Unit Commitment in Restructured Power systems

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Gangavarapu Rabbuni

Dedicated to

Almighty and My Parents

Abstract

As the power industry across the world is experiencing a radical change by separation of transmission from generation activities, creation of competition by bidding or through provision of bilateral transactions in spot markets, there is need for the unit commitment in power industry with generation biddings, load biddings and bilateral transaction biddings.

In general Unit Commitment can be formulated as non-linear, large scale, mixed integer combinatorial optimization problem. For Better optimized result with quick response, piece-wise linearization of cost function and slack terms with high penalty factor are incorporated in unit commitment along with all generator, system, operator and line constraints.

In order to get convergence solution with UC, OPF is performed with fixed unit status from unit commitment solution by taking account of generator ramp rates.

Unit Commitment with 3-part generator bidding, load bidding and bilateral transaction with both elastic and inelastic parts is performed which is suitable for the recent power industry.

Nomenclature

List of Symbols

n	index of bus bar
h	index of period of hour
k	index of generator
ld	index of load
ln	index of line
se	index of sections of cost function
t	index of bilateral transaction
m1	penalty factor
z1	slack term
z	objective function
pmin	minimum generation limit
pmax	maximum generation limit
fcst	fixed cost
scst	start-up cost
Rdn	ramp down limit
Rup	ramp up limit
Rsup	start-up ramp limit
Rshdn	shutdown ramp limit
Tup	minimum up time limit
Tdn	minimum down time limit
a0	generator cost function double proportional term coefficient
a1	generator cost function proportional term coefficient
a2	generator cost function constant term
slope	slope of section in cost function
pload	load

blmtt	line limit
d	angle of bus
p	output power generation
p1	output power in section
u	unit status
ustrt	unit just start status
usht	unit just down status
bidprice_gen	bid price of generator
pmax_bid	elastic output generation limit
pmax_load	elastic load limit
pmax_biltra	elastic transaction limit
pload_fix	inelastic load
pload_var_price	elastic load price
pbiltra_fix	inelastic bilateral transaction
pbiltra_var_price	inelastic bilateral transaction price
pminloadprice	minimum load price of generator
pbidprice	bid price of generator
startupprice	start-up cost
pload_var	elastic load
pbiltra_var	elastic transaction
χ	reactance
δ	angle at bus
σ	must run status
ρ	must not run status

List of Acronyms

ISO	Independent system operator
GAMS	Generalised algebraic modelling system
OPF	Optimal power flow
UC	Unit commitment
SCUC	Security Constrained Unit Commitment
PBUC	Profit Based Unit Commitment

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Chapter 1

Introduction

1.1 Restructured Power Systems

The Power Industry across the world are being unbundled and opened up for competition with private players unlike in vertically integrated utilities where power sector was characterized by operation of a single utility generating, transmitting and distributing electric energy in its area of operation.

The reasons for power sector to allow for private players vary from country to country as most probably developed countries do this to achieve social welfare, on other hand developing countries do this for capacity addition through private players. And so the format of deregulation and its process has been different in different parts of the world.

Separation of transmission from generation activities is one of first tasks in restructuring process of power industry. The next step is creation of competition by bidding or through provision of bilateral transactions in spot markets.

In deregulated power system, ISO plays a central coordination role and performs important responsibility of providing system reliability and security. The ISO also ensures quality and safety. It is an independent authority ,does not involve in electricity trade. In this regard there are some services apart from basic energy and power delivery services called ancillary services such as scheduling and dispatch, frequency regulation, voltage control, generation reserves etc. These services are not integral part of the electric supply in deregulated environment.

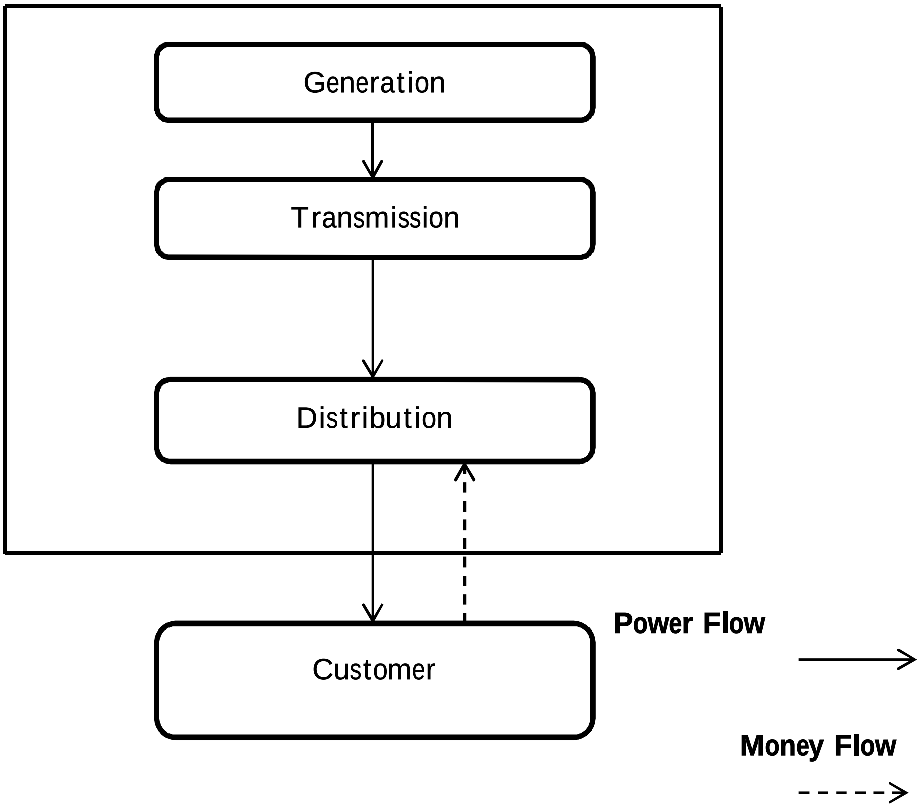


Figure 1.1: Vertically Integrated Utility

From the Figure 1.1, it is said that there is only one utility with which customer dealt with. Thus, there are only two entities in power business: a monopoly utility and the customer.

From the Figure 1.2, it is noticeable that apart from vertically integrated utility and the customers, there are many more other entities present. It also observed that there are many alternative paths along which money flows unlike in regulated environment.

1.2 Unit Commitment

Unit commitment is the problem of determining the schedule of generating units with in a power system, subject to device and operating constraints results in great saving of electricity utilities.

Several optimizations techniques have been applied to the solution of unit commitment. Exhaustive Enumerating all possible combinations in [1], Priority list arranges at the generating units in start-up heuristic ordering by operating cost combined with transition costs in [2], Dynamic programming searches the solution space that consists of the units status for an optimal solution in [3], Integer and Mixed Integer programming solves the UC problem by reducing the solution search space systematically through discarding the infeasible subsets in [4], Branch and bound essentially determines a lower bound to the optimal solution and then finds near optimal feasible commitment schedule in [5], Lagrangian Relaxation decomposes the UC problem into a master problem and more manageable sub problems that are solved iteratively in [6] have been presented and are applied to the unit commitment.

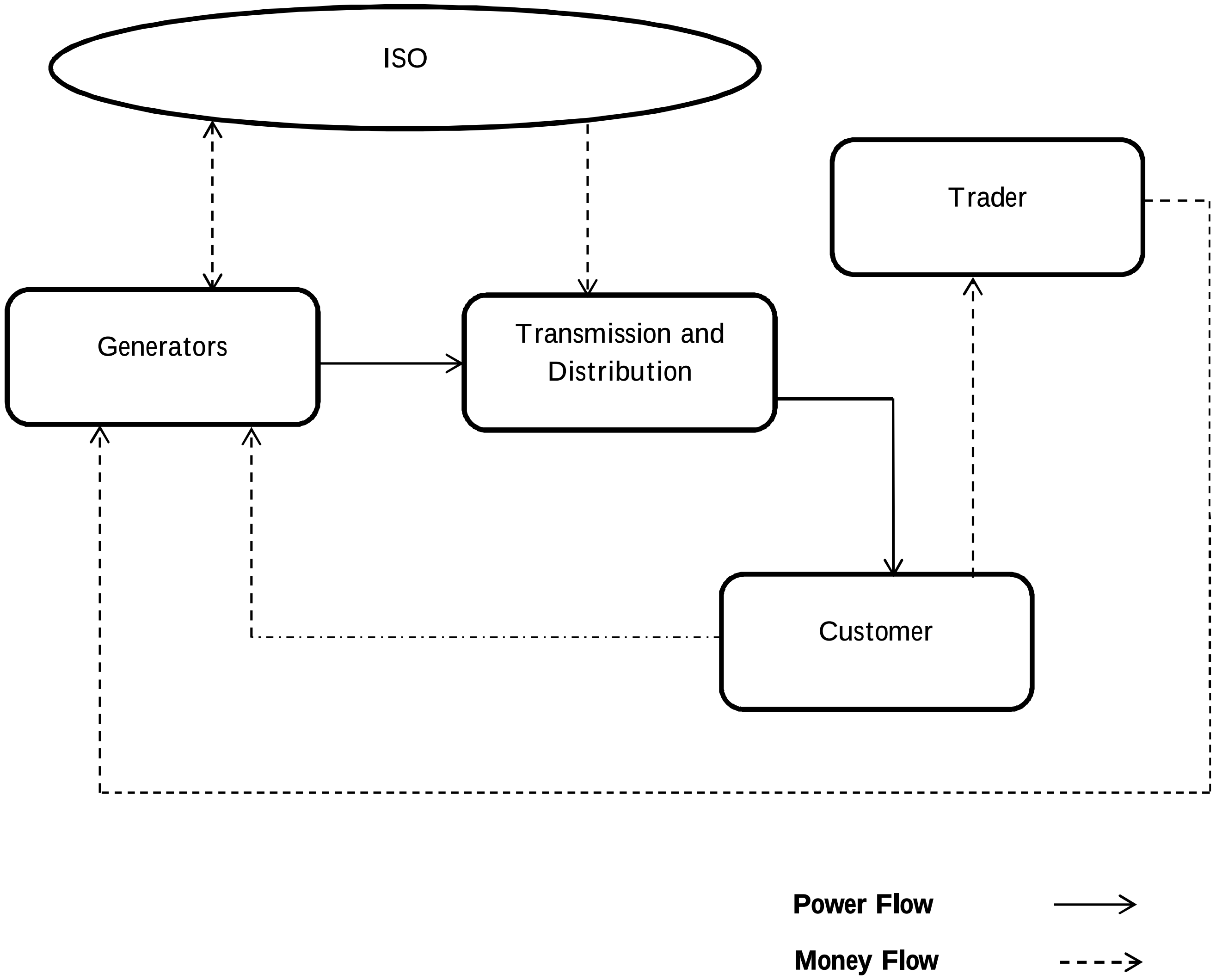


Figure 1.2: Representative Structure of Deregulated Power System

In [7],[8] generic UC problem formulation and objective function as minimization of fuel costs by proper commitment of the available generating units . The total cost includes the total unit production cost, start-up cost and shut down cost. It is also proposed production cost is modelled as polynomial curve ,a piece wise constant curve or piece wise linear curve. From [8], [9] cost function and start-up cost of generator are modelled by equations 1.1, 1.2,1.3.

