained unit commitment with generation and transmission contingency," *IEEE Transaction on Power System*, Vol.32, No.1, (2017).

[29] A. Nikoobakht, M. Mardaneh, J. Aghaei, V. Gueerero-Mestre and J. Contreras,"Flexible power System operation accomdating uncertain wind power generation using transmission toplogy control: an improved lineraised AC SCUC model," *IET Generation, Transmission andDistribution*,Vol.11, No.1, (2016), pp.142-153

[30] Bertsimas, D., Litvinov, E., Sun., X. A., Jinye., Z. andTongxin., Z.,"Adaptive robust optimization for the security constraint unit commitment problem,"*IEEE Transaction on Power System*, Vol. 28, (2013), pp. 52-63

[31] Fu Y, Shahidehpour M, Li Z.," AC contingency dispatch based on securityconstrained unit commitment." *IEEE Transaction on Power System*, Vol.21,No.2, (2006), pp.897-908

[32] The GAMS Software Website; 2016. [Online]. Available: http://www.gams.com/dd/docs/solvers/cplex.pdf.

Table 4: Dispatch of SCUC without network security

Hr	Hour(1-24)																							
	Daily operation costs = $1643854.51																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
H1-H2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H4	213	189	146	62	104	157	213	248	258	275	278	265	254	241	275	281	268	279	293	300	300	281	273	258
H5	208	186	143	58	98	154	208	245	250	271	276	260	246	233	272	277	262	274	289	300	300	277	269	255
H6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H7	0	0	0	0	0	0	0	5.0	15	27	36	19	10	5.0	32	36	25	34	48	57	63	36	31	24
H8-H9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H10	213	189	146	62	104	157	213	248	258	275	280	265	254	241	275	281	268	279	293	300	300	281	273	258
H11	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350
H12-H13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H14	0	0	0	0	0	0	0	13	23	36	40	28	18	9.0	38	43	30	40	52	64	72	43	35	23
H15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H16	0	0	0	0	0	0	0	13	23	36	40	28	18	9.0	38	43	30	40	52	64	72	43	35	23
H17-H18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H19	0	0	0	0	0	0	0	13	23	36	40	28	18	9.0	38	43	30	40	52	64	72	43	35	23
H20-H21	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250
H22-H23	0	0	0	0	0	0	0	13	23	36	40	28	18	9.0	38	43	30	40	52	64	72	43	35	23
H24	200	200	200	87	190	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
H25	100	100	100	65	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
H26	0	0	0	0	0	0	0	13	23	38	40	28	18	9.0	38	43	30	40	52	64	72	43	35	23
H27-H28	420	403	358	272	315	370	420	420	420	420	420	420	420	420	420	420	420	420	420	420	420	420	420	420
H29	213	189	147	62	104	157	213	250	258	275	278	265	256	241	275	281	268	279	293	300	300	281	273	258
H30	12	6	0	0	0	0	12	20	23	26	30	24	22	19	29	28	27	29	34	37	39	28	29	23
H31-H32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H34-H35	0	0	0	0	0	0	0	13	23	38	40	28	18	9.0	38	43	30	40	52	64	72	43	35	23
H36	212	189	147	62	104	157	212	248	258	275	278	265	254	241	275	281	268	279	293	300	300	281	273	258
H37	0	0	0	0	0	0	0	13	37	38	40	28	18	9.0	38	43	30	40	52	64	72	43	35	23
H38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H39	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300
H40	200	187	147	62	104	157	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
H**41**-H42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H43-H44	213	189	146	62	104	157	213	248	258	278	278	265	254	241	275	281	268	279	293	300	300	281	273	258
H45	213	189	146	62	104	157	213	248	258	278	278	265	254	241	275	281	268	279	293	300	300	281	273	258
H46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H47-H48	0	0	0	0	0	0	0	13	23	40	40	28	18	9.0	38	43	30	40	52	64	72	43	35	23
H49-H50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H51-H52	0	0	0	0	0	0	0	13	23	40	40	28	18	9.0	38	43	30	40	52	64	72	43	35	23
H53	0	0	0	0	0	0	0	13	23	40	40	28	18	9.0	38	43	30	40	52	64	72	43	35	23
H54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 5: Dispatch of SCUC with network security

