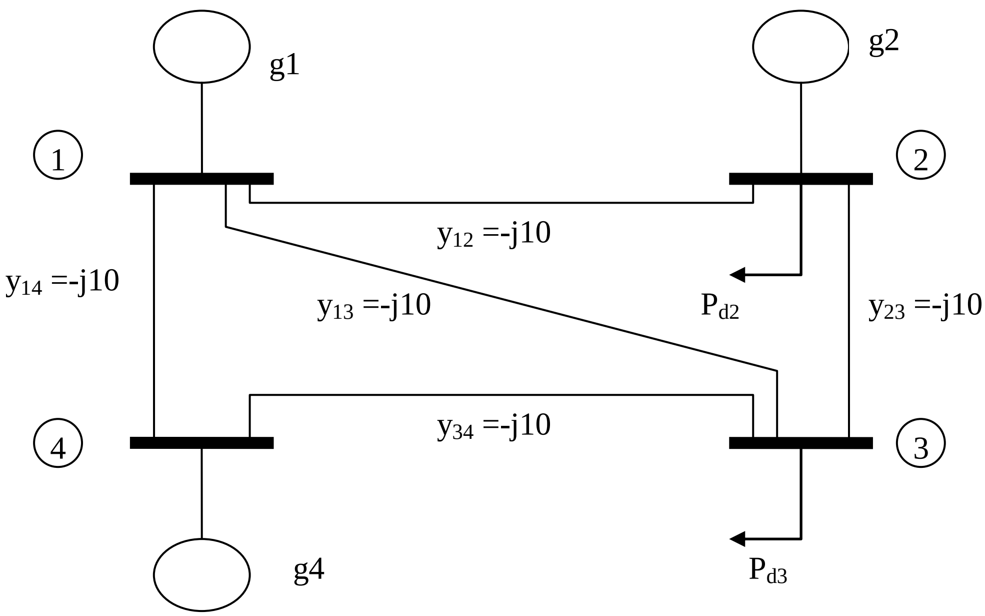
EE 553, Spring 2012, HW7, Due Monday 12/3/2012

Consider the network we have been using in class and replicated below.



Starting from the CPLEX file provided on the website (UC24a.lp), add appropriate code to model the following additional constraints.

1. <u>Modeling reserve margin</u>: Spinning reserve should be, in any hour, according to $\sum_i r_{it} \geq 0.10 \times D_t$, Note that this replaces constraint (3) in our formulation (slide 4 of SCUC ppt slides). Note also that these constraints are on the *units*, not on individual *offers*. Provide the solution in terms of a plot of unit dispatch (generation) vs. time for all three units. Compare the 24-hour solution in terms of hourly unit dispatch with and without these constraints. Identify any differences. Provide a sample of your CPLEX code to show how you implemented this.

   <u>Solution</u>:
   Sample code:

   ```
   reservehr1: r11+r12+r14-0.1 d21-0.1 d31>=0
   reservehr2: r21+r22+r24-0.1 d22-0.1 d32>=0
   reservehr3: r31+r32+r34-0.1 d23-0.1 d33>=0
   reservehr4: r41+r42+r44-0.1 d24-0.1 d34>=0
   ```

   r11, r12, r14 represent the reserves corresponding to the three generators in the first period and d21 and d31 correspond to the demand in buses 2 and 3 in the first period. Only four periods are shown for clarity. The maximum generation levels of the generators are also affected by the addition of the reserves. It is represented in CPLEX as follows.

   ```
   g111+g121+g131+r11 - 1.5 z11<=0
   g211+g221+g231+r12 - 1.15 z21<=0
   g411+g421+g431+r14 - 1.35 z41<=0
   ```

The factors 1.5, 1.15 and 1.35 represent the maximum capacity of the generators. Only the first period is shown for clarity. The following plots show the load profile, unit dispatch and the status of all the generators vs time.

