Reliability of hybrid systems - Conventional-solar photovoltaic generation

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Abstract—Considering last years, it is undeniable that there has been a huge growth in terms of renewable energy, namely the photovoltaics. Taking into consideration the aforementioned growth, it aims to find a green alternative for the generation of electrical power. The number of studies around this renewable source in particular, has been extremely significant.

To consolidate the research, it is important to understand the impact that the inclusion of photovoltaic parks will have in a short and long term.

From long-term perspective, the main objective is to determine the power required to be installed, so that the load is satisfied by fulfilling the "reliabilities levels" of the system. The long-term study may be divided into two stages. In the first stage, will be added to a conventional system, photovoltaic units that are responsible for assessing the values that LOLE takes over.

In a second stage, it is crucial to determine the photovoltaic power needed to add to the system, in order to replace the conventional power that will be removed.

In short, PJM modified method will be implemented. This method results in an extension of PJM itself. The objective is to evaluate the operational risk, associated with the presence of each photovoltaic unit.

Summarize, it is intended to gauge to what extent it is beneficial to the electrical system (in short/long term), the inclusion of photovoltaic generation into the network.

Index Terms—Photovoltaic power, Reliability, LOLE, Modified PJM method, Markov chain, Risk rate.

I. INTRODUCTION

Renewable power sources are very important for our future. It is a generation source in growth, because it can make the electric system more sustainable. This study focuses in the reliability evaluation of a hybrid system, of conventional/photovoltaic generation. At first, it is supposed to analyse the reliability of the conventional system, at long-term, when it is added some photovoltaic power.

The second stage of this study, the short-term analysis, the aims is understand the behavior of the conventional system operational risk to be inserted photovoltaic generation units.

II. MODELING AND RELIABILITY OF A ENERGY GENERATION SYSTEM

The intent of this chapter, is to analyse the reliability of a conventional power system. A generation model with conventional units is presented to determine the amount of power to supply the load.

A. System reliability

Reliability is the probability of one system to be capable to do their functions in a certain way and in a certain period of time.

To ensure the electric system reliability, the installed power have to be enough to supply the predicted load at long-term, taking into account the unavailable generation caused by failures and/or maintenance.[1],[2]

1) COPT (Capacity Outage Probability Table) table:

FOR - Forced outage rate

The concept of probability is the most important indicator to characterize a system reliability. Therefore, it is possible to obtain a numeric value to evaluate the system reliability.

The probability of a favorable event (P) to happen is:

\[ P = \frac{\text{Number of favorable events}}{\text{Number of possible events}} \]  

In engineering, the concept of probability is associated to an regularity of behavior, obtained by several experiences or a continuous operation.

On electric systems reliability analysis, the determination of failure probability is very important. This probability is known by Forced Outage Rate (FOR), and is given by:

\[ \text{FOR} = \frac{\text{Failure time}}{\text{Operation time} + \text{Failure time}} \]  

2) COPT table construction: The COPT table shows the generators power and the respective probability of that power occurs. This table can be obtained by using an algorithm which is possible to add and to remove power units. When units are included on the system, the fact they can be in more states, it is called multi-state power unit.[1]

Example 1 No multi-states units

The cumulative probability of a capacity outage state of X MW after a unit of capacity C MW and FOR U is added is given by:

\[ P(X) = (1 - U)P'(X) + U \cdot P'(X - C) \]
• $P(X)$: The cumulative probability of a contingency power output $X$ MW after adding a power unit;
• $P(X)$: The cumulative probability of a contingency power output $X$ MW before adding a power unit;
• $C$: Unit capacity to be added;
• $U$: Probability of power to be added being out of service (FOR).

