Two new methods to assess short-term transmission reliability

♣ ** José R. Arce
jarce@iee.unsj.edu.ar
jarce@mit.edu

** Marija D. Ilić
ilic@mit.edu

♣ Francisco F. Garcés
garces@iee.unsj.edu.ar

♣ Instituto de Energía Eléctrica
Universidad Nacional de San Juan
San Juan, Argentina

** Energy Laboratory
Massachusetts Institute of Technology
Cambridge, MA, USA

Abstract: *In this paper we present the short-term reliability assessment problem as a risk management problem, where the uncertainty involved is related with transmission outages and the consequences are measured by the deficit experimented by loads. Two new methods are formulated and implemented in an academic test system*
First, we formulate the short-term reliability related risks associated with the possibility of transmission failures, which are measured through the probability of several scenarios in consideration and the respective consequences experimented by some market participants, in this paper the load curtailment
Second we develop a new market-based method to allocate reserve considering explicitly reliability requirements submitted by the demand In this new method the energy price after the occurrence of contingency (redispatch) is calculated after the fact, due to this issue the method is called ex-post
Third, we formulate another market-based method to allocate reserve considering the reliability requirement submitted by the demand in an explicit way In this case the energy price calculated before the occurrence of contingency (redispatch) does not change, independent of the system condition, therefore the method is called ex-ante
Finally, we compare both new methods in an academic test system where we conclude that both methods allocate reserve fulfilling pre-specified reliability requirements The difference in allocation results in a difference in costs but not in reliability level Moreover, the tradeoff is in between the economic signal given by stability of the energy price in presence of contingencies and cost necessary to have different amount of reserve

Keywords: *Short-term reliability assessment, reliability related risks reliability requirement, ex-post method, ex-ante method*

I Introduction

One of the most difficult tasks after the deregulation process in the electric energy industry is related with the assessment of reliability. Moreover, it is proved that some of the criteria and methods usually used by System Operators in vertically integrated structures and by Independent System Operators in deregulated environments cannot guarantee a pre-specified reliability level [1]. The results of this problem are reflected through undesired interruptions and/or highly volatile prices.

Furthermore, it is important to recognize that it is no longer realistic to expect that risks associated with reliable service would necessarily be borne by one entity, and not by the others, especially after the unbundling process that is in place in the electric sector. In order to take into consideration this important issue, we unbundled the reliability problem considering that it actually represents different problems and interests, ranging from power suppliers, through wire (transmission and/or distribution) providers and, finally, the customers.
Moreover, we point out that it is extremely helpful to think of reliability primarily as a risk taking and management process since one deals with the problem of ensuring uninterrupted service despite unexpected changes [2]. In an industry structure characterized by a full corporate unbundling of generation, transmission and distribution, responsibilities for risk taking have to be clearly defined through a type of contractual agreements between entities. This requires first of all definition of reliability-related products for which there are sellers and buyers, and technical "standards" are replaced by contractual expectations.

As a result, the aim of this paper is to introduce two different approaches to assess short-term reliability considering it as a risk-management problem. The paper is organized as follows: in Section II some criteria and methods to assess reliability in the short-term are presented, in Section III the ex-post method is formulated, in Section IV the ex-ante method is developed, in Section V both new methods are implemented in the same test system, and finally in Section VI the main conclusions are summarized.

II Criteria and methods to assess reliability

In order to be consistent with the view of reliability as a risk management problem, it is fundamental to understand that risk management is related with the quantification of potential failure and needs the answers to the following three issues:

#1 What can go wrong within a system?

#2 How likely is the failure to happen?

#3 What consequence will the failure cause?

In this paper the occurrence of line outages is studied (Issue #1), the probability of this occurrence is

0-7803-7173-9/01/$10.00 © 2001 IEEE

computed (Issue #2), and the deficit experimented by the demand is considered the state of interest (Issue #3).

Following with the trend of having a market to assess reliability separated from a market to supply energy, here is introduced a new way of formulating this problem.