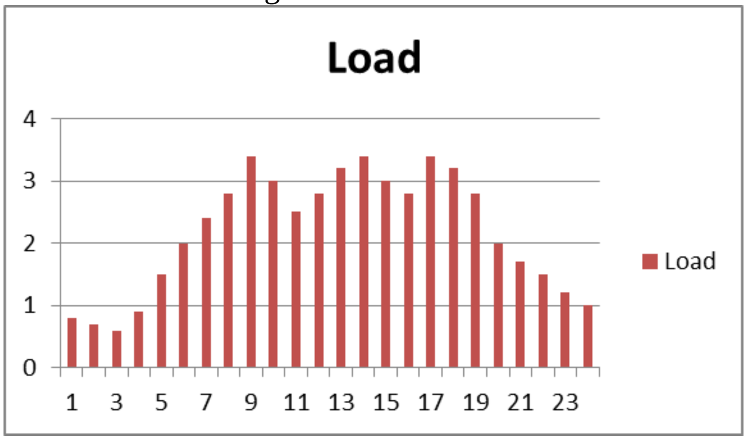


Fig. 1 Load Profile

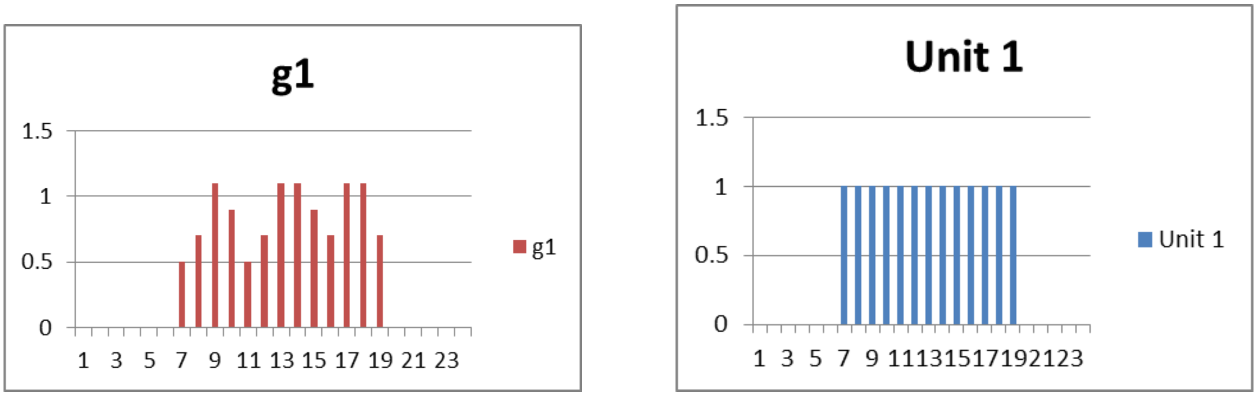


Fig.2 Capacity and Status of the Generator at bus 1

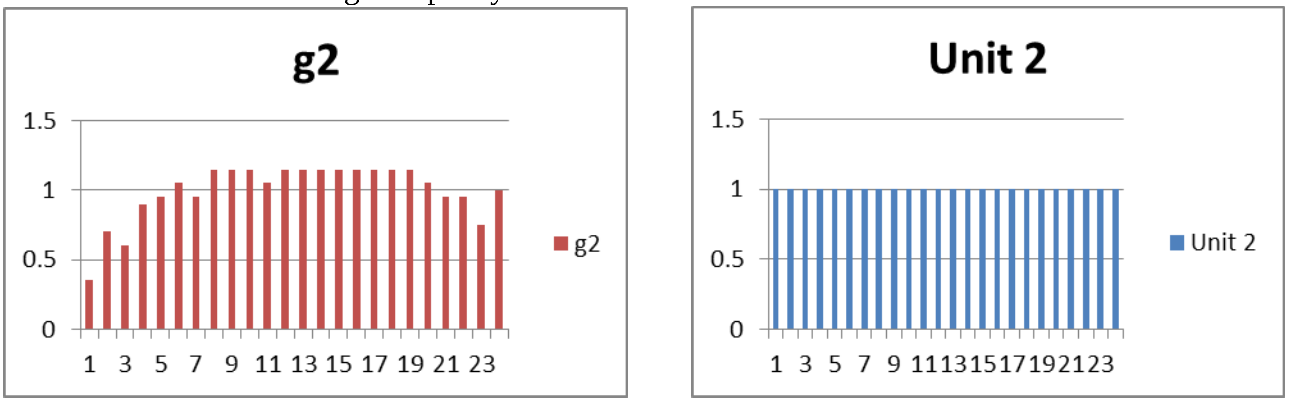


Fig.3 Capacity and Status of the Generator at bus 2

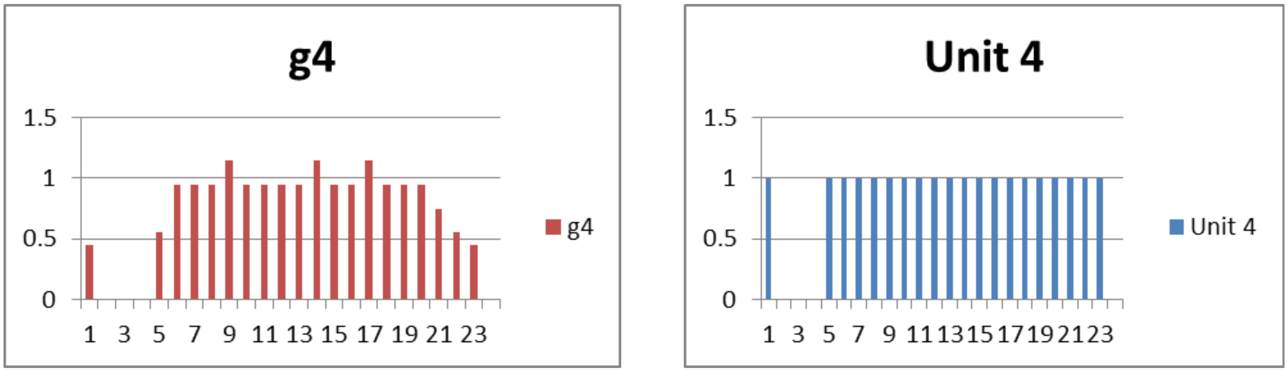


Fig.4 Capacity and Status of the Generator at bus 4

The only difference with the initial case without reserves is that the generator 1 comes online in hour 7. Generator 1 was off at hour 7 without reserves. The reason for this generator coming online is that the reserve requirements are not met at this hour. (i.e.) G2 and G4 are 1.15 and 1.25 pu respectively at hour 7 without reserves. Here the spinning reserve capability is only 0.1 pu (G2 max=1.15 pu and G3 max=1.35 pu) which is less than the expected 0.24 pu at hour 7. Hence, unit 1 is brought online to satisfy the deficiency.

2. Modeling ramp rates: Assume Unit 1 has $MxInc_i$=$MxDec_i$=0.4 pu, Unit 2 has $MxInc_i$=$MxDec_i$=0.3 pu, and Unit 4 has $MxInc_i$=$MxDec_i$=0.2 pu. Note that these affect constraints (7) and (8) in our formulation (slide 4 of SCUC ppt slides). Add these constraints to the model you developed in #1 of this assignment (the one