Consider two units of 25 MW and one of 50 MW with an outage rate of 0.02 (Table II-A2), the COPT Table is given by:

Table I: System Data

<table>
<thead>
<tr>
<th>Capacity [MW]</th>
<th>FOR</th>
<th>(1-FOR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>0.02</td>
<td>0.98</td>
</tr>
<tr>
<td>25</td>
<td>0.02</td>
<td>0.98</td>
</tr>
<tr>
<td>50</td>
<td>0.02</td>
<td>0.98</td>
</tr>
</tbody>
</table>

Example 2 - With Multi-states Units: Considering a system with multi-state, the equation 3 should be rewritten:

$$P(X) = \sum_{i=1}^{n} p_i \cdot P'(X - C_i)$$

(4)

Onde,
• $p_i$: Probability of $i$ state occurring;
• $n$: Number of states of outage power;
• $C_i$: $i$ state of power output of unit to be added.

Table II: Three States of 50 MW

<table>
<thead>
<tr>
<th>State</th>
<th>Outage capacity [MW]</th>
<th>(State probability ($p_i$))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0.0360</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>0.03</td>
</tr>
<tr>
<td>3</td>
<td>50</td>
<td>0</td>
</tr>
</tbody>
</table>

Using the equation 4 and considering the 50 MW unit in the previous example, it’s possible to determine the COPT table of a three state unit, as shown in table II-A2:

Table III: Outage Cumulative Probability - Multi-States

<table>
<thead>
<tr>
<th>Outage capacity [MW]</th>
<th>Cumulative probability ($p_i$)</th>
</tr>
</thead>
</table>
| 0                    | 1
| 20                   | 0.078016
| 25                   | 0.0463228
| 50                   | 0.0073972
| 70                   | 0.0002904
| 75                   | 0.0002772
| 100                  | 0.0000028

B. Measuring Indices of Generation Reliability

1) LOLE - Loss of load expectation: LOLE is the reliability index more used, and it is determined combining the COPT table and the number of occurrences of the peak performance of daily load curve. [1],[3]

$$LOLE = \sum_{i=1}^{np} N(L_i) \cdot P(C_i - L_i)$$

(5)

Where,
• $np$: Number of peak load;
• $N(L_i)_{i}$: Number of occurrences of the peak performance of daily load, $L_i$, on a period of time;
• $L_i$: Daily peak load $i$;
• $C_i$: Available power for daily peak load $i$;
• $P(C_i - L_i)$: Probability of loss of load for daily peak load $i$. Obtained by COPY table.

Other method to determine LOLE is using the number of occurrences of the peak performance of daily load curve:

$$LOLE = \sum_{k=1}^{n} p_k \cdot t_k$$

(7)

Where,
• $O_k$: Capacity outage $k$;
• $t_k$: Time for each load loss will occur.

For each value of $O_k$ lower than reserve, will not contribute to LOLE calculation.

$$O_k = p_k \cdot t_k$$

(6)

$p_k$ is the probability of outage capacity $O_k$.

It’s possible to determine the LOLE value using the cumulative probabilities of outage power $P_k$ with the following difference:

$$LOLE = \sum_{k=1}^{n} P_k \cdot (t_k - t_{k-1})$$

(8)
To make it easier, is possible to despise probabilities for values lower than $10^{-6}$. This way, the load system model takes a linear form, like is shown at figure 2.

Fig. 2. Time for which load loss will occur

The number of days that generation will not supply the load is given by:

$$LOLE = 0.04124575 \cdot (\frac{365}{100}) = 0.150547 \text{ dias/ano}$$

Using the cumulative probabilities, $LOLE$ is given by:

$$LOLE = 0.04125044 \cdot (\frac{365}{100}) = 0.150564 \text{ dias/ano}$$

### 3) $LOLE$ calculation with uncertainty in forecasting load:

To determine $LOLE$ with uncertainty in forecasting load, it is necessary calculate first all associated risk to each load value for each interval of a normal distribution.

With the inclusion of the uncertainty the $LOLE$ value increase of 0.0252130 to 0.07832545 with 2% of uncertainty.