The general objective of unit commitment is to minimize system total operating cost while satisfying all of the constraints. In general it can be formulated as non-linear, large scale, mixed integer combinatorial optimization problem with both binary and continuous variables. N units for total period of H intervals, the maximum number of possible combinations is $(2^N - 1)^H$.For 24-hour period with 5, 10 units, it becomes $6.2*10^{35}$, $1.73*10^{72}$ respectively

1.2.1 **Cost function**

The cost function of generator is typically expressed as a quadratic function of generator as given by equation 1.1

$$C\ (p) = a + b*p + c*p^2 \quad \text{Rs/MWh} \qquad (1.1)$$

Where ,

C (p) is cost of production in Rs

P is amount of generation in MW

a,b,c are generator constants in \$/hr, \$/MWh, \$/Mw^2h respectively.

1.2.2 **Start-up cost:**

Temperature and pressure of the thermal unit should be rolled slowly and such certain amount of energy must be expended to make unit on-line. This energy does not count in any Mw generation from the unit and this account to start-up cost.

There are two possible ways the unit can be turned down.one is to bring down unit to cool down and then heat back up to operating temperature in time for a scheduled turn on.

$$\text{Start-up cost when cooling} = C_c(1 - \varepsilon^{-t/\alpha})*F+C_f \qquad (1.2)$$

Where

C_c = cold –start cost (MBtu)

F= fuel cost

C_f = fixed cost

α= thermal time constraint for the unit

t= time (h) the unit was cooled

Second is banking. In that sufficient energy is input to boiler in order to maintain operating temperature.

Start –up cost When banking= C_t *t*F*C_f (1.3)

Where

C_t = Cost (MBtu/hr) of maintaining unit at operating temperature.

Different formulations of unit commitment like PBUC, SCUC ,unit commitment of power system with renewable energy sources along with respective constraints have been modelled in [10]. Ramp-rate characteristics in starting up and shutting down the generating units as well as increasing and decreasing power generation have studied briefly in [11].Non-linear constraints minimum up time and minimum down time and idea of linearizing them have described in [12].In the Sections 1.2.3 to 1.2.11, a brief discussion on constraint is attempted.

1.2.3 **Constraints in Unit Commitment:**

Each Individual Power System, Power pool may have different rules and different motives to operate. Respectively different constraints are placed on unit commitment problem as per requirement.

1.2.4 **System Real Power balance :**

The generated power from all the committed units must be equal to load demand.

1.2.5 **Unit generation limits:**

Under normal operating condition, each generator has limits of sustained generation and is called as generation limit. It is not economical to load the unit below the minimum limit and the unit should not be committed above the maximum limit.

1.2.6 **Unit Initial Status:**

The initial status value indicates the number of hours the unit has already been on or off before the schedule. It can be ±. It's an important factor to determine whether the just committed units satisfy the minimum up time and minimum down time, it also effects the start-up calculations.

1.2.7 **Ramp rate limits:**

Usually Generators incur more maintenance cost when there are rapid changes in temperature or output generation, safe ramp up and safe ramp down rates are provided by manufacturer based on physical design.

Ramp up rate is the rate at which particular generator can increase its output generation in an hour. Ramp down rate is the rate at which particular generator can decrease its output generation in an hour.

Start-up Ramp rate is the rate at which particular generator can increase its output generation in an hour while bringing a unit on-line from off. Shut down Ramp down rate is the rate at which particular generator can decrease its output generation in an hour while bringing down a unit off from on-line**.**

1.2.8 **Minimum up Time:**

Thermal units usually need a crew to operate them in order to turn on and turned off. More over thermal unit can undergo only gradual temperature changes, and this necessitates into a time period of some hours required to bring unit on-line. These restrictions formulate minimum up time and minimum down constraint. Minimum up time is the time it should run, once it turned on. In Other sense it should not be turned off immediately.

1.2.9 **Minimum down Time:**

Minimum down is the time it should in decommitted mode, once it turned off.

1.2.10 **Must-run:**

For some purposes as supply for uses outside the plant itself or for voltage support on the transmission network etc., some units are given must-run status.

1.2.11 **Must not-run:**

For some maintenance reasons and on forced outages, some units are given must-not run status.

1.3 Unit Commitment in Restructured environment

In Restructured power system, markets were divided based on their approach to supply-side bidding. Some systems used “one-part” incremental energy bids that take care of all accounts, while some employed “three-part” bids.

In [12], multi block price bids are incorporated and solved the unit commitment. Optimal power flow with transmission and security and voltage constraints is incorporated in [14],[15] and penalty factor is added to limits of constraints in [15]. A set of heuristic rules is applied with OPF for unit commitment with network constraints in [16]. In [17] ,transaction bid, load bid, generation bid and their bid prices are discussed. In [18], [19] organization of restructured power systems and its structure are discussed. In [20] designing of competitive power markets are studied. Brief information relating to them is as follows.

The three parts are start-up costs, minimum load costs and energy bids.

Start-up costs are based on status of unit whether unit was cooled down or in hot start mode. If the unit was in banking mode then it becomes some constant function whereas when it is in cooling, it is in terms of exponential form. The minimum load cost is a fixed cost occurs whenever unit is on.it is as called as no-load cost because at this minimum level the units are no longer supplying electricity.

The energy bid is a incremental function of incremental costs to produce required MWh of energy. This is limited by minimum and maximum loads of generator.

1.4 Scope of work:

Traditional unit commitment with the objective of minimizing costs of generator such as production cost which is modelled as quadratic, start-up cost which is assumed to be in banking mode and shut down cost, is solved with generator limits, ramp up limits , up time and down time limits, must run and must not run constraints. Respective problem formulations are done in chapter 2, section 2.1 and is implemented on a test sytem1 with 10 generators and 24 hours. Results are presented in Section 4.1.

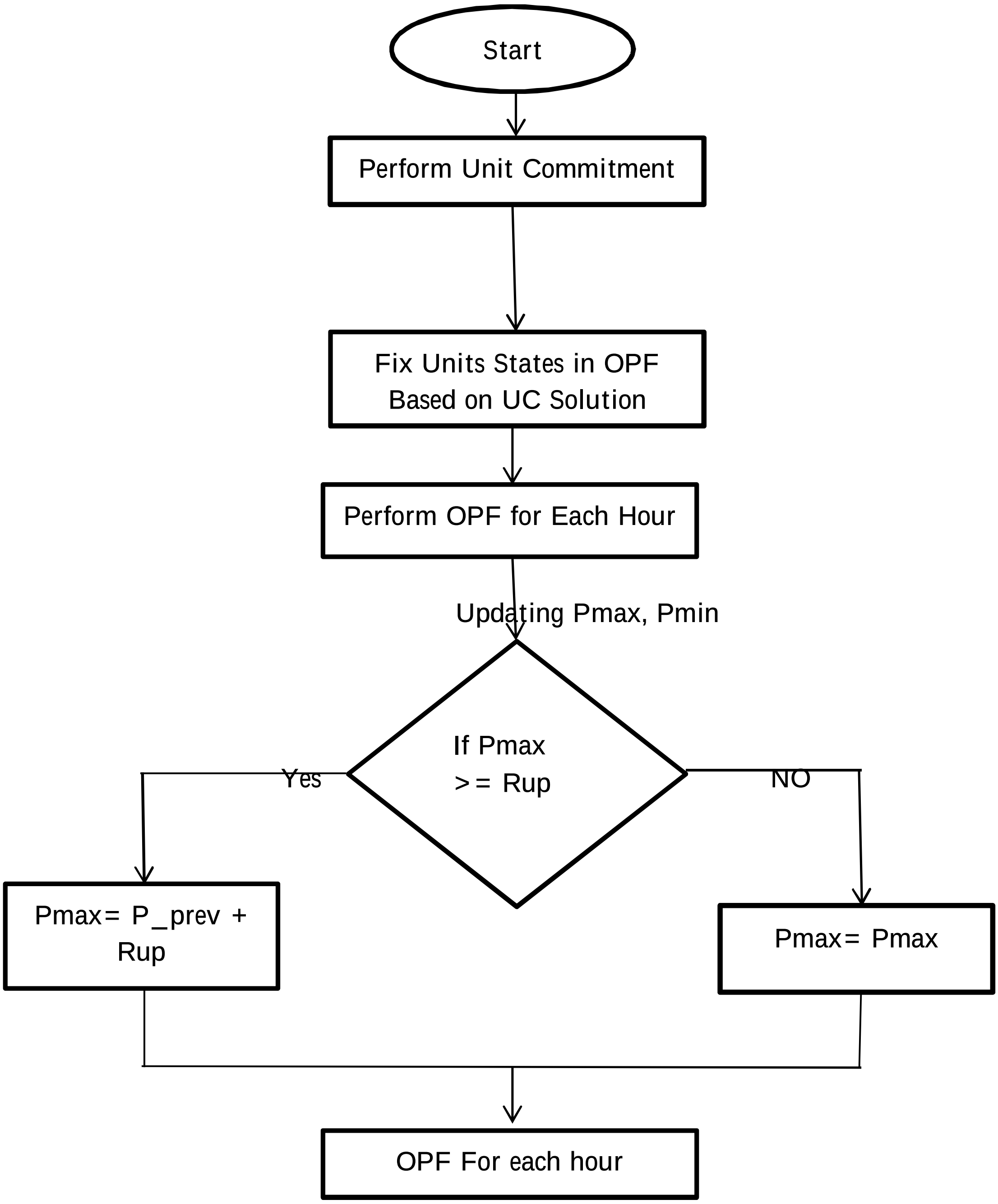


Figure 1.3: Outline of attempt to improve OPF solution

Piece wise linearization of quadratic cost function, adding slack term to inequality constraints with high penalty factor, adding DC power flow constraints is the next consecutive step. Respective problem formulations are done in chapter 2, section 2.2 and is implemented on a test sytem2 with 10 generators and 24 hours.

Unit Commitment in Restructured power systems in tune with traditional unit commitment, with the objective of maximizing social welfare and with a provision of paying start-up cost and fixed cost only if the generator is not turned on by itself. It is explained with a test case as for generator G1 with minimum uptime of 3 hours is turned on h=4 by generator itself then up to minimum up time hours for that generator, even if generator turned on by Unit commitment, there should be no start-up cost and fixed cost are paid to the generator. In addition three part generator biddings, load bidding and bilateral transaction bidding is included to the unit commitment. Respective problem formulations are done in chapter 3, section 3.4 and is implemented on a test sytem3 with 10 generators and 24 hours.