It is assumed that participants in this reliability-reserve market submit bids to supply reserve (generation reserve and/or interruptible demand), where the performance criterion is to minimize the cost (bid-based) of supplying reserve.

$$\underset{R_i}{Min} \sum C_i(R_i) \qquad (1)$$

In contrast with the reserve requirement usually used [3-4], a reliability requirement -according with the requirements submitted by the demand- is explicitly formulated. It is assumed that participants at the wholesale level are able to estimate the value associated with their reliability requirements.

$$\sum_j \Pr_j Idef_j \le P \qquad (2)$$

Additionally the reserve bids are constrained by technical limits.

$$R_i^{min} \le R_i \le R_i^{max} \qquad (3)$$

II.1 Reliability requirement (Issues #1, #2, and #3)

The reliability requirement can be either system wide or user wide defined. In any case, the initial step is to agree in the reliability index in order to quantify the reliability level. Only as an illustrative example of the methodology, in this paper the reliability index used is the loss of load probability LOLP [5].

a System-wide reliability requirement P

For the system wide reliability requirement formulation, P represents the maximum system LOLP acceptable.

$$\sum_j \Pr_j Idef_j \le P \qquad (4)$$

Where $\Pr_j$ represents the probability of the scenario "*j*" considered, which in this model is the occurrence of the single contingency of line "*j*".

$$\Pr_j = \Pr(F)_j \prod_{l \ne j} \Pr(O)_l \qquad (5)$$

The state of interest is the deficit experimented by the load. In order to link the occurrence of this event with the scenario "*j*" in study, $Idef_j$ is defined as a function that takes value one when there is deficit greater than zero in any bus in the system On the contrary, this function takes value zero.

$$Idef_j = \begin{cases} 1 & if \sum_i Pdef_i^j > 0 \\ 0 & otherwise \end{cases} \qquad (6)$$

b. User-wide reliability requirement P_i

Other alternative that is more suitable for a genuine competitive electric energy industry is to define the reliability requirement P_i according to the reliability desired by the user located at bus *i*. It is here assumed that there is only one user at each bus, however this condition could be easily relaxed and does not affect the main idea of the model.

$$\sum_j \Pr_j Idef_{i,j} \le P_i \qquad (7)$$

As before, $\Pr_j$ represents the probability of the single contingency of line "*j*" scenario.

$$\Pr_j = \Pr(F)_j \prod_{l \ne j} \Pr(O)_l \qquad (8)$$

In this case $Idef_{i,j}$ is defined as a function that takes the value one when there is deficit greater than zero at bus "*i*" for scenario "*j*". On the contrary, this function takes the value zero.

$$Idef_{i,j} = \begin{cases} 1 & if\ Pdef_i^j > 0 \\ 0 & otherwise \end{cases} \qquad (9)$$

II.2 Transmission model (Issues #1 and #2)

Regarding the stochastic behavior of transmission lines, it is necessary to calculate the short-term failure probabilities and the order of line contingencies to be considered.

It is assumed that a line could be in only two states, either in operation or in failure. The probability of these two states can be calculated assuming a two-state Markov chain model [6].

$$\Pr(O,t)_l = \left(\frac{\mu_l}{\mu_l + \lambda_l} + \frac{\lambda_l \Pr(O,t_0)_l - \mu_l \Pr(F,t_0)_l}{\mu_l + \lambda} e^{-(\mu_l+\lambda_l)t} \right) \qquad (10)$$

$$\Pr(F,t)_l = \left(\frac{\lambda_l}{\mu_l + \lambda_l} - \frac{\lambda_l \Pr(O,t_0)_l - \mu_l \Pr(F,t_0)_l}{\mu_l + \lambda_l} e^{-(\mu_l+\lambda_l)t} \right) \qquad (11)$$

Figure 1 and Figure 2 show the evolution in time of both the probability of operation $\Pr(O,t)_l$ and the probability of failure $\Pr(F,t)_l$ for line *l*, and initial conditions $\Pr(O,t_0)_l = 1$ and $\Pr(F,t_0)_l = 0$.