### C. EIR Energy index of reliability

Using the daily peak load curve, the area below of diagram represents the consumed energy during the respective period.

![Energy not supplied because generation outage](image)

Where,

- $O_k$ magnitude of the capacity outage;
- $P_k$ probability of a capacity outage equal to $O_k$;
- $E_i$ energy curtailed by a capacity outage equal to $O_k$.

The energy not supplied is given by $E_k \cdot P_k$. To determine the LOEE (Loss of energy expectation), is necessary to sum all the obtained products:
\[ \text{LOEE} = \sum_{k=1}^{n} E_k \cdot P_k \]  \hspace{1cm} (9)

To normalize the equation 9, the LOEE is divided by the total energy of the system (E). This represents the probability of energy be cut because the energy unavailability:

\[ \text{LOEE}_{pu} = \frac{\sum_{k=1}^{n} E_k \cdot P_k}{E} \]  \hspace{1cm} (10)

Finally, it is possible determine the probability of the energy be supplied, EIR:

\[ EIR = 1 - \text{LOEE}_{pu} \]  \hspace{1cm} (11)

III. MODELLATION OF A SOLAR GENERATING SYSTEM

The aim of this chapter is to study the impact of inclusion of photovoltaic generation system on a conventional system. For that, it will be developed models for solar irradiation and for photovoltaic panels.

1) Irradiation model: A big inconvenience in solar power sources is the unpredictability of knowing which power will be produced. For that was developed a stochastic model of a hourly solar irradiation series to predict the amount of irradiation for a specific location. [4]

Solar irradiation is given by the next expression:

\[ G_0 = \int_{\text{sunset}}^{\text{sunrise}} I_0 \cdot \cos(\theta_z) \cdot dt \hspace{1cm} (kWh/m^2) \]  \hspace{1cm} (12)

Where,

- \( I_0 \) Extra-terrestrial solar irradiance kWh/m²;
- \( \theta_z \) zenith angle.

Figure 4 represents a correlation series of solar irradiation aforesaid for Lisbon at March 9, 2014.

2) Power output of a photovoltaic panel: For photovoltaic panels, the value of output power is not constant and depends on the number of hours of sun on each day as the panel characteristics.

Figure 5 shows a model for the photovoltaic panel power output.

In this model the output power is divided in three levels, which power output is calculate differently for each level, in order to maintain the power proportional to the solar radiation.

The generated power is dependent on solar irradiation and can’t pass the panel rated power. For example, a photovoltaic panel is limited between zero and the rated power value.[5]

Where,

- \( P_0 \) Solar radiation-to-energy conversion function for solar radiation band i [MW];
- \( G_{bi} \) Forecasted solar radiation at band i [W/m²];
- \( G_{std} \) Solar radiation in the standard environment [W/m²];
- \( R_c \) A certain radiation point [W/m²];
- \( P_{sn} \) Equivalent rated capacity [MW];

There are two ways to include this systems on electric system, with the modelation of each panel individually or with the modelation of an equivalent panel.

3) Equivalent model of a photovoltaic park: With expression 13, it is possible to obtain the output power levels: [6]

\[ X_j = K \cdot C(V_i) \]  \hspace{1cm} (13)

Where,

- \( X_j \) photovoltaic park power output;
- \( K \) number of photovoltaic panels;
- \( C(V_i) \) photovoltaic panel output power, in function of solar irradiation;

It is necessary determine the available probabilities of panels for obtain the power levels probabilities.
Where,
- K number of photovoltaic panels;
- i number of available photovoltaic panels.

With the equation 15 it’s possible determine the power output probabilities using the values obtain with equation 14.

\[
P(X_j) = \sum_{i=0}^{K} \left( \sum_{j=0}^{S} Q_j \cdot \left( \frac{x_i}{l} - C_j \right) \right) \cdot P_i \tag{15}
\]

Wich,
- \( P(X_j) \) probability of photovoltaic park output power;
- S number of power levels;
- \( C_j \) jth capacity level;
- \( P_i \) probability of i units being available;
- \( Q_j \) probability of a photovoltaic panel operating in output stage \( C_j \).