with reserves). Provide the solution in terms of a plot of unit dispatch (generation) vs. time for all three units. Compare the 24-hour solution you obtain (with these constraints modeled) with the solution you obtained in #1 (with reserves but without these new ramp rate constraints modeled). Identify any differences. Provide a sample of your CPLEX code to show how you implemented this.

   Note: At hour 19 the load is 2.8 pu. At hour 20 it is 2.0 pu, dropping by 0.8 pu, the largest drop of the simulation. Therefore the composite ramping capability of the three units has to be at least 0.8 in order to avoid infeasibility.

   Solution:
   The up and down ramp rates are given. These ramp rates are modeled as constraints and the implementation of the same in CPLEX is shown below.

```
rampuphr2u1:g112+g122+g132-g111-g121-g131<=0.4
rampuphr2u2:g212+g222+g232-g211-g221-g231<=0.3
rampuphr2u4:g412+g422+g432-g411-g421-g431<=0.2

rampdownhr2u1:g112+g122+g132-g111-g121-g131>=-0.4
rampdownhr2u2:g212+g222+g232-g211-g221-g231>=-0.3
rampdownhr2u4:g412+g422+g432-g411-g421-g431>=-0.2
```

   where 0.4, 0.3 and 0.2 are the MxInc and MxDec of the three generators. Only the second period is shown here for clarity.