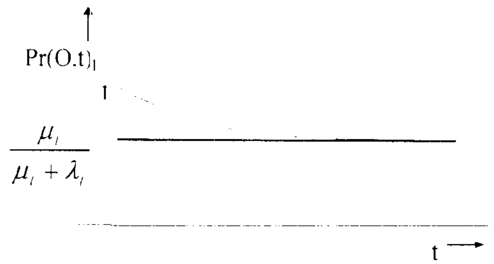

Figure 1:The evolution of probability of operation in time.

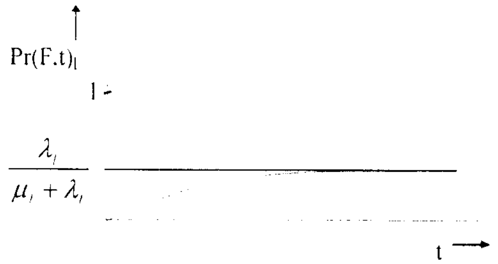

Figure 2: The evolution of probability of failure in time.

Both the line failure rate $\lambda_l = \frac{1}{\mathrm{E}(TO)_l}$ and the line repair rate $\mu_l = \frac{1}{\mathrm{E}(TF)_l}$ are usually considered constants, but in reality they can change with investment in transmission system.

For t large enough $\Pr(O,t_x)_l = \Pr(O)_l$ and $\Pr(F,t_x)_l = \Pr(F)_l$ and the equations (10) and (11) change to:

$$\Pr(O)_l = \frac{\mu_l}{\mu_l+\lambda_l} = \frac{E(TO)_l}{E(TO)_l + E(TF)_l} \qquad (12)$$

$$\Pr(F)_l = \frac{\lambda_l}{\mu_l+\lambda_l} = \frac{E(TF)_l}{E(TO)_l + E(TF)_l} \qquad (13)$$

Where $E(TO)_l$ is the expected value of the time in operation and $E(TF)_l$ is the expected value of the repair time for line l.

It is essential to point out that most of the formulations consider stationary equations (12) and (13) to model the availability of lines, but in the short-term (hour) $\Pr(O,t_x)_l$ can be completely different from $\Pr(O)_l$ for a specific time "t" and this issue needs to be properly considered for a realistic short-term reliability analysis.

Furthermore, the use of stationary probabilities can lead to an uneconomic overestimation of reserve requirements resulting from the fact that the knowledge of the system's initial conditions is neglected.

Moreover, if we consider that a line has only 2 states, and there are N lines, then the system has 2^N states. To give an idea of this number, consider 100 lines, the number of possible states to consider is 2^{100}= 1.27e30. So, it can be concluded that the consideration of the whole possible system state space is not feasible.

However, not all the states have the same probability of occurrence, therefore a reasonable assumption is to consider a subset with the most likely states. To define this subset, it is necessary to calculate the probability of single line contingency scenarios and compare with multiple line contingency scenarios.

Real examples show that it is reasonable to disregard high order line failures and consider only single line contingencies. For very specific cases double line contingencies must be taken into account. After this simplification the number of possible scenarios to consider is reasonably small [7].

The next step is related with Issue #3, that is the occurrence of deficit. This calculation strongly depends on the method used for redispatch after contingencies. In this paper we present two alternatives to do this, ex-post and ex-ante methods, which are described and analyzed in the following sections.

III The ex-post method

III.1 Redispatch (Issue #3)

When a contingency "j" is present, it is necessary to use the capacity R_i previously reserved. For the ex-post alternative, the objective function is to minimize the generation cost of the redispatch for each scenario "j" analyzed. The occurrence of deficit is modeled as a fictitious deficit generator located on each bus with demand. For this alternative the energy price is defined after the contingency, because of this fact we named this method ex-post.

$$\underset{Pg_i^j,\,Pdef_i^j}{Min} \sum_j \left[\sum_i C_i^j\left(Pg_i^j\right) + \sum_i C_i^j\left(Pdef_i^j\right) \right] \qquad (14)$$

The minimization problem is constrained by the following set of requirements:
The generation redispatched plus the amount of deficit needs to be equal to the demand for each scenario "j".