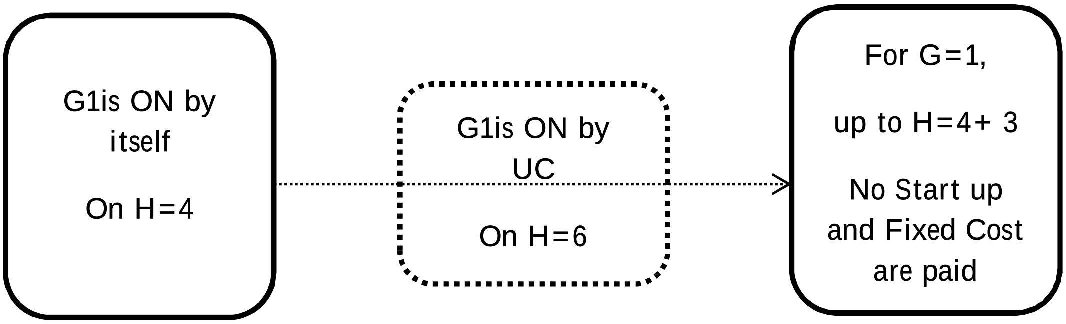


Figure 1.4: Test case

Chapter 2

Problem Formulation-Unit Commitment with Piece-wise linearization of Cost function

2.1 Unit Commitment

2.1.1 Objective Function

$$\sum_{h=0}^{24+\max(Tup,Tdn)-1} \sum_{k=1}^{n} C\big(p(k,h)\big) * u(k,h)$$

$$+ \quad \sum_{h=0}^{24+\max(Tup,Tdn)-1} \sum_{k=1}^{n} \Big(s(k) * \big(1-u(k,h)\big)\Big) \qquad (2.1)$$

Where

$C(p(k,h)) = a + b * p(k,h) + c*p(k,h)^2$

$s(k)$ is start –up cost When banking= C_t *t*F*C_f

C_t = cost (MBtu/hr) of maintaining unit at operating temperature.

C_f = fixed cost

F= fuel cost

t= time(h) the unit was cooled

2.1.2 Load constraint

$$\sum_{k=0}^{n} p(k,h) = pload(ld,h) \qquad (2.2)$$

2.1.3 Generation Limit Constraint

$$u(k,h) * pmin(k,h) \;\leq\; p(k,h) \;\leq\; u(k,h) * pmax(k,h) \qquad (2.3)$$

2.1.4 Ramp up Limit

$$\mathrm{p(k,h) - p(k,h-1) \;\leq\; ustrt(k,h) *Rstrt(k) + (1 - ustrt(k,h)) * Rup(k)} \qquad (2.4)$$

2.1.5 **Ramp Down Limit**

$$p(k,h-1) - p(k,h) \quad \leq \quad usht(k,h) *Rsht(k) \; + \; (1-usht(k,h)) * Rdn(k) \qquad (2.5)$$

2.1.6 **Up Time Constraint**

$$\sum_{\tau=h}^{(h+\max(Tup(k),Tdn(k))-1)} u(k,\tau) \quad \leq \quad ustrt(k,h) \; *Tup(k) \qquad (2.6)$$

2.1.7 **Down Time Constraint**

$$\sum_{\tau=h}^{(h+\max(Tup(k),Tdn(k)))-1)} \big(1-u(k,\tau)\big) \quad \leq \quad usht(k,h) \; *Tdn(k) \qquad (2.7)$$

2.1.8 **Must Run Constraint**

$$\sigma(k,h) * u(k,h) \leq \sigma(k,h) \qquad (2.8)$$

$\sigma(k,h) = 1$ if unit k is a must run for a hour

$= 0$ otherwise

2.1.9 **Must Not Run Constraint**

$$\rho(k,h) * (1-u(k,h)) \leq \rho(k,h) \qquad (2.9)$$

$\rho(k,h) = 1$ if unit k is a must not run for a hour

$= 0$ otherwise

2.1.10 **Generating units state logic**

$$-\alpha u(k,h-1) \;\leq\; ustrt(k,h) - (u(k,h) - u(k,h-1)) \;\leq\; \alpha u(k,h-1) \qquad (2.10)$$

$$-\alpha(1-u(k,h-1)) \;\leq\; ustrt(k,h) \;\leq\; \alpha(1-u(k,h-1))$$

(2.11)

2.1.11 **Generating units state logic**

$$\alpha(1-u(k,h-1)) \;\leq\; usht(k,h) - (u(k,h-1) - u(k,h)) \;\leq \alpha(\,1-u(k,h-1))(2.12)$$

$$-\alpha(1-u(k,h-1)) \;\leq\; usht(k,h) \;\leq\; \alpha u(k,h-1) \qquad (2.13)$$

2.2 Piece Wise Linearization Of Cost Function

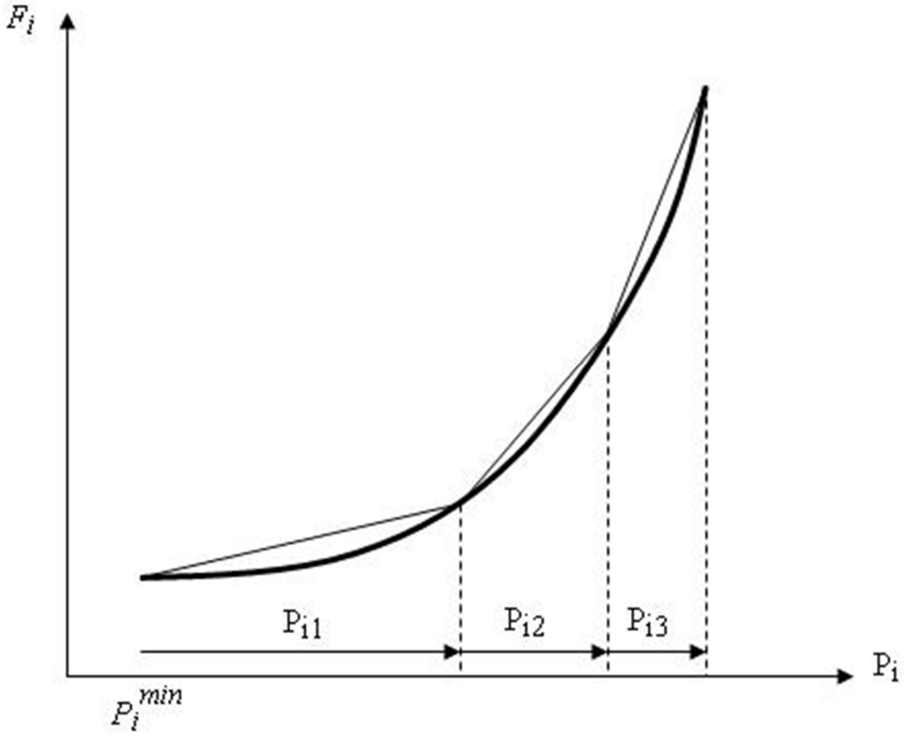


Figure2.1: Piece Wise Linearization Of Cost Function

Where F_i $is\ production\ cost\ \left(\frac{Rs}{MWh}\right)$

$C(p(k,h)) = a + b * p(k,h) + c{*}p(k,h)^2$

P_i is Production level of generator (MW)

$P_i{}^{min}$ is minimum production level of generator

P_{i1}, P_{i2}, P_{i3} are sectional production levels of generator

C(p(k,h)) = C(pmin(k)) + $\sum_{s=1}^{5}\mathbf{slope}(\mathbf{se},\mathbf{k}) * \mathbf{p1(}$k,h,se) (2.14)

P(k,h) = pmin(k) + $\sum_{s=1}^{5}\mathbf{p1}(\mathbf{k},\mathbf{h},\mathbf{se})$ (2.15)

$0 \leq \mathrm{p1(k,h,se)} \leq (\mathrm{pmin(k)} - \mathrm{pmax(k)})/5$ (2.16)

Where

$slope(k,s)$ is slope of section s of k th generator

$p1(k,h,se)$ is power output of k th generating unit at hour h in section s

2.3 Dealing Infeasibility With Penalty Factor

F(x)+M1*Z1+M2*Z2 (2.17)

f(x)≤c1 +Z1 (2.18)

g(x)≤ c2+Z2 (2.19)

Where

F(x) is objective function which is to be minimize

f(x),g(x) are inequality constraints

M1,M2 are penalty factors

Z1,Z2 are slack terms

2.4 DC Power Flow

$Flow = A_{line} * \chi^{-1} * \boldsymbol{\delta}$ (2.20)

$Pinj(n,h) = \sum_k A_g(n,k) * p\ (k,h) - \sum_{ld}(A_d(n,ld) * pload$ (ld,h)) (2.21)

$Where$

$A_g(n,k)$= 1 if $p\ (k)$ is from node n.

= -1 if $p\ (k)$ is to node n.

= 0 if $p\ (k)$ is not related to node n.

$A_d(n,ld)$= 1 if $pload\ (ld)$ is from node n.

= -1 if $pload\ (ld)$ is to node n.

= 0 if $pload\ (ld)$ is not related to node n.

-$Flow_{min}$≤ $Flow$ ≤ $Flow_{max}$ (2.22)

Chapter 3

Problem Formulation – UC in Restructured environment.

3.1 Optimal Power Flow

3.1.1 Objective Function

Min (-W (p)) (3.1)

Where W (p) = $\sum_{h=0}^{24+\max(Tup,Tdn)-1} \sum_{k=1}^{n} p(k,h) * pbidprice(k)$ (3.2)

3.1.2 Generation Limit Constraint

$u(k,h) * pmin(k,h) \ \leq \ p(k,h) \ \leq \ u(k,h) * pmax(k,h)$ (3.3)

3.1.3 DC Power Flow

$Flow = A_{line} * \boldsymbol{\chi}^{-1} * \boldsymbol{\delta}$ (3.4)

$Pinj(n,h) = \sum_k A_g(n,k) * p\ (k,h) - \sum_{ld}(A_d(n,ld) * pload$ (ld,h)) (3.5)

$Where$

$A_g(n,k)$ = 1 if $p\ (k)$ is from node n.

= -1 if $p\ (k)$ is to node n.

= 0 if $p\ (k)$ is not related to node n.

$A_d(n,ld)$ = 1 if $pload\ (ld)$ is from node n.

= -1 if $pload\ (ld)$ is to node n.

= 0 if $pload\ (ld)$ is not related to node n.

$$-Flow_{min} \leq Flow \leq Flow_{max} \qquad (3.6)$$

3.2 Unit Commitment in Restructured Environment

3.2.1 Objective Function

Min {-W(p) } (3.7)

Where

W(p) is social welfare =

$$\sum_{h=0}^{24+\max(Tup,Tdn)-1} \sum_{ld=1}^{2} pload\_var(ld,h) * pload\_var\_price(ld,h)$$

$$- \sum_{h=0}^{24+\max(Tup,Tdn)-1} \sum_{k=1}^{n} p(k,h) * pbidprice(k)$$

$$- \sum_{h=0}^{24+\max(Tup,Tdn)-1} \sum_{k=1}^{n} ustrt(k,h) * fixed(k,h) * startupprice(k)$$

$$- \sum_{h=0}^{24+\max(Tup,Tdn)-1} \sum_{k=1}^{n} pfixed(k,h) * pminloadprice(k)$$

$$+ \sum_{h=0}^{24+\max(Tup,Tdn)-1} \sum_{k=1}^{n} pbiltra_{var(t,h)} * pbiltra\_var\_price(t,h)$$

Here $pfixed(k,h)$ is defined in such a way that $pminloadprice(k)$ will not be paid to generator from just started hour till minimum up-time hours if there is turn on by generator itself for fixed load and bilateral transaction.