   The following plots show the unit dispatch and the status of all the generators vs time.

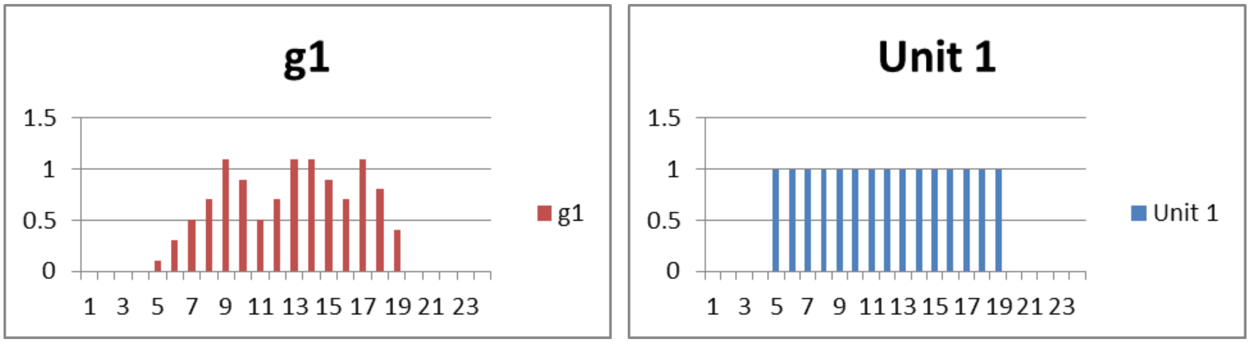


Fig.5 Capacity and Status of the Generator at bus 1

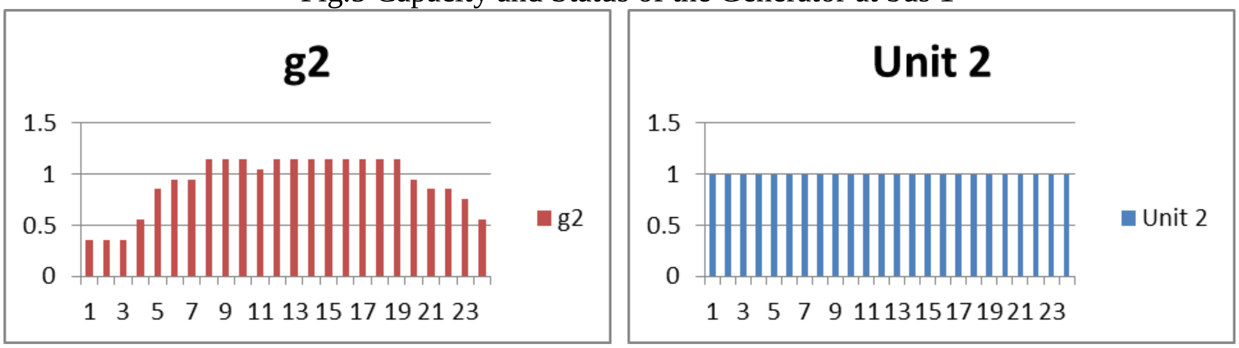


Fig.6 Capacity and Status of the Generator at bus 2

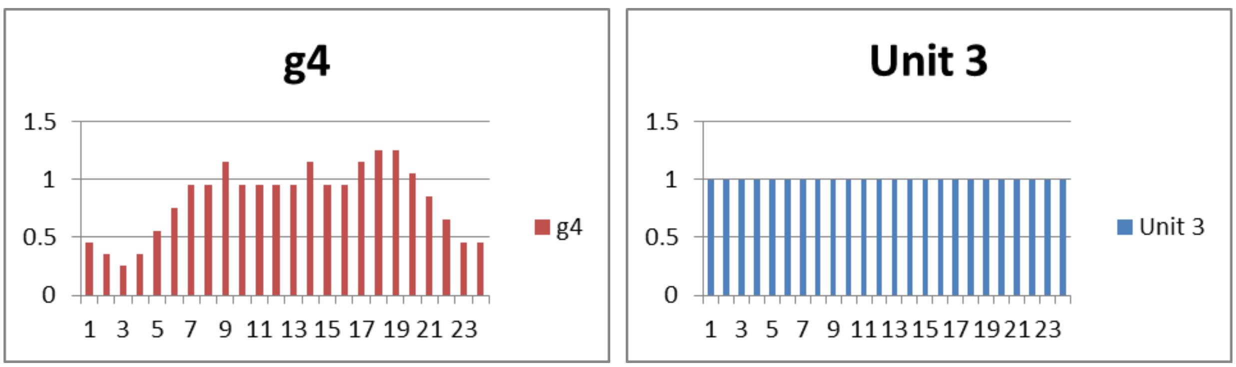


Fig.7 Capacity and Status of the Generator at bus 4

The dispatch of the units is different from the first problem. Unit 1 comes online at hour 5 whereas it comes online at hour 7 in the first problem. This is due to the reduced capacity in the other units due to the ramp rate constraint. Unit 3 is run for all 24 hours as shutting it down and starting it would violate the ramp rate constraint. The generator commitment is also smooth due to the ramp rate.

3. <u>Modeling ramp rate requirements</u>: Describe how you would implement the following constraint: 50% of the reserve requirement must be able to ramp up at least 0.3 pu in one hour. Describe why implementing such a constraint could be of interest. Add this constraint for all hours to the model you developed in #2 of this assignment. Provide the solution in terms of a plot of unit dispatch (generation) vs. time for all three units. Compare the 24-hour solution you obtain (with this constraint) to the solution obtained without this constraint. Identify any differences. Provide a sample of your CPLEX code to show how you implemented this.

<u>Solution</u>:
This requires the following:

Sum (reserves at time t that have ramping capability $\geq$ 0.3) $\geq$ 0.5×Sum (reserves at time t)

Assuming that r_{it}=0 if unit i is not committed at time t (this is enforced by constraint (6)), then the above may be written as:

$$\sum_i \left(r_{it} \text{for which MaxInc}_i \geq 0.3\right) \geq 0.5 \times \sum_i r_{it}$$