$$\sum_i Pg_i^j + \sum_i Pdef_i^j = \sum_i Pd_i \qquad \forall j \qquad (15)$$

The amount of deficit experimented by a load located on bus i cannot be greater than the respective demand Pd_i for each scenario "j".

$$0 \le Pdef_i^j \le Pd_i \qquad \forall j \qquad (16)$$

The generators cannot increase their generation in a value greater than the amount that they have as a generation reserve R_i. In this model and only for simplicity is assumed that generators can reduce their generation up to zero MW.

$$0 \le Pg_i^j \le Pg_i + R_i \qquad \forall j \qquad (17)$$

The topology, the generation, the deficit, and the demand define the power flow on line l for scenario "j".

$$F_l^j = \sum_i H_{l,i}^j \left(Pg_i^j + Pdef_i^j - Pd_i \right) \le F_l^{max} \; \forall j \; (18)$$

Lastly, the energy price for location i after the redispatch and for contingency "j", depicted in Figure 3, is calculated as:

$$\rho_i^{e\,j} = \lambda^j + \sum_l \eta_l^j H_{l,i}^j \qquad (19)$$

Where λ^j is the Lagrange multiplier associated with the balance constraint for scenario j (15), and η_l^j is the Lagrange multiplier associated with the transmission capacity constraint for line l and for scenario "j" (18).

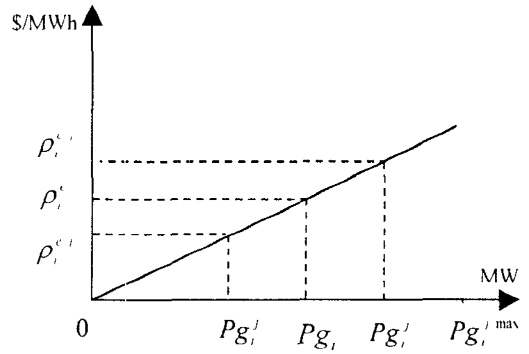

Figure 3: Generation readjustment for the ex-post method.

III.2 The ex-post method to assess short-term reliability

In order to solve this optimization problem, the reserve allocation (Section II) and the redispatch (Section III.1) equations need to be coupled to formulate the ex-post method to assess short-term reliability.

The objective is to minimize the cost of the reserve allocation and the cost of the generation redispatch for the set of scenarios in consideration.

$$\underset{Pg_i^j,\,Pdef_i^j,\,R_i}{Min} \left(\begin{array}{l} \sum_j \left[\sum_i C_i^j \left(Pg_i^j \right) + \sum_i C_i^j \left(Pdef_i^j \right) \right] + \\ \sum_i C_i \left(R_i \right) \end{array} \right) \qquad (20)$$

This optimization problem is constrained by:

$$\sum_j \Pr_j \, Idef_j \le P \qquad (21)$$

$$R_i^{min} \le R_i \le R_i^{max} \qquad (22)$$

$$\sum_i Pg_i^j + \sum_i Pdef_i^j = \sum_i Pd_i \qquad \forall j \qquad (23)$$

$$0 \le Pdef_i^j \le Pd_i \qquad \forall j \qquad (24)$$

$$0 \le Pg_i^j \le Pg_i + R_i \qquad \forall j \qquad (25)$$

$$F_l^j = \sum_i H_{l,i}^j \left(Pg_i^j + Pdef_i^j - Pd_i \right) \le F_l^{max} \; \forall j \; (26)$$

This model can be implemented either for system-wide reliability requirement P or for user-wide reliability requirement P_i.

IV The ex-ante method

IV.1 Redispatch (Issue #3)

An alternative way to implement the redispatch using the capacity R_i previously reserved is considering the energy price ρ_i^e fixed before the fact (contingency) and independent of the system conditic MW equently we named this method ex-ante.