3.2.2 Power balance Constraint

$$Pinj(n,h) = \sum_k A_g(n,k) * p\,(k,h) - \sum_{ld} A_d(n,ld) * (pload\_fix(\text{ld,h})) + (\sum_{ld} A_{1d}(n,ld) * pload\_var(\text{ld,h})\,) + \sum_t A_{bil}(n,t) * (pbiltra\_fix\,(\text{t, h}) + \sum_t A_{1bil}(n,t) * pbiltra\_var\,(\text{t, h}) \qquad (3.9)$$

Where

$A_g(n,k)$ = 1 if $p\,(k)$ is from node n.

= -1 if $p\,(k)$ is to node n.

= 0 if $p\ (k)$ is not related to node n.

$A_d(n, ld)$ = 1 if $pload\_fix\ (ld)$ is from node n.

= -1 if $pload\ \_fix(ld)$ is to node n.

= 0 if $pload\_fix\ (ld)$ is not related to node n.

$A_{1d}(n, ld)$ = 1 if $pload\_var\ (ld)$ is from node n.

= -1 if $pload\_var\ (ld)$ is to node n.

= 0 if $pload\_var\ (ld)$ is not related to node n.

$A_{bil}(n, t)$ = 1 if $pbiltra\_fix\ (t)$ is from node n.

= -1 if $pbiltra\_fix(t)$ is to node n.

= 0 if $pbiltra\_fix\ (t)$ is not related to node n.

$A_{1bil}(n, t)$ = 1 if $pbiltra\_var\ (t)$ is from node n.

= -1 if $pbiltra\_var(t)$ is to node n.

= 0 if $pbiltra\_var(t)$ is not related to node n.

3.2.3 elastic Limits

$P\ (k,h) \quad < \quad pmax\_bid(k)$ (3.10)

$Pload\_var\ (ld,h) \quad < \quad pmax\_load(ld)$ (3.11)

$pbiltra\_var(t, h) \quad < \quad pmax\_biltra(t)$ (3.12)

3.2.4 Network Capacity Constraint

$-Flow_{min} \leq Flow \leq Flow_{max}$ (3.13)

3.2.5 Generation Limit Constraint

$u(k, h) * pmin(k, h) \;\leq\; p(k, h) \;\leq\; u(k, h) * pmax(k, h)$ (3.14)

3.2.6 Ramp up Limit

$p(k, h) - p(k, h-1) \;\leq\; ustrt(k, h) * Rstrt(k) \;+\; (1 - ustrt(k, h)) * Rup(k)$ (3.15)

3.2.7 Ramp Down Limit

$\mathrm{p(k, h-1) - p(k, h) \;\leq\; usht(k, h) * Rsht(k) \;+\; (1 - usht(k, h)) * Rsht(k)}$ (3.16)

3.2.8 Up Time Constraint

$\sum_{\tau=h}^{(h+\max(Tup(k), Tdn(k))-1)} u(k, \tau) \;\leq\; ustrt(k, h) * Tup(k)$ (3.17)

3.2.9 Down Time Constraint

$$\sum_{\tau=h}^{(h+\max(Tup(k),Tdn(k)))-1}\left(1-u(k,\tau)\right) \quad \leq \quad usht(k,h) \ {*}Tdn(k) \qquad (3.18)$$

3.2.10 Must Run Constraint

$$\sigma(k,h) * u(k,h) \leq \sigma(k,h) \qquad (3.19)$$

$\sigma(k,h) = 1$ if unit k is a must run for a hour

$= 0$ otherwise

3.2.11 Must Not Run Constraint

$$\rho(k,h) * (1-u(k,h)) \leq \rho(k,h) \qquad (3.20)$$

$\rho(k,h) = 1$ if unit k is a must not run for a hour

$= 0$ otherwise

3.2.12 Generating units state logic

$$-u(k,h-1) \leq ustrt(k,h) - (u(k,h) - u(k,h-1)) \leq u(k,h-1) \qquad (3.21)$$

$$-(1-u(k,h-1)) \leq ustrt(k,h) \leq (1-u(k,h-1)) \qquad (3.22)$$

3.2.13 Generating units state logic

$$(1-u(k,h-1)) \leq usht(k,h) - (u(k,h-1) - u(k,h)) \leq 1-u(k,h-1) \qquad (3.23)$$

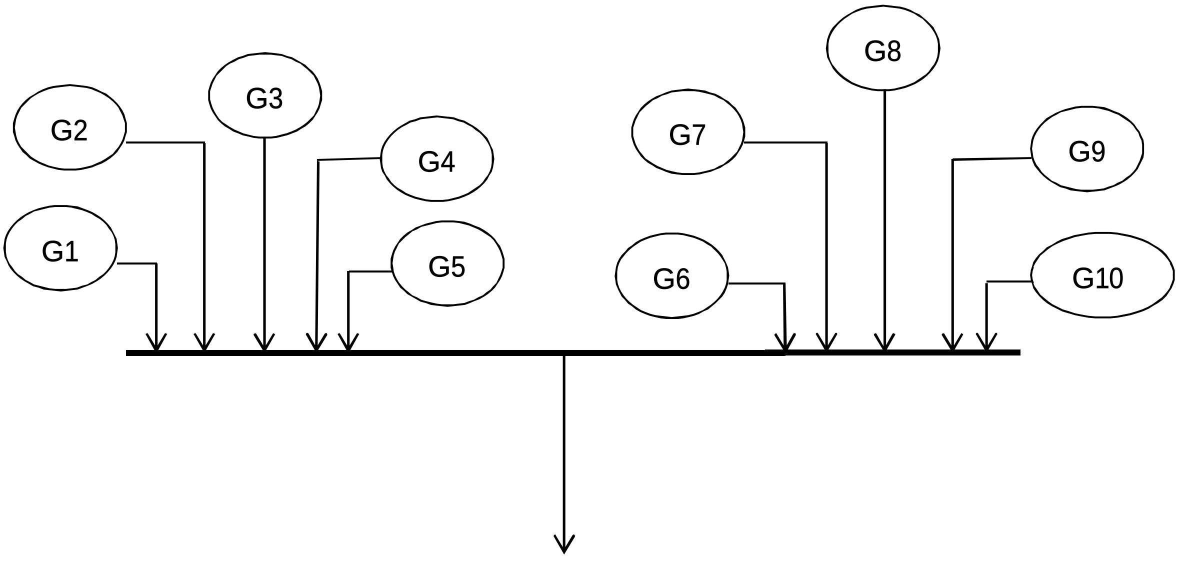
$$-(1-u(k,h-1)) \leq usht(k,h) \leq u(k,h-1) \qquad (3.24)$$

Chapter 4

Results and discussion- UC with Piece-wise linearization of Cost function

4.1 Unit Commitment

4.1.1 Test System Lay Out



ld =1

Figure 4.1: Test System1

4.1.2 Specifications

Table 4.1 contains generators minimum power limit, maximum power limit, ramp up limit, ramp down limit, start-up ramp limit, shutdown ramp rate, minimum up time, minimum down time and generator cost function coefficients a0, a1, a2. Table 4.2 contains required load demand for 24 hours. All the generators are assumed to be off initially.

Table 4.1: Specifications of Generator

Gen.no	1	2	3	4	5	6	7	8	9	10
Pmin(MW)	300	130	165	130	225	50	250	110	275	75
Pmax(MW)	1000	400	600	420	700	200	750	375	850	250
Rdn (MW/hr)	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Rup (MW/hr)	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Rshdn (Mw/hr)	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Rsup (Mw/hr)	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Tup(hr)	1	5	2	1	4	3	1	5	2	1
Tdn(hr)	1	2	1	1	3	2	1	0	1	2
a0($/hr)	820	400	600	420	540	175	600	400	725	200
a1($/MWhr)	9.023	7.654	8.752	8.431	9.223	7.054	9.121	7.762	8.162	8.149
a2($/$MWhr^2$)	0.00113	0.0016	0.00147	0.0015	0.00234	0.00515	0.00131	0.00171	0.00128	0.00452
S(k) $	100	500	200	100	400	300	100	500	200	100

Table 4.2: Load

hr	1	2	3	4	5	6	7	8	9	10	11	12
ld=1(MW)	1025	1000	900	850	1025	1400	1970	2400	2850	3150	3300	3400
hr	13	14	15	16	17	18	19	20	21	22	23	24
ld=1(MW)	3275	2950	2700	2550	2725	3200	3300	2900	2125	1650	1300	1150

4.1.3 **Results:**

Minimized cost for 10 generators 24 hours period to meet load specified in Table 4.2 is 5.5837e+005 $. Table 4.3 depicts generators cleared amount of power schedule for each hour up to 24 hours . Table 4.4, Table 4.5, Table 4.6 contains binary values. Table 4.4 shows the generators which are online in present hour. Table 4.5 shows the generators which are coming online from previous off state. For h=1, generators 2,6,8 10 are online and status in Table 4.4 are 1 .Table 4.5 shows the generators which are coming offline from previous on state. Generator 2 is scheduled 300 MW in 5 hour, 0 MW in 6 hour.it is coming off from on status and its status in Table 4.5 in 6 hour is 1.

Table 4.3a: Output Generation of 1,2,3 Units Power in Simple UC for 1-12 hours

P(k,h) (MW)	h=1	2	3	4	5	6	7	8	9	10	11	12
k=1	0	300	0	0	0	0	300	300	300	300	300	300
2	400	390	400	290	300	0	0	400	400	400	400	400
3	0	0	0	0	165	0	0	165	225	355	255	355

Table 4.3b: Output Generation of 4-10 Units Power in Simple UC for 1-12 hours

4	0	0	130	0	0	0	0	0	0	420	420	420
5	0	0	0	0	0	0	0	0	0	0	0	0
6	200	200	200	200	200	200	200	200	200	200	200	200
7	0	0	0	250	250	250	250	0	250	0	250	250
8	350	110	170	110	110	375	375	375	375	375	375	375
9	0	0	0	0	0	325	595	710	850	850	850	850
10	75	0	0	0	0	250	250	250	250	250	250	250

Table 4.3c: Output Generation of power for 13 - 24 hours in Simple UC

P(k,h)	h=13	14	15	16	17	18	19	20	21	22	23	24
k=1	300	300	300	300	300	300	300	300	300	0	0	0
2	400	400	400	400	400	400	400	400	400	0	0	0
3	230	165	0	0	350	405	255	275	0	0	0	0
4	420	410	130	175	0	420	420	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	200	200	200	200	200	200	200	200	200	200	200	200
7	250	0	250	0	0	0	250	250	0	250	250	325
8	375	375	375	375	375	375	375	375	375	375	375	375
9	850	850	795	850	850	850	850	850	600	575	275	0
10	250	250	250	250	250	250	250	250	250	250	200	250

Table 4.4a: Unit Status in Simple UC for 1-12 hours

u(k,h)	h=1	2	3	4	5	6	7	8	9	10	11	12
k=1	0	1	0	0	0	0	1	1	1	1	1	1
2	1	1	1	1	1	0	0	1	1	1	1	1
3	0	0	0	0	1	0	0	1	1	1	1	1
4	0	0	1	0	0	0	0	0	0	1	1	1
5	0	0	0	0	0	0	0	0	0	0	0	0
6	1	1	1	1	1	1	1	1	1	1	1	1
7	0	0	0	1	1	1	1	0	1	0	1	1
8	1	1	1	1	1	1	1	1	1	1	1	1
9	0	0	0	0	0	1	1	1	1	1	1	1
10	1	0	0	0	0	1	1	1	1	1	1	1