IV. IMPACT OF INTEGRATION OF PHOTOVOLTAIC GENERATION UNITS IN ELECTRIC SYSTEM

In this chapter, the intent is to analyse the impact of the two previously methods when included on the electric system. The reliability indexes must maintain constant.

A. Inclusion of photovoltaic units in a conventional generation system

To determine the generation capacity to install from photovoltaic units, was used a conventional system, generally used for academic studies and researches. [7]

<table>
<thead>
<tr>
<th>Unit size [MW]</th>
<th>Type</th>
<th>Number of units</th>
<th>FOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Hydro</td>
<td>2</td>
<td>0.01</td>
</tr>
<tr>
<td>10</td>
<td>Thermal</td>
<td>1</td>
<td>0.02</td>
</tr>
<tr>
<td>20</td>
<td>Hydro</td>
<td>4</td>
<td>0.015</td>
</tr>
<tr>
<td>20</td>
<td>Thermal</td>
<td>1</td>
<td>0.025</td>
</tr>
<tr>
<td>40</td>
<td>Hydro</td>
<td>1</td>
<td>0.02</td>
</tr>
<tr>
<td>40</td>
<td>Thermal</td>
<td>2</td>
<td>0.03</td>
</tr>
</tbody>
</table>

B. Increase of photovoltaic capacity

Considering the RBTS system, table IV-A, with a peak load of 185 MW. Using the model refered on section II-B2 it is possible calculate LOLE value of the conventional system.

<table>
<thead>
<tr>
<th>Number of units</th>
<th>Capacity [MW]</th>
<th>FOR</th>
<th>LOLE [hours/year]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>5</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>10</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>20</td>
<td>0.015</td>
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<tr>
<td>1</td>
<td>20</td>
<td>0.025</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>40</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>40</td>
<td>0.03</td>
<td></td>
</tr>
</tbody>
</table>

Total 240 -

In order to study the impact of the power increase, from the inclusion of the sun followers in the conventional system, as well as, the variation of LOLE values, considering the system of table IV-B.

<table>
<thead>
<tr>
<th>Number of panels</th>
<th>Capacity [MW]</th>
<th>FOR</th>
<th>LOLE [hours/year]</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>0.04125</td>
<td>0.1</td>
<td></td>
</tr>
</tbody>
</table>

In this part, each unit are composed by a large number of solar panels, called solar followers.

C. Substitution of conventional units by photovoltaic units

Generate electrical energy from photovoltaic sources is always an unpredictable process. It is known that 1 MWp produced by a photovoltaic unit, don’t support the same amount of load than 1 MW produced by a conventional unit. Thus, using the RBTS system, the aim is to study the impact of the substitution of conventional units by photovoltaic units.[8]

With the inclusion of photovoltaic units, it is possible to conclude that the LOLE value will take lower values. This decrease of LOLE happens because the installed power is not kept constant while new units are being added and because the peak load remains constant, resulting on the increase of the reserve power of the system.
It's possible to conclude that the ratio between conventional and photovoltaic is not regular. For units of 40 MW, it is possible to see in figure IV-C that it is not possible to replace them by any photovoltaic unit. This happens because the FOR of conventional units and of photovoltaic units are not the same.

![LOLE vs Photovoltaic capacity increase](image)

**V. PJM METHOD**

This method evaluates the operational risk of the committed generation, satisfying or not, the forecasting load during the lead time (LT).\[^{[3]}\]

The unit unavailability is given by:

\[
P(\text{unit out}) = 1 - e^{-\lambda \cdot T}
\]  

(16)

This probability is generally known as outage replacement rate (ORR), because their similarity with FOR used in static reserve studies. This method is much similar to the one used to calculate LOLE previously. The risk value can be deducted from the outage table too, like the method before, taking into account the corresponding cumulative probability.