As a result, the objective function for the redispatch is to minimize for each scenario "j" the total cost of the generation changes defined in the energy market. The occurrence of deficit is modeled as a fictitious deficit generator located on each load bus.

$$\underset{\Delta Pg_i^{in\,j},\,\Delta Pg_i^{de\,j},\,Pdef_i^j}{Min} \sum_j \left[\begin{array}{l} \sum_i \left(\rho_i^e \left(\Delta Pg_i^{in\,j} \right) - \rho_i^e \left(\Delta Pg_i^{de\,j} \right) \right) + \\ \sum_i C_i^j \left(Pdef_i^j \right) \end{array} \right] \qquad (27)$$

The optimization problem is constrained by the following set of requirements:

The net change in generation is defined by the increment $\Delta Pg_i^{in\,j}$ and the decrement $\Delta Pg_i^{de\,j}$ in generation for each scenario "j".

$$Pg_i^j = Pg_i + \Delta Pg_i^{in\,j} - \Delta Pg_i^{de\,j} \qquad \forall j \qquad (28)$$

0-7803-7173-9/01/$10.00 © 2001 IEEE

The generation redispatched plus the amount of deficit needs to be equal to the demand for all scenarios "*j*".

$$\sum_i Pg_i^j + \sum_i Pdef_i^j = \sum_i Pd_i \qquad \forall j \qquad (29)$$

The amount of deficit experimented by a load located on bus *i* cannot be greater than the respective demand Pd_i for each scenario "*j*".

$$0 \le Pdef_i^j \le Pd_i \qquad \forall j \qquad (30)$$

The generators cannot increase their generation in a value greater than the amount that they have as a generation reserve R_i. In this model is assumed that generators can reduce their generation up to zero MW.

$$0 \le Pg_i \le Pg_i + R_i \qquad \forall j \qquad (31)$$

The power flow on line *l* and for scenario "*j*" is defined by the topology, the generation, the deficit, and the demand.

$$F_l^j = \sum H_{l,i}^j \left(Pg_i^j + Pdef_i^j - Pd_i\right) \le F_l^{\max} \quad \forall j \quad (32)$$

After the contingency "*j*", the generation readjustment is implemented considering the energy price ρ_i^e fix as depicted in Figure 4. In case that a generator located on bus *i* increases its generation $\Delta Pg_i^{in,j}$, it losses the equivalent to area I in the figure (in particular for generators around the margin), on the other hand if it decreases its generation $\Delta Pg_i^{de,j}$, it losses to make profit equivalent to area II. These facts should be internalized by generators either through energy bids or through reserve bids.

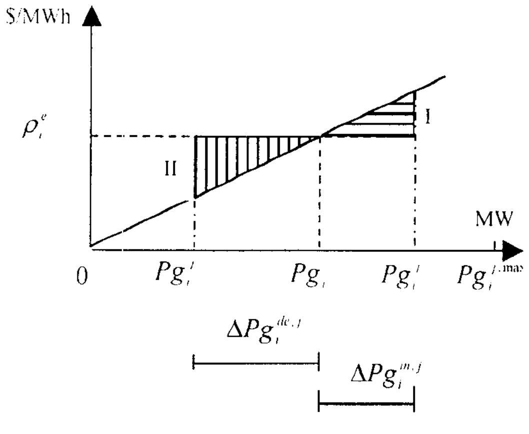

Figure 4: Generation readjustment for the ex-ante method.

IV.2 The ex-ante method to assess short-term reliability

In order to solve this optimization problem, the reserve allocation (Section II) and the redispatch (Section IV.1) equations need to be coupled, resulting the ex-ante method to assess short-term reliability.

$$\underset{\Delta Pg_i^{in,j},\, \Delta Pg_i^{de,j},\, \mathrm{Pdef}_i^j,\, R_i}{Min} \left(\begin{array}{l} \sum_j \left[\begin{array}{l} \sum_i \left(\rho_i^e\left(\Delta Pg_i^{in,j}\right) - \rho_i^e\left(\Delta Pg_i^{de,j}\right)\right) + \\ \sum_i C_i^j\left(Pdef_i^j\right) \end{array} \right] + \\ \sum_i C_i(R_i) \end{array} \right)$$

$$(33)$$

This optimization problem is subject to the following set of constraints:

$$\sum_j \Pr_j Idef_j \le P \qquad (34)$$

$$R_i^{\min} \le R_i \le R_i^{\max} \qquad (35)$$

$$Pg_i^j = Pg_i + \Delta Pg_i^{in,j} - \Delta Pg_i^{de,j} \qquad \forall j \qquad (36)$$