Table 4.4b: Unit Status of 1-5 Units in Simple UC for 13-24 hours

u(k,h)	h=13	14	15	16	17	18	19	20	21	22	23	24
k=1	1	1	1	1	1	1	1	1	1	0	0	0
2	1	1	1	1	1	1	1	1	1	0	0	0
3	1	1	0	0	1	1	1	1	0	0	0	0
4	1	1	1	1	0	1	1	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.4c: Unit Status of 6-10 Units in Simple UC for 13-24 hours

6	1	1	1	1	1	1	1	1	1	1	1	1
7	1	0	1	0	0	0	1	1	0	1	1	1
8	1	1	1	1	1	1	1	1	1	1	1	1
9	1	1	1	1	1	1	1	1	1	1	1	0
10	1	1	1	1	1	1	1	1	1	1	1	1

Table 4.5a: Just Start Status in Simple UC for 1-12 hours

ustrt(k,h)	h=1	2	3	4	5	6	7	8	9	10	11	12
k=1	0	1	0	0	0	0	1	0	0	0	0	0
2	1	0	0	0	0	0	0	1	0	0	0	0
3	0	0	0	0	1	0	0	1	0	0	0	0
4	0	0	1	0	0	0	0	0	0	1	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	1	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	1	0	0	0	0	1	0	1	0
8	1	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	1	0	0	0	0	0	0
10	1	0	0	0	0	1	0	0	0	0	0	0

Table 4.5a: Just Start Status in Simple UC for 13 -24 hours

ustrt(k,h)	h=13	14	15	16	17	18	19	20	21	22	23	24
k=1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	1	0	0	0	0	0	0	0
4	0	0	0	0	0	1	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	1	0	0	0	1	0	0	1	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.6: Just Shut Down Status of 1-5 Units in Simple UC for 1-12 hours

usht(k,h)	h=1	2	3	4	5	6	7	8	9	10	11	12
k=1	0	0	1	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	1	0	0	0	0	0	0
3	0	0	0	0	0	1	0	0	0	0	0	0
4	0	0	0	1	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.6: Just Shut Down Status of 6-10 Units in Simple UC for 1-12 hours

6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	1	0	1	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	1	0	0	0	0	0	0	0	0	0	0

Table 4.6: Just Shut Down Status in Simple UC for 13-24 hours

usht(k,h)	h=13	14	15	16	17	18	19	20	21	22	23	24
k=1	0	0	0	0	0	0	0	0	0	1	0	0
2	0	0	0	0	0	0	0	0	0	1	0	0
3	0	0	1	0	0	0	0	0	1	0	0	0
4	0	0	0	0	1	0	0	1	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	1	0	1	0	0	0	0	1	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	1
10	0	0	0	0	0	0	0	0	0	0	0	0

4.2 UC with Piece-Wise Linearization of Cost Function, Dealing Infeasibility, DC Power Flow

4.2.1 **Test System Lay Out**

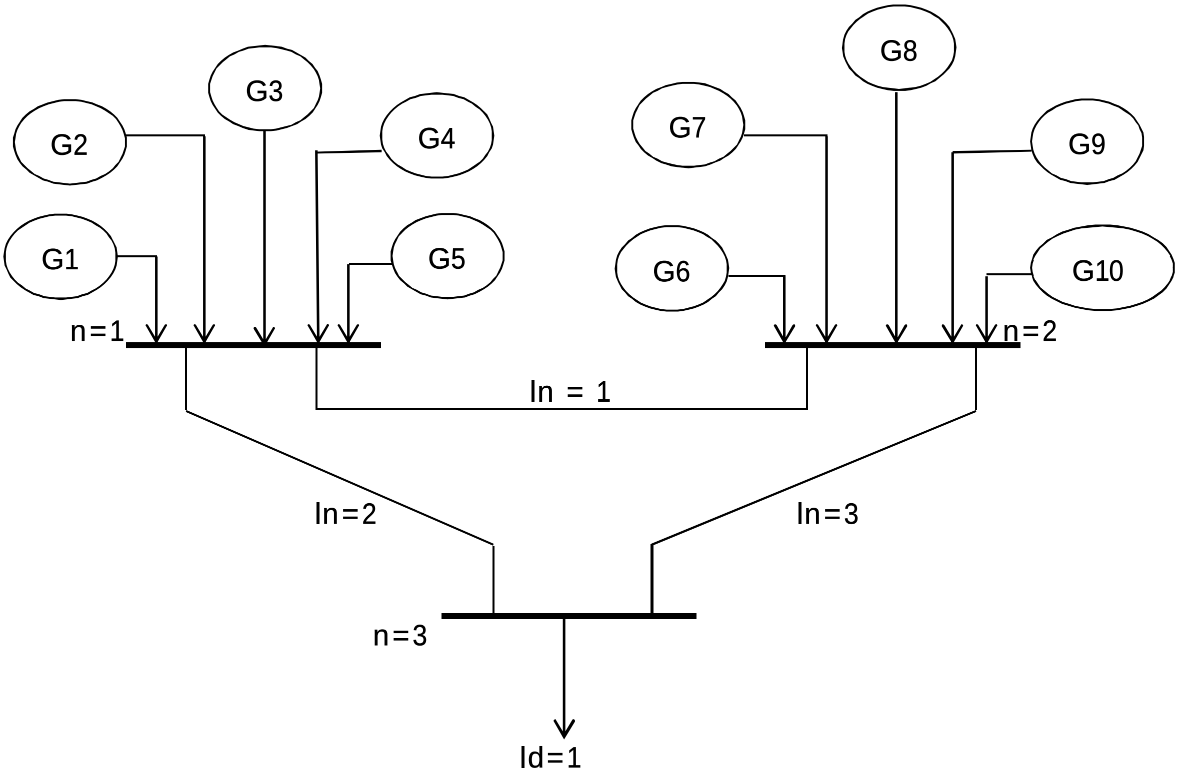


Figure 4.2: Test System2

4.2.2 **Specifications**

Table 4.7 contains generators minimum power limit, maximum power limit, sart up cost, fixed cost, ramp up limit, ramp down limit, start up ramp limit, shutdown ramp rate, minimum up time, minimum down time .Table 4.8 contains required load demand for 24 hours. Table 4.9 contains slopes of sections in generator cost function. Table 4.10 contains flow limits of each line and their Susceptance. Table 4.11 shows which units initial status and its generation in zero hour.

Table 4.7: Specifications of Generator

Gen.no	1	2	3	4	5	6	7	8	9	10
Pmin(MW)	150	10	150	10	10	10	10	10	10	10
Pmax(MW)	455	55	455	55	130	80	130	85	162	55
Fcst($)	50	50	50	50	50	50	50	50	50	50
Scost($)	50	50	50	50	50	50	50	50	50	50
Rdn(MW/hr)	142	52	142	147	185	148	163	186	178	176
Rup(MW/hr)	300	211	186	198	212	193	245	235	289	321
Rshdn(MW/hr)	480	15	1000	15	150	10	150	10	80	10
Rsup(MW/hr)	480	15	1000	15	150	10	150	10	120	10
Tdn(hr)	1	1	2	0	1	2	0	1	0	1
Tup(hr)	1	5	2	1	4	5	1	5	1	2

Table 4.8: Load

hr	1	2	3	4	5	6	7	8	9	10	11	12
ld=1 (Mw)	700	750	850	950	300	1100	1150	1200	1300	1400	1450	1500
hr	13	14	15	16	17	18	19	20	21	22	23	24
ld=1 (Mw)	1400	1300	200	1050	1000	400	600	750	1300	500	1000	800

Table 4.9: Slope of Cost Function Sections

Gen.No	Sec1	Sec2	Sec3	Sec4	Sec5
1	16.36328	16.42184	16.4804	16.53896	16.59752
2	27.84017	27.87131	27.90245	27.93359	27.96473
3	17.37191	17.40973	17.44755	17.48537	17.52319
4	27.33438	27.37434	27.4143	27.45426	27.49422
5	16.724	16.812	16.9	16.988	17.076
6	22.63024	22.80112	22.972	23.14288	23.31376
7	16.63082	16.72366	16.8165	16.90934	17.00218
8	27.78898	27.80794	27.8269	27.84586	27.86482
9	20.00805	20.22616	20.44426	20.66236	20.88047
10	26.03977	26.11411	26.18845	26.26279	26.33713

Table 4.10: Flow Limits

ln	Susceptance(pu)	Power Rating Of lines(pu)
1	2.5	2.5
2	3.5	3.5
3	1.4	1.4

Table 4.11: Initial Unit Status

generator	U(k,0)	P(k,0)
1	1	200
2	0	0
3	0	0
4	0	0
5	0	0
6	0	0
7	1	50
8	0	0
9	0	0
10	0	0

4.2.3 **Results:**

Minimized cost for 10 generators 24 hours period to meet load specified in Table 4.8 is 2.5883e+005 $. Slack terms off all the inequality limits such as z1,z2,z3,z4,z5,z6 are zero which shows obtained solution is optimal. Table 4.12 depicts generators cleared amount of power schedule for each hour up to 24 hours. Table 4.13, Table 4.14, Table 4.15 contains binary values. Table 4.13 shows the generators which are online from in present hour. Table 4.14 shows the generators which are coming online from previous off state. For h=1, generators 2,3,4,5,6,8,9 10 are coming online from off and status in Table 4.13 are 1 .Table 4.15 shows the generators which are coming offline from previous on state. Generator 1 is scheduled 455 MW in 4 hour, 0 MW in 5 hour.it is coming off from on status and its status in Table 4.15 in 5 hour is 1. Table 4.16 contains bus angles at each hour to accommodate power flow as required by load. Table 4.17, Table 4.18, Table 4.19, Table 4.20, Table 4.21 contains output power in 5 sections of cost function. Generator 1, 1 hour in Table 4.12 is scheduled 455 MW. This is shared by five sections as 61MW in Table 4.17, 61MW in Table 4.18, 61MW in Table 4.19, 61MW in Table 4.20, 61MW in Table 4.21 plus minimum generation of 150MW in Table 4.7.

modelstat=0

solvestat=1

z1:slack of pmax limit

z1 = 0

z2:slack of pmin limit

z2 = 0

z3:slack of flow upper limit

z3 = 0

z4:slack of flow lower limit

z4 = 0

z5:slack of rampup limit

z5 = 0

z6:slack of rampdwn limit

z6 = 0

Table 4.12a: Output Power Generation of 1-4 Units in UC with Piece-wise linearization for 1-12 hours

P(k, h) (Mw)	h=0	h=1	2	3	4	5	6	7	8	9	10	11	12
k=1	200	455	455	455	455	0	455	455	455	455	455	455	455
2	0	10	10	10	10	10	10	10	10	10	10	10	10
3	0	150	150	150	175	150	325	375	425	455	455	455	455
4	0	10	10	10	10	10	10	10	10	10	10	10	13
5	0	10	27	82	130	32	130	130	130	130	130	130	130

Table 4.12b: Output Power Generation of 6-10 Units in UC with Piece-wise linearization for 1-12 hours

6	0	10	10	10	10	10	10	10	10	10	28	78	80
7	50	25	58	103	130	58	130	130	130	130	130	130	130
8	0	10	10	10	10	10	10	10	10	10	10	10	10
9	0	10	10	10	10	10	10	10	10	80	162	162	162
10	0	10	10	10	10	10	10	10	10	10	10	10	55