Hr	Hour(1-24)																							
	Total operation costs = $1723019.51																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
H1	30	30	30	0	0	0	0	0	0	0	0	30	30	0	0	0	0	0	0	0	0	30	30	30
H2	30	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	30	30	30
H3	30	30	0	0	0	0	0	0	0	0	30	30	30	0	0	0	0	0	0	0	0	0	0	0
H4	300	266	300	150	300	150	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	0	0
H5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	300	300	300	300	300	300	300	150	300	300
H6	30	30	0	0	0	0	0	0	0	0	30	30	0	0	0	0	0	0	0	0	0	0	30	30
H7	0	0	0	0	0	0	0	50	100	100	100	100	50	50	50	50	50	50	100	100	100	100	100	100
H8	30	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	30	30
H9	30	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H10	300	150	300	270	100	100	300	300	300	300	207	300	300	300	300	300	300	300	132	300	300	300	300	300
H11	0	0	0	0	309	267	234	350	343	350	344	337	293	282	344	344	344	344	344	344	322	322	322	0
H12	30	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	30	0	0	0
H13	30	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H14	100	75	0	0	0	100	75	25	0	50	100	75	50	50	50	50	75	75	100	100	100	100	100	100
H15	30	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H16	100	40	0	0	0	50	40	60	80	100	100	40	20	20	20	20	40	80	100	100	100	100	100	100
H17	30	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	30	0	0	0
H18	30	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H19	100	67	33	0	33	100	67	67	66	67	67	0	0	0	0	0	0	100	100	100	100	100	100	100
H20	0	0	0	0	0	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250
H21	0	0	0	0	0	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	0	0
H22	100	77	0	0	0	100	78	23	0	92	100	78	47	39	92	84	78	70	92	92	92	92	92	92
H23	100	100	50	0	0	100	100	50	50	100	100	100	50	50	50	50	50	50	100	100	100	100	100	100
H24	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
H25	133	0	0	0	0	0	200	200	133	67	200	200	200	200	200	200	133	133	133	133	0	0	0	0
H26	100	75	0	0	0	100	75	25	50	100	100	75	50	50	50	75	75	75	100	100	100	100	100	100
H27	420	420	420	420	420	389	420	420	420	420	420	420	420	420	420	420	420	420	420	420	420	420	420	420
H28	0	0	420	420	420	389	420	420	420	420	420	420	420	420	420	420	420	420	420	420	420	420	420	419
H29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	300	300	227	300	150	272	150	300	300
H30	80	35	0	17	80	35	17	17	62	35	62	80	44	0	27	18	44	36	27	36	72	35	72	72
P31-P32	30	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	30	0	0	0
H33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	20
H34	100	100	68	0	92	100	0	68	38	92	48	0	68	64	60	57	53	100	96	96	96	96	96	96
H35	100	67	33	0	33	100	67	67	66	67	67	67	0	0	0	0	0	33	100	100	100	100	100	100
H36	0	300	300	150	275	150	150	300	300	300	300	300	300	300	300	300	150	300	300	300	300	150	300	300
H37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	25	100	25	100	100
H38	30	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	30
H39	300	300	300	0	95	0	300	300	300	200	100	0	200	207	300	260	300	200	200	200	200	200	200	0
H40	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	0	0	0	0	0	0	0
H41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H42	50	50	50	0	0	0	0	0	0	0	50	50	0	0	0	0	0	0	0	0	0	0	0	0
H43	300	270	210	120	0	100	150	300	291	270	240	210	180	150	212	100	100	270	90	258	270	270	90	270
H44	0	268	232	229	220	70	195	192	271	267	264	296	292	289	285	296	229	148	296	296	296	296	153	296
H45	297	275	234	174	97	0	0	0	296	278	259	240	222	203	300	296	296	282	282	282	282	282	282	282
H46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	20
H47	100	55	0	0	0	100	55	33	0	55	100	55	78	67	55	45	33	23	89	89	89	89	89	89
H48	100	0	0	0	48	100	0	22	34	48	52	0	22	15	10	5	0	94	94	94	94	94	94	94
H49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H50	50	25	50	25	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50	50	50
H51	0	0	0	0	0	0	0	75	50	100	75	100	75	75	50	75	25	75	75	75	75	50	50	0
H52	0	0	0	0	0	0	0	100	50	100	100	100	100	50	100	50	0	50	50	50	50	50	50	0
H53	100	100	0	0	28	100	57	0	0	86	72	57	43	43	85	85	85	85	100	100	100	100	100	100
H54	50	25	50	25	25	0	0	16	0	16	33	50	16	16	0	0	0	0	0	0	0	0	0	0