$$\sum_i Pg_i^j + \sum_i Pdef_i^j = \sum_i Pd_i \qquad \forall j \qquad (37)$$

$$0 \le Pdef_i^j \le Pd_i \qquad \forall j \qquad (38)$$

$$0 \le Pg_i^j \le Pg_i + R_i \qquad \forall j \qquad (39)$$

$$F_l^j = \sum_i H_{l,i}^j \left(Pg_i^j + Pdef_i^j - Pd_i\right) \le F_l^{\max} \quad \forall j \quad (40)$$

This model can also be implemented either for system-wide reliability requirement *P* or for user-wide reliability requirement P_i.

V Comparison

In this section both new methods are implemented in the same test system depicted in Figure 5. It is easy to see that the energy demand located on bus 6 experiments 1 MW of deficit in case of outage of line 16, and the energy demand located on bus 8 experiments 10 MW of deficit in case of outage of line 48. Assuming that each line has the same probability of failure equals to 0.01 and assuming only single line contingencies, the reliability benchmark is given by the probability of deficit LOLP=2*0.01*(1-0.01)^7 = 0.0186.

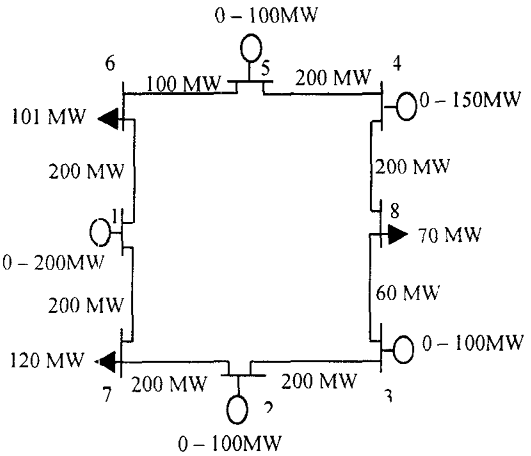

Figure 5: Power system example.

Ex-post method

To clear the energy market is assumed the following energy bids, $MC_1=5\$/\text{MWh}$, $MC_2=1.5\$/\text{MWh}$, $MC_3=3.2\$/\text{MWh}$, $MC_4=3.5\$/\text{MWh}$, and $MC_5=1.2\$/\text{MWh}$, using the data given in Figure 5, and the typical formulation for the energy dispatch [8], we obtain $Pg_1 = 0$ MW, $Pg_2 = 100$ MW, $Pg_3 = 82$ MW, $Pg_4 = 9$ MW, and $Pg_5 = 100$ MW.

Here is assumed that all generators participate in both energy and reserve markets, so we can calculate the reserve capacity limit for the units as $R_i^{max} = P_{gi}^{max} - P_{gi}$ resulting $R_1^{max} = 200$ MW, $R_2^{max} = 0$ MW, $R_3^{max} = 18$ MW, $R_4^{max} = 141$ MW, and $R_5^{max} = 0$ MW.

Using the formulations given in Section III.2 for the ex-post methodology, and the reserve bids $MCR_1=0.5\$/\text{MW}$, $MCR_2=2\$/\text{MW}$, $MCR_3=0.2\$/\text{MW}$, $MCR_4=1.8\$/\text{MW}$, and $MCR_5=3.0\$/\text{MW}$ the reserve allocation results $R_1 = 121$ MW, $R_2 = 0$ MW, $R_3 = 9$ MW, $R_4 = 1$ MW, and $R_5 = 0$ MW. Therefore, the reserve cost results $\$(121*0.5 + 9*0.2 + 1*1.8) = \$64.1$

Finally, it is necessary to simulate the operation of the system for different single contingency scenarios, and look for cases in which the system experiments deficit, calculating its amount and the probability of this event. The sum of the probabilities of all deficit states is the well known reliability index LOLP.