Table 4.12c: Output Power Generation in UC with Piece-wise linearization for 13-24 hours

P(k,h)	h=13	14	15	16	17	18	19	20	21	22	23	24
k=1	455	455	0	454	312	170	370	455	412	270	455	455
2	10	10	0	10	10	10	10	10	10	10	10	10
3	434	292	150	276	292	150	150	150	292	150	225	150
4	10	10	10	10	10	10	10	10	19	10	10	10
5	130	130	0	130	130	10	10	27	130	10	130	58
6	49	80	10	10	10	10	10	10	80	10	10	10
7	130	130	10	130	130	10	10	58	130	10	130	77
8	10	10	0	10	10	10	10	10	10	10	10	10
9	162	162	10	10	86	10	10	10	162	10	10	10
10	10	21	10	10	10	10	10	10	55	10	10	10

Table 4.13a: Unit Status in in UC with Piece-wise linearization for 1-12 hours

u(k, h)	h=0	h=1	2	3	4	5	6	7	8	9	10	11	12
k=1	1	1	1	1	1	0	1	1	1	1	1	1	1
2	0	1	1	1	1	1	1	1	1	1	1	1	1
3	0	1	1	1	1	1	1	1	1	1	1	1	1
4	0	1	1	1	1	1	1	1	1	1	1	1	1
5	0	1	1	1	1	1	1	1	1	1	1	1	1
6	0	1	1	1	1	1	1	1	1	1	1	1	1
7	1	1	1	1	1	1	1	1	1	1	1	1	1
8	0	1	1	1	1	1	1	1	1	1	1	1	1
9	0	1	1	1	1	1	1	1	1	1	1	1	1
10	0	1	1	1	1	1	1	1	1	1	1	1	1

Table 4.13b: Unit Status of 1-5 Units in UC with Piece-wise linearization for 13-24 hours

u(k,h)	h=13	14	15	16	17	18	19	20	21	22	23	24
k=1	1	1	0	1	1	1	1	1	1	1	1	1
2	1	1	0	1	1	1	1	1	1	1	1	1
3	1	1	1	1	1	1	1	1	1	1	1	1
4	1	1	1	1	1	1	1	1	1	1	1	1
5	1	1	0	1	1	1	1	1	1	1	1	1

Table 4.13b: Unit Status of 6-10 Units in UC with Piece-wise linearization for 13-24 hours

6	1	1	1	1	1	1	1	1	1	1	1	1
7	1	1	1	1	1	1	1	1	1	1	1	1
8	1	1	0	1	1	1	1	1	1	1	1	1
9	1	1	1	1	1	1	1	1	1	1	1	1
10	1	1	1	1	1	1	1	1	1	1	1	1

Table 4.14a: Unit Just Start Status in UC with Piece-wise linearization for 1-12 hours

ustrt(k,h)	h=0	h=1	2	3	4	5	6	7	8	9	10	11	12
k=1	0	0	0	0	0	0	1	0	0	0	0	0	0
2	0	1	0	0	0	0	0	0	0	0	0	0	0
3	0	1	0	0	0	0	0	0	0	0	0	0	0
4	0	1	0	0	0	0	0	0	0	0	0	0	0
5	0	1	0	0	0	0	0	0	0	0	0	0	0
6	0	1	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	1	0	0	0	0	0	0	0	0	0	0	0
9	0	1	0	0	0	0	0	0	0	0	0	0	0
10	0	1	0	0	0	0	0	0	0	0	0	0	0

Table 4.14b: Unit Just Start Status in UC with Piece-wise linearization for 12-24 hours

ustrt(k,h)	h=13	14	15	16	17	18	19	20	21	22	23	24
k=1	0	0	0	1	0	0	0	0	0	0	0	0
2	0	0	0	1	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	1	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	1	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.15a: Unit Just Shutdown Status of 1-3 Units in UC with Piece-wise linearization for 1-12 hours

usht(k, h)	h=0	h=1	2	3	4	5	6	7	8	9	10	11	12
k=1	0	0	0	0	0	1	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.15b: Unit Just Shutdown Status of 5-10 Units in UC with Piece-wise linearization for 1-12 hours

5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.15c: Unit Just Shutdown Status in UC with Piece-wise linearization for 13-24 hours

usht(k,h)	h=13	14	15	16	17	18	19	20	21	22	23	24
k=1	0	0	1	0	0	0	0	0	0	0	0	0
2	0	0	1	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	1	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	1	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.16a: Angle at Buses in in UC with Piece-wise linearization for 1-10 hours

d(n, h) radians	h=1	2	3	4	5	6	7	8	9	10
n=1	0.06271	0.060299	0.060579	0.065234	0.009832	0.082056	0.087664	0.093271	0.087477	0.074393
2	0	0	0	0	0	0	0	0	0	0
3	-0.07393	-0.08292	-0.09815	-0.11103	-0.04086	-0.12505	-0.12972	-0.13439	-0.1529	-0.17533

Table 4.1ba: Angle at Buses in in UC with Piece-wise linearization for 11-20 hours

d(n, h) radians	h=11	12	13	14	15	16	17	18	19	20
n=1	0.06785	0.062037	0.06929	0.047869	0.01271	0.076449	0.052374	0.03271	0.05514	0.060299
2	0	0	0	0	0	0	0	0	0	0
3	-0.18654	-0.19736	-0.17807	-0.17422	-0.02393	-0.12037	-0.12564	-0.04393	-0.06262	-0.08292

Table 4.16c: Angle at Buses in in UC with Piece-wise linearization for 21-22 hours

d(n,h)	h=21	22	23	24
n=1	0.039607	0.043925	0.070841	0.06129
2	0	0	0	0
3	-0.17867	-0.05327	-0.1157	-0.09007

Table 4.17a: First Section Output Power Generation in UC with Piece-wise linearization for 1-12 hours

P1(:, :,1) (MW)	h=0	h=1	2	3	4	5	6	7	8	9	10	11	12
k=1	0	61	61	61	61	0	61	61	61	61	61	61	61
2	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	25	0	61	61	61	61	61	61	61
4	0	0	0	0	0	0	0	0	0	0	0	0	3
5	0	0	17	24	24	22	24	24	24	24	24	24	24
6	0	0	0	0	0	0	0	0	0	0	14	14	14
7	0	15	24	24	24	24	24	24	24	24	24	24	24
8	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	30.4	30.4	30.4	30.4
10	0	0	0	0	0	0	0	0	0	0	0	0	9

Table 4.17b: First Section Output Power Generation in UC with Piece-wise linearization for 13-24 hours

P1(:,:,1)	h=13	14	15	16	17	18	19	20	21	22	23	24
k=1	61	61	0	61	61	20	61	61	61	61	61	61
2	0	0	0	0	0	0	0	0	0	0	0	0
3	61	61	0	61	61	0	0	0	61	0	61	0
4	0	0	0	0	0	0	0	0	9	0	0	0
5	24	24	0	24	24	0	0	17	24	0	24	24
6	14	14	0	0	0	0	0	0	14	0	0	0
7	24	24	0	24	24	0	0	24	24	0	24	24
8	0	0	0	0	0	0	0	0	0	0	0	0
9	30.4	30.4	0	0	30.4	0	0	0	30.4	0	0	0
10	0	9	0	0	0	0	0	0	9	0	0	0

Table 4.18a: Second Section Output Power Generation of 1-3 Units in UC with Piece-wise linearization for 1-12 hours

P1(:, :,2) (MW)	h=0	h=1	2	3	4	5	6	7	8	9	10	11	12
k=1	0	61	61	61	61	0	61	61	61	61	61	61	61
2	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	61	61	61	61	61	61	61

Table 4.18b: Second Section Output of 4-10 Units in UC with Piece-wise linear cost

4	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	24	24	0	24	24	24	24	24	24	24
6	0	0	0	0	0	0	0	0	0	0	4	14	14
7	0	0	24	24	24	24	24	24	24	24	24	24	24
8	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	30.4	30.4	30.4	30.4
10	0	0	0	0	0	0	0	0	0	0	0	0	9

Table 4.18c: Second Section Output in UC with Piece-wise linearization for 13-24 hours

P1(:,:,2)	h=13	14	15	16	17	18	19	20	21	22	23	24
k=1	61	61	0	61	61	0	61	61	61	59	61	61
2	0	0	0	0	0	0	0	0	0	0	0	0
3	61	61	0	61	61	0	0	0	61	0	14	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	24	24	0	24	24	0	0	0	24	0	24	24
6	14	14	0	0	0	0	0	0	14	0	0	0
7	24	24	0	24	24	0	0	24	24	0	24	24
8	0	0	0	0	0	0	0	0	0	0	0	0
9	30.4	30.4	0	0	30.4	0	0	0	30.4	0	0	0
10	0	2	0	0	0	0	0	0	9	0	0	0

Table 4.19a: Third Section Output Power Generation in UC with Piece-wise linearization for 1-12 hours

P1(:, :,3) (MW)	h=0	h=1	2	3	4	5	6	7	8	9	10	11	12
k=1	0	61	61	61	61	0	61	61	61	61	61	61	61
2	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	53	61	61	61	61	61	61
4	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	24	24	0	24	24	24	24	24	24	24
6	0	0	0	0	0	0	0	0	0	0	0	14	14
7	0	0	0	24	24	0	24	24	24	24	24	24	24
8	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	9.2	30.4	30.4	30.4
10	0	0	0	0	0	0	0	0	0	0	0	0	9

Table 4.19b: Third Section Output Power Generation of 1-3 Units in UC with Piece-wise linearization for 12-24 hours

P1(:,:,3)	h=13	14	15	16	17	18	19	20	21	22	23	24
k=1	61	61	0	61	40	0	61	61	61	0	61	61
2	0	0	0	0	0	0	0	0	0	0	0	0
3	61	20	0	4	20	0	0	0	20	0	0	0

Table 4.19b: Third Section Output Power Generation of 4-10 Units in UC with Piece-wise linearization for 12-24 hours

4	0	0	0	0	0	0	0	0	0	0	0	0
5	24	24	0	24	24	0	0	0	24	0	24	0
6	11	14	0	0	0	0	0	0	14	0	0	0
7	24	24	0	24	24	0	0	0	24	0	24	19
8	0	0	0	0	0	0	0	0	0	0	0	0
9	30.4	30.4	0	0	15.2	0	0	0	30.4	0	0	0
10	0	0	0	0	0	0	0	0	9	0	0	0

Table 4.20a: Fourth Section Output Power Generation in UC with Piece-wise linearization for 1-12 hours

P1(:, :,4) (MW)	h=0	h=1	2	3	4	5	6	7	8	9	10	11	12
k=1	0	61	61	61	61	0	61	61	61	61	61	61	61
2	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	42	61	61	61	61	61
4	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	24	0	24	24	24	24	24	24	24
6	0	0	0	0	0	0	0	0	0	0	0	14	14
7	0	0	0	21	24	0	24	24	24	24	24	24	24
8	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.20a: Fourth Section Output Power Generation of 9,10 Units in UC with Piece-wise linearization for 1-12 hours

9	0	0	0	0	0	0	0	0	0	0	30.4	30.4	30.4
10	0	0	0	0	0	0	0	0	0	0	0	0	9

Table 4.20b: Fourth Section Output Power Generation in UC with Piece-wise linearization for 12-24 hours