We can implement the above in CPLEX by establishing an input flag at the beginning, call it v_i, which is 1 if $\text{MaxInc}_i \geq 0.3$ and 0 otherwise. With such a flag, we can write

$$\sum_i \left(r_{it} \times v_i\right) \geq 0.5 \times \sum_i r_{it}$$

Some people may be tempted to do the following: $0.5 \times \sum_i \left(r_{it} - r_{it-1}\right) \geq 0.3$. However, this will require that 50% of the reserve change by 0.3 each time period; this is different from simply requiring 50% of the reserve have the ability to change this much.

4. <u>Line flow constraints</u>: Assume the total load equally divides between buses 2 & 3.
   a. Determine the generation shift factors a_{ki} for this network under the assumption of a single slack (see notes on "Sensitivities," pp. 14-16 to understand why you need to use a single slack), where a_{ki} is the linearized coefficient relating bus i injection to line k flow.
   b. Assume each line k is constrained to a flow limit of MxFlow_k under normal conditions, i.e., under conditions when all circuits are in. Using your generation shift factors obtained in (a), write down constraints corresponding to normal flow limits for all circuits, per equation (11) of slides 12-13 in the SCUC ppt slides.
   c. Determine the effective generation shift factors $a^{(j)}_{ki}$ for this network under the assumption of a single slack and outage of the circuit terminated by buses 1 and 2, where $a^{(j)}_{ki}$ is the linearized coefficient relating bus i injection to line k flow under the condition that branch j is outaged.
   d. Assume each line k is constrained to a flow limit of EMxFlow_k under emergency conditions, i.e., under conditions associated with an outage. Using your effective generation shift factors obtained in part (c), write down constraints corresponding to security line flow limits for outage of circuit 1-2, per equation (12) of slides 12-13 in the SCUC ppt slides.