Under this framework, and with this reserve allocation the system experiments deficit when either line L_{16} or L_{48} is out of service, the respective deficits for buses 6 and 8 are 1 MW and 10 MW, and the probability of deficit is given by $LOLP=2*0.01*(1-0.01)$^7 = 0.0186.

If we compare the scenarios with deficit, the load that experiments it, its amount, and the probability of deficit, we can see that they coincide exactly with the benchmark that it is being used as a comparison.

Ex-ante method

For this case, and using the same test system and data, the energy market clears in the same way as before $Pg_1 = 0$ MW, $Pg_2 = 100$ MW, $Pg_3 = 82$ MW, $Pg_4 = 9$ MW, and $Pg_5 = 100$ MW.

The energy prices on generator buses calculated according to [8] are $\rho_1^e = 3.35\ \$/\text{MWh}$, $\rho_2^e = 3.25\ \$/\text{MWh}$, $\rho_3^e = 3.2\ \$/\text{MWh}$, $\rho_4^e = 3.5\ \$/\text{MWh}$, and $\rho_5^e = 3.45\ \$/\text{MWh}$.

As in the preceding example, here is assumed that all generators participate in both energy and reserve markets, where the reserve capacity limit for the units are calculated as $R_i^{max} = P_{gi}^{max} - P_{gi}$, consequently $R_1^{max} = 200$ MW, $R_2^{max} = 0$ MW, $R_3^{max} = 18$ MW, $R_4^{max} = 141$ MW, and $R_5^{max} = 0$ MW.

Using the formulations given in Section IV.2 for the ex-ante methodology, and the reserve bids $MCR_1=0.5\$/\text{MW}$, $MCR_2=2\$/\text{MW}$, $MCR_3=0.2\$/\text{MW}$, $MCR_4=1.8\$/\text{MW}$, and $MCR_5=3.0\$/\text{MW}$, the reserve allocation results $R_1 = 121$ MW, $R_2 = 0$ MW, $R_3 = 18$ MW, $R_4 = 1$ MW, and $R_5 = 0$ MW. Then, the reserve cost is $\$(121*0.5 + 18*0.2 + 1*1.8) = \$65.9$.

Lastly, it is necessary to simulate the operation of the system for single contingency scenarios and look for cases in which the system experiments deficit, calculate its amount and its probability. The sum of the probabilities of all deficit states is the reliability index LOLP.

Under this structure, and with this reserve allocation the system experiments deficit when either line L_{16} or line L_{48} is out of service. The deficit values are 1 MW or 10 MW on buses 6 and 8 respectively, resulting a $LOLP=2*0.01*(1-0.01)$^7 = 0.0186.

If we compare the scenarios where the system experiments deficit, the load that is affected, the amount and the probability of it, we can see that they exactly coincide again with the benchmark that it is being used for the comparison.

The reason for this coincidence is the correct inclusion of transmission equations in the reserve allocation procedure and in the approach to define the amount of reserve required considering a clear reliability requirement as explained in sections II, III and IV.

VI Conclusions

In this paper we formulated the short-term reliability assessment problem as a risk management problem, where the uncertainty associated is related with transmission outages and the consequences are measured by the deficit experimented by loads. Two new methods were introduced and implemented in an academic test system.

First, we formulated the short-term reliability related risks associated with the possibility of transmission failures, which are measured through the probability of the scenarios in consideration and the respective consequences experimented by the load. The lines were represented through two-state Markov models using time dependent probabilities. The state of the lines at the time of calculation is assumed to be known. Moreover, in this paper we only considered single contingency scenarios.

Second, we formulated the ex-post method as a new market-based method to allocate reserve considering explicitly the reliability requirement submitted by the demand. In this formulation the price for the energy used in the redispatch should be calculated after the occurrence of the contingency.

Third, we developed the ex-ante method as another market-based method to allocate reserve considering the reliability requirement submitted by the demand in an explicit way. In this case the energy price after the occurrence of contingency (redispatch) does not change, independent of the system condition.