P1(:,:,4)	h=13	14	15	16	17	18	19	20	21	22	23	24
k=1	61	61	0	61	0	0	37	61	61	0	61	61
2	0	0	0	0	0	0	0	0	0	0	0	0
3	61	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	24	24	0	24	24	0	0	0	24	0	24	0
6	0	14	0	0	0	0	0	0	14	0	0	0
7	24	24	0	24	24	0	0	0	24	0	24	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	30.4	30.4	0	0	0	0	0	0	30.4	0	0	0
10	0	0	0	0	0	0	0	0	9	0	0	0

Table 4.21a : Fifth Section Output Power Generation in UC with Piece-wise linearization for 1-12 hours

P1(:, :,5) (MW)	h=0	h=1	2	3	4	5	6	7	8	9	10	11	12
k=1	0	61	61	61	61	0	61	61	61	61	61	61	61
2	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	31	61	61	61	61
4	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	24	0	24	24	24	24	24	24	24
6	0	0	0	0	0	0	0	0	0	0	0	12	14
7	0	0	0	0	24	0	24	24	24	24	24	24	24
8	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	30.4	30.4	30.4
10	0	0	0	0	0	0	0	0	0	0	0	0	9

Table 4.21b : Fifth Section Output Power Generation in UC with Piece-wise linearization for 12-24 hours

P1(:,:,5)	h=13	14	15	16	17	18	19	20	21	22	23	24
k=1	61	61	0	60	0	0	0	61	18	0	61	61
2	0	0	0	0	0	0	0	0	0	0	0	0
3	40	0	0	0	0	0	0	0	0	0	0	0

Table 4.21b : Fifth Section Output Power Generation of 4-10 Units in UC with Piece-wise linearization for 12-24 hours

4	0	0	0	0	0	0	0	0	0	0	0	0
5	24	24	0	24	24	0	0	0	24	0	24	0
6	0	14	0	0	0	0	0	0	14	0	0	0
7	24	24	0	24	24	0	0	0	24	0	24	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	30.4	30.4	0	0	0	0	0	0	30.4	0	0	0
10	0	0	0	0	0	0	0	0	9	0	0	0

4.3 Discussion:

4.3.1 Unit Commitment with quadratic cost function

Modelstat=8 i.e. INTEGER SOLUTION

4.3.2 Unit commitment with piece-wise linear cost function

Modelstat=0 i.e. MODEL STATUS 1 Optimal

Solvestat=1 i.e. SOLVER STATUS 1 Normal Completion

By the above status, we can conclude that, Piece-Wise Linearization improves solution and so model status of Gams has improved.

Chapter 5

Results and discussion UC in Restructured environment.

5.1 OPF With UC Status

5.1.1 Specifications

Table 5.1 contains generators minimum power limit, maximum power limit, ramp up limit, ramp down limit, start-up ramp limit, shutdown ramp rate, minimum up time, minimum down time and bid price of generator. Table 5.3 contains required load demand for 24 hours. Table 5.2 contains flow limits of each line and their Susceptance.

Table 5.1: Flow Limits

ln	Susceptance(pu)	Power flow limits(pu)
1	2.5	2.5
2	3.5	3.5
3	1.4	1.4

Table 5.2: Load for Each Hour

Ld(MW)	
1	Pload(ld,h)

Table 5.3: Specifications of Generator

Gen.no	1	2	3	4	5	6	7	8	9	10
Pmin(MW)	150	10	150	10	10	10	10	10	10	10
Pmax(Mw)	455	55	455	55	130	80	130	85	162	55
Rdn(MW/hr)	142	52	142	147	185	148	163	186	178	176
Rup(Mw/hr)	300	211	186	198	212	193	245	235	289	321
Rshdn(MW/hr)	480	15	1000	15	150	10	150	10	80	10
Rsup(Mw/hr)	480	15	1000	15	150	10	150	10	120	10
Bidprice_gen($)	455	55	448	10	130	10	10	10	162	10

5.1.2 **Results:**

Table 5.4 depicts generators cleared amount of power schedule for each hour up to 24 hours in unit Commitment. Table 5.5 depicts generators cleared amount of power schedule for each hour up to 24 hours by OPF which is performed by fixing unit status from unit commitment solution from Table 5.4 . Table 5.6 depicts generators cleared amount of power schedule for each hour up to 24 hours by proposed OPF given by Figure 3.1.

Table 5.4a: Output Power Generation in Simple UC for 1-12 hours

P(k,h) (MW)	h=1	2	3	4	5	6	7	8	9	10	11	12
k=1	455	455	455	455	0	455	455	455	455	455	455	455
2	10	10	10	10	10	10	10	10	10	10	10	10
3	150	150	150	175	150	325	375	425	455	455	455	455
4	10	10	10	10	10	10	10	10	10	10	10	13
5	10	27	82	130	32	130	130	130	130	130	130	130
6	10	10	10	10	10	10	10	10	10	28	78	80
7	25	58	103	130	58	130	130	130	130	130	130	130
8	10	10	10	10	10	10	10	10	10	10	10	10
9	10	10	10	10	10	10	10	10	80	162	162	162
10	10	10	10	10	10	10	10	10	10	10	10	55

Table 5.4b: Output power Generation in Simple UC for 12-24 hours

P(k,h)	h=13	14	15	16	17	18	19	20	21	22	23	24
k=1	455	455	0	454	312	170	370	455	412	270	455	455
2	10	10	0	10	10	10	10	10	10	10	10	10
3	434	292	150	276	292	150	150	150	292	150	225	150
4	10	10	10	10	10	10	10	10	19	10	10	10
5	130	130	0	130	130	10	10	27	130	10	130	58

Table 5.4c: Output power Generation of 6-10 Units in Simple UC for 12-24 hours

6	49	80	10	10	10	10	10	10	80	10	10	10
7	130	130	10	130	130	10	10	58	130	10	130	77
8	10	10	0	10	10	10	10	10	10	10	10	10
9	162	162	10	10	86	10	10	10	162	10	10	10
10	10	21	10	10	10	10	10	10	55	10	10	10

Table 5.5a: Output Power Generation with Fixed Unit Status from UC for 1-12 hours

P(k,h)	h=1	2	3	4	5	6	7	8	9	10	11	12
k=1	153	203	303	403	0	455	455	455	455	455	455	455
2	55	55	55	55	10	55	55	55	55	55	55	55
3	150	150	150	150	150	248	253	303	448	455	455	455
4	10	10	10	10	10	10	10	10	10	10	10	38
5	130	130	130	130	80	130	130	130	130	130	130	130
6	10	10	10	10	10	10	10	10	10	10	10	10
7	10	10	10	10	10	10	10	10	10	58	108	130
8	10	10	10	10	10	10	10	10	10	10	10	10
9	162	162	162	162	10	162	162	162	162	162	162	162
10	10	10	10	10	10	10	55	55	10	55	55	55

Table 5.5b: Output Power Generation with Fixed unit Status from UC for 12-24 hours

P(k,h)	h=13	14	15	16	17	18	19	20	21	22	23	24
k=1	455	455	0	455	453	150	150	203	455	150	453	253
2	55	55	0	55	55	10	10	55	55	10	55	55
3	455	448	150	153	150	150	150	150	448	150	150	150
4	10	10	10	10	10	10	10	10	10	10	10	10
5	130	130	0	130	130	30	130	130	130	130	130	130
6	10	10	10	10	10	10	10	10	10	10	10	10
7	58	10	10	10	10	10	10	10	10	10	10	10
8	10	10	0	10	10	10	10	10	10	10	10	10
9	162	162	10	162	162	10	110	162	162	10	162	162
10	55	10	10	55	10	10	10	10	10	10	10	10

Table 5.6a: Output Power Generation of 1-5 Units with Fixed Unit Status and Ramp rates

1-12 hours

P(k,h)	h=1	2	3	4	5	6	7	8	9	10	11	12
k=1	235	203	303	403	0	455	455	455	455	455	455	455
2	15	55	55	55	10	55	55	55	55	55	55	55
3	150	150	150	150	150	248	253	303	448	455	455	455
4	10	10	10	10	10	10	10	10	10	10	10	38
5	130	130	130	130	80	130	130	130	130	130	130	130

Table 5.6a: Output Power Generation of 6-10 Units with Fixed Unit Status and Ramp rates

1-12 hours

6	10	10	10	10	10	10	10	10	10	10	10	10
7	10	10	10	10	10	10	10	10	10	58	108	130
8	10	10	10	10	10	10	10	10	10	10	10	10
9	120	162	162	162	10	162	162	162	162	162	162	162
10	10	10	10	10	10	10	55	55	10	55	55	55

Table 5.6b: Output Power Generation with Fixed Unit Status and Ramp rates 13-24 hours

P(k,h)	h=13	14	15	16	17	18	19	20	21	22	23	24
k=1	455	455	0	455	453	170	150	203	455	226	453	311
2	55	55	0	15	55	10	10	55	55	10	55	10
3	455	448	150	238	150	150	150	150	336	194	150	150
4	10	10	10	10	10	10	10	10	10	10	10	10
5	130	130	0	130	130	10	130	130	130	10	130	130
6	10	10	10	10	10	10	10	10	10	10	10	10
7	58	10	10	10	10	10	10	10	77	10	10	10
8	10	10	0	10	10	10	10	10	10	10	10	10
9	162	162	10	162	162	10	110	162	162	10	162	149
10	55	10	10	10	10	10	10	10	55	10	10	10