To finish, we implemented both methods in an academic test system where we verified that both methods allocate reserve fulfilling pre-specified reliability requirements submitted by the demand. The difference in reserve allocation resulted in cost differences but not in reliability levels. Furthermore, the tradeoff analysis should be done between the economic signal given by the stability of the energy prices in presence of contingencies and the cost of having different amount of reserve. More specifically, in the ex-ante method the risk of receiving a price for the redispatched energy lower than the current marginal production cost is taken by generators. On the other hand, in the ex-post method the risk of having higher prices after the contingency is taken by the demand.

VII Acknowledgements

The authors greatly appreciate the financial support by the MIT Energy Lab Consortium on "New Concepts and Software for Deregulated Power Industry", and the FOMEC fellowship from Ministry of Education of Argentina.

VIII References

[1] J. Arce, M. Ilić, and F. Garcés, "Managing short-term reliability related risks", Submitted to the 2001 IEEE PES Summer Meeting, January 2001.

[2] M. Ilić, J. Arce, Y. Yoon, and E. Fumagalli, "Assessing Reliability as the Electric Power Industry Restructures", The Electricity Journal, March 2001.

[3] H Singh and A. Papalexopoulos, "Competitive Procurement of Ancillary Services by an Independent System Operator", IEEE Transaction on Power Systems, vol 14, no 2. May 1999, pp 448-504

[4] P Cheung, D. Shamsollahi, J Sun, J. Milligan, and M Potishnak, "Energy and Ancillary Service Dispatch for the Interim ISO New England Electricity Market", IEEE Transaction on Power Systems, vol. 15, no 3, August 2000, pp. 968-974.

[5] J Endrenyi, "Reliability Modeling in Electric Power Systems", John Wiley and Sons, 1978.

[6] F. Garcés, "Reliability assessment and optimal reserve requirement", Graduate course lectures, Universidad Nacional de San Juan, Argentina, 1997.

[7] D. Greco, "Assessing Reliability in Interconnected Electric Power Systems Considering the Most Relevant Network Constraints", PhD Thesis Dissertation, Universidad Nacional de San Juan, Argentina, February 2000

[8] F Schweppe, M. Caramanis, R Tabors, and R. Bohn, "Spot Pricing of Electricity", Kluwer Academics Publishers, 1988

VII Biographies

Dr Marija Ilic has been at MIT since 1987 as a Senior Research Scientist in the EECS Department where she conducts research and teaches graduate courses in the area of electric power systems. Since September 1999 she has had a 50% appointment at the National Science Foundation as a Program Director for Control, Networks and Computational Intelligence.
Prior to coming to MIT, she was a tenured faculty at the University of Illinois at Urbana-Champaign. Dr Ilic is a recipient of the First Presidential Young Investigator Award for Power Systems, she is an IEEE Fellow and an IEEE Distinguished Lecturer.
She has co-authored several books on the subject of large-scale electric power systems (Ilic, M., Zaborszky, J., Dynamics and Control of Large Electric Power Systems, John Wiley &Sons, Inc , 2000; Ilic, M , Galiana, F , Fink, L. (Editors), Power Systems Restructuring: Engineering and Economics, Kluwer Academic Publishers, Second printing 2000.; Allen, E , Ilic, M , Price-Based Commitment Decisions in the Electricity Markets, Springer-Verlag London Limited, 1999; Ilic, M., Liu, S , Hierarchical Power Systems Control Its Value in a Changing Industry, Springer-Verlag London Limited, 1996) . She is also a contributor to the edited book on Blue Print for Transmission (PU Reports, 2000). Her interest is in control and design of large-scale systems.

José R. Arce is pursuing his Ph D in Electrical Engineering at Universidad Nacional de San Juan, Argentina Currently he is Visiting Student at the MIT Energy-Lab. His main interest is in the areas of power system operation, reliability assessment, and economics He received his degree in Electrical Engineering from the Universidad Nacional del Nordeste, Argentina in 1995

Francisco F. Garcis was born in San Juan, Argentina. in 1951 He obtained the Eng. degree from the University of Cuyo, Argentina, in 1974 and Dr -Ing Degree from the Technical University Aachen, Federal Republic of Germany, in 1982. Presently is a vice director of Instituto de Energma Elictrica, University of San Juan, Argentina. His main research interest is on power system reliability and reserve calculations.