5.2 UC in Restructured Environment

5.2.1 **Test System Lay Out**

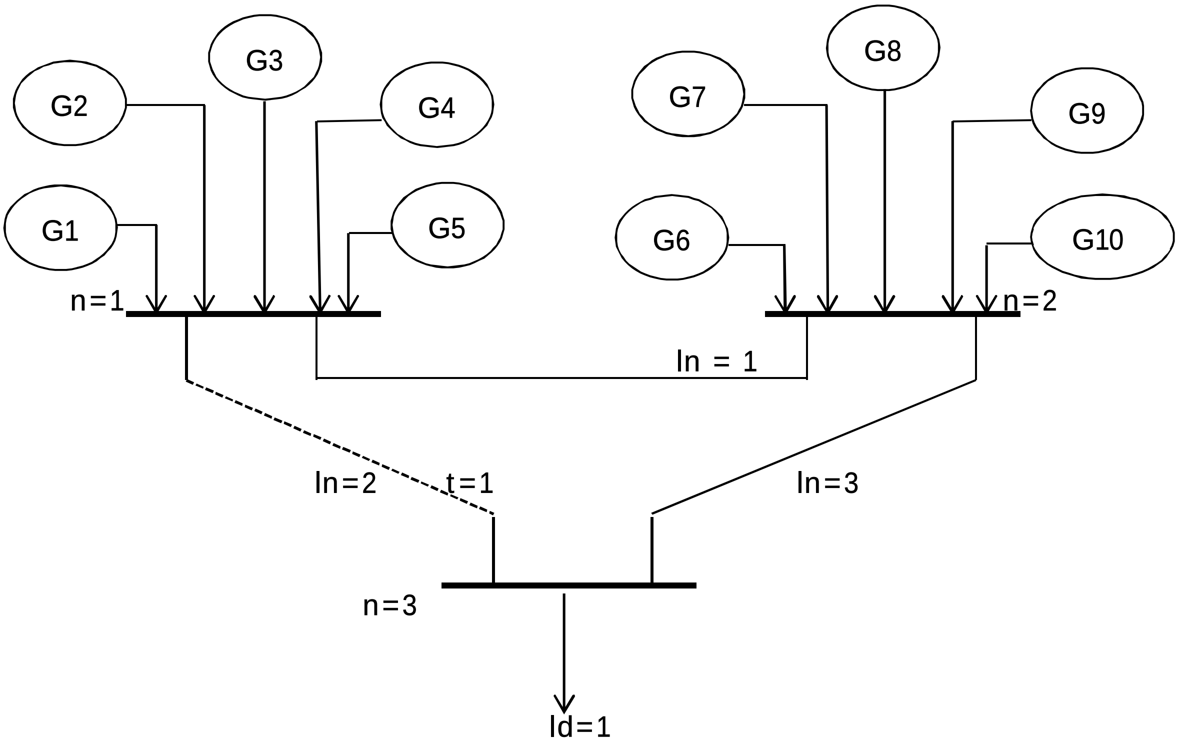


Figure 5.1: Test System

5.2.2 **Specifications**

Table 5.7 contains generators minimum power limit, maximum power limit, ramp up limit, ramp down limit, start up ramp limit, shutdown ramp rate, minimum up time, minimum down time. Table 5.8 shows which units initial status and its generation in zero hour. Table 5.9 contains minimum load price, bid price of generated power, start-up price of generator and maximum power bid power limit. Table 5.10 contains elastic load price. Table 5.11 contains fixed bilateral transaction price. Table 5.12 contains inelastic bilateral amount. Table 5.13 contains fixed load amount. Table 5.14 contains load limit. Table

5.15 contains maximum bilateral transaction limit. Table 5.16 contains flow limits of each line and their Susceptance.

Table 5.7: Specification of generator

Gen.no	1	2	3	4	5	6	7	8	9	10
Pmin(MW)	30	20	10	10	30	10	15	10	20	10
Pmax(MW)	455	55	455	55	130	80	130	85	162	55
Rdn(MW/hr)	142	52	142	147	185	148	163	186	178	176
Rup(MW/hr)	300	211	186	198	212	193	245	235	289	321
Rshdn(MW/hr)	480	15	1000	15	150	10	150	10	80	10
Rsup(MW/hr)	480	15	1000	15	150	10	150	10	120	10
Tup(hr)	1	5	2	1	4	5	1	5	1	2
Tdn(hr)	1	0	2	0	1	0	1	1	0	3

Table 5.8: Unit Initial Status of 1- 6 Units

generator	U(k,0)	P(k,0)
1	1	200
2	0	0
3	0	0
4	0	0
5	0	0
6	0	0

Table 5.8: Unit Initial Status of 1- 6 Units

7	1	50
8	0	0
9	0	0
10	0	0

Table 5.9: Bid Prices and Max Bid Limits

Gen.no	1	2	3	4	5	6	7	8	9	10
Pminloadprice($)	0	10	52	12	25	45	2	65	12	12
pmax_bid(Mw)	423	189	120	548	102	251	325	198	214	120
Pbidprice($)	20	20	40	50	10	60	45	65	15	40
Startupprice($)	20	30	50	12	0	12	86	10	45	20

Table 5.10: Elastic Load Price

hr	1	2	3	4	5	6	7	8	9	10	11	12
Ld=1($)	10	15	12	24	45	65	12	86	-95	12	45	0
hr	13	14	15	16	17	18	19	20	21	22	23	24
Ld=1	52	16	0	-56	1	12	12	45	25	-22	18	-9

Table 5.11: Max Bilateral Transaction Limit

t(MW)	
1	120

Table 5.12: Elastic Bilateral Transaction Price

hr	1	2	3	4	5	6	7	8	9	10	11	12
trans=1($)	0	10	-20	17	20	-54	12	0	18	50	45	-25
hr	13	14	15	16	17	18	19	20	21	22	23	24
trans=1	5	0	-20	14	18	50	-10	21	-24	-25	14	0

Table 5.13: Fixed Bilateral Transaction Specification

hr	1	2	3	4	5	6	7	8	9	10	11	12
trans=1(MW)	12	0	45	0	6	0	56	50	0	81	0	0
hr	13	14	15	16	17	18	19	20	21	22	23	24
trans=1	14	0	25	0	12	0	0	0	12	0	0	50

Table 5.14: Fixed Load Specification

hr	1	2	3	4	5	6	7	8	9	10	11	12
ld=1(MW)	200	100	200	100	50	100	150	100	40	100	150	140
hr	13	14	15	16	17	18	19	20	21	22	23	24
ld=1	130	200	45	80	100	50	80	70	100	50	100	150

Table 5.15: Max Load Limit

ld(MW)	
1	100

5.2.3 **Results :**

Maximum social welfare obtained is –z =32364 $. Table 5.16 depicts generators cleared amount of power schedule for each hour up to 24 hours depending upon load bid price , power bid price, bilateral transaction bid price . Table 5.17, Table 5.18 , Table 5.19 contains binary values. Table 5.17 shows the generators which are online in present hour. Table 5.18 shows the generators which are coming online from previous off state. For h=1, generators 5,9 are coming online from off and status in Table 5.18 are 1.Table 5.19 shows the generators which are coming offline from previous on state. Generator 5 is scheduled 102 MW in 8 hour, 0 MW in 9 hour.it is coming off from on status and its status in Table 5.1 in 9 hour is 1. Table 5.20 contains bus angles at each hour to accommodate power flow.

From Table 5.26 , total amount of cleared power generation in hour1 is 200 MW, in hour 3 is 264 MW. From Table 5.20 and Table 5.13, total amount of elastic and elastic load cleared for h=1,3 also 200 264 MW. Table 5.21 and Table 5.12 shows cleared amount of elastic and inelastic bilateral transaction.

```
modelstat=0    solvestat=1
OPTIMAL VALUE OF THE OBJECTIVE FUNCTION Z:  Z =-32364
```

Table 5.16a: Output power Generation in UC with biddings for 1-12 hours

P(k,h) (MW)	h=0	h=1	2	3	4	5	6	7	8	9	10	11	12
k=1	200	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	102	102	102	102	102	102	102	102	0	102	102	102
6	0	0	0	0	0	0	0	0	0	0	0	0	0
7	50	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	98	98	162	98	48	98	148	98	40	98	148	38
10	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 5.16b: Output power Generation in UC with Biddings for 12-24 hours

P(k,h)	h=13	14	15	16	17	18	19	20	21	22	23	24
k=1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	102	102	0	0	0	0	102	102	102	30	102	102

Table 5.16c: Output power Generation of 6-10 Units in UC with Biddings for 12-24 hours

6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	128	162	45	80	100	150	78	68	98	20	98	48
10	0	0	0	0	0	0	0	0	0	0	0	0

Table 5.17a: Unit Status in UC with Biddings for 1-12 hours

u(k,h)		h=1	2	3	4	5	6	7	8	9	10	11	12
k=1	1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	1	1	1	1	1	1	1	1	0	1	1	1
6	0	0	0	0	0	0	0	0	0	0	0	0	0
7	1	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	1	1	1	1	1	1	1	1	1	1	1	1
10	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 5.17b: Unit Status in UC with Biddings for 13-24 hours

u(k,h)	h=13	14	15	16	17	18	19	20	21	22	23	24
k=1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	1	1	0	0	0	0	1	1	1	1	1	1
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	1	1	1	1	1	1	1	1	1	1	1	1
10	0	0	0	0	0	0	0	0	0	0	0	0

Table 5.18a: Unit Just Start Status in UC with Biddings for 1-12 hours

ustrt(k,h)	h=0	h=1	2	3	4	5	6	7	8	9	10	11	12
k=1	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	1	0	0	0	0	0	0	0	0	1	0	0

Table 5.18a: Unit Just Start Status of 6-10 Unitsin UC with Biddings for 1-12 hours

6	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	1	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 5.18b: Unit Just Start Status in UC with biddings for 12-24 hours

ustrt(k,h)	h=13	14	15	16	17	18	19	20	21	22	23	24
k=1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	1	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0

Table 5.19a: Unit Just shutdown Status in UC with biddings for 1-12 hours

usht(k,h)	h=0	h=1	2	3	4	5	6	7	8	9	10	11	12
k=1	0	1	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	1	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	1	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 5.19b: Unit Just shutdown Status in UC with biddings for 13-24 hours

usht(k,h)	h=13	14	15	16	17	18	19	20	21	22	23	24
k=1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	1	0	0	0	0	0	0	0	0	0

Table 5.19b: Unit Just shutdown Status of 6-10 Units in UC with biddings for 13-24 hours

6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0

Table 5.20a: Angle at Buses for 1-10 hours

d(n, h)radians	h=1	2	3	4	5	6	7	8	9	10
n=1	-0.0044	-0.0201	-0.0074	-0.0177	-0.0165	0.0004	-0.0228	-0.0075	-0.0159	-0.0122
2	0	0	0	0	0	0	0	0	0	0
3	-0.0496	-0.0416	-0.0755	-0.0403	-0.0329	-0.0336	-0.0593	-0.0271	-0.0301	-0.0498

Table 5.20b: Angle at Buses for 11-20 hours

d(n, h)	h=11	12	13	14	15	16	17	18	19	20
n=1	-0.0044	-0.0201	-0.0074	-0.0177	-0.0165	0.0004	-0.0228	-0.0075	-0.0159	-0.0122
2	0	0	0	0	0	0	0	0	0	0
3	-0.0496	-0.0416	-0.0755	-0.0403	-0.0329	-0.0336	-0.0593	-0.0271	-0.0301	-0.0498

Table 5.20c: Angle at Buses for 21-24 hours

d(n,h)	h=21	22	23	24
n=1	-0.0114	-0.0062	-0.0225	-0.0137
2	0	0	0	0
3	-0.0572	-0.0449	-0.0429	-0.0536

Table 5.21: Output Bilateral Transaction

hr	1	2	3	4	5	6	7	8	9	10	11	12
trans=1 (MW)	120	120	0	120	120	0	120	120	120	120	120	0
Hr	13	14	15	16	17	18	19	20	21	22	23	24
trans=1	120	120	0	120	120	120	0	120	0	0	120	120

Table 5.22: Output Load

Hr	1	2	3	4	5	6	7	8	9	10	11	12
ld=1 (MW)	0	100	64	100	100	100	100	100	0	100	100	0
Hr	13	14	15	16	17	18	19	20	21	22	23	24
ld=1	100	64	0	0	0	100	100	100	100	0	100	0

Chapter 6

Conclusion

The present thesis attempts to perform unit commitment in competitive power market . Unit commitment with quadratic cost function becomes complex as the solution takes long time for convergence and it gives integer solution, whereas unit commitment with piece-wise linearization of cost function gives fast and optimal solution. OPF is performed with fixed unit status from unit commitment solution by taking account of generator ramp rates for close convergence of OPF and UC solution. Unit Commitment with 3-part generator bidding, load bidding and bilateral transaction involving elastic and inelastic parts is performed as demanded by the recent power industry.

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