With this procedure, were calculated approximate values of the probabilities over time, which is very different from using the FOR to calculate the long-term probability.

**VI. SHORT-TERM RELIABILITY OF A PHOTOVOLTAIC SYSTEM**

Applying the Markov chain to the considered system, it is possible by modified PJM method calculate operational risk evaluation of a photovoltaic unit on a energy system.

1) **Markov chain**: To implement the Markov model, it is necessary to take attention to the panels failures and to unavailability of solar irradiation. For that, it is need apply a discretization of solar irradiation series, and divide on 4 levels (a, b, c, d), where a is de maximum level of power and d is null. The transition rates are represented by \( \lambda \), like it is possible to see in figure VI-1.\[^{[9]}\]

![Markov chain for four power solar states](image)

Every transition are considered possible with this model, like the a-d transition for sudden loss of sun and excessive cloudiness.\[^{[9]}\]

2) **Markov model of a photovoltaic park**: The Markov model for a photovoltaic park with \( N \) units is represented in figure VI-1, if 4 power levels are considered. Therefore, depending on the actual data, only the first 8 or 12 levels are considered. Figure VI-3, show us the state diagram when 8 states are retained. The states 4 and 8 correspond to the same situation (no power), so the diagram became in a seven states diagram.

3) **State probabilities**: It is necessary determine the probabilities of residence in each states when \( t = LT \). To solve this problem, a discrete approximation is used, for a convenient step \( \Delta T = \frac{LT}{k} \) that must be much less than the minimum mean residence time in the states.

Once fixed \( \Delta T \), it is possible determine the stochastical transitional probability marix \( S \).

Now, with the vector of initial probabilities, we can calculate \( p(LT) \), the row vector of the probabilities of each state, using

\[
p(LT) = p(0) \cdot S^k
\]  

(17)

![Markov model of a photovoltaic park with N sun followers](image)

![Eight states Markov model for N sun followers](image)
Finally it is possible determine the COPT table.

4) Application: In order to illustrate the concepts and the methodology, an example is now presented for a small power system. In study 1, it is used only traditional thermal units. Next, we show how the calculations are carried out if one of the units was instead a wind park with the same rated power (study 2). Then, for this case, we calculate the risk reduction that can be obtained through the commitment of more units (study 3) or by the inclusion of a rapid start unit (study 4).

We consider the same system of the base case, but we exchange one of the 60-MW machines by a photovoltaic park with a maximum power of equal value. The wind farm has 10 units of 6 MW each, and = 24 failures/yr. We set µ = 0. Like it said before, it will be considered four power states for each unit, a=100%, b=70%, c=30% and d=0. The state transition rates are given by:

\[
\begin{align*}
\lambda_{ab} &= 7.50h^{-1}, \quad \lambda_{bc} = 3.34h^{-1}, \quad \lambda_{cd} = 0.00h^{-1}, \quad \lambda_{da} = 1.50h^{-1} \\
\lambda_{ba} &= 2.67h^{-1}, \quad \lambda_{cb} = 6.00h^{-1}, \quad \lambda_{dc} = 6.00h^{-1}, \quad \lambda_{db} = 0.00h^{-1} \\
\lambda_{bd} &= 0.67h^{-1}, \quad \lambda_{db} = 6.00h^{-1}, \quad \lambda_{ac} = 0.00h^{-1}, \quad \lambda_{ca} = 3.00h^{-1}
\end{align*}
\]

For a \( \Delta T = 1 \) minute and a LT = 1 hour, it is possible determine the initial probabilities for a photovoltaic unit of 6 MW:

\[
[p(0)] = [0.041667 0.33333 0.20833 0.41667 0 0 0 0]
\]

With the initial probabilities vector, we can calculate the probabilities of each output power level for \( t = LT \).

\[
[p(LT)] = [0.21625 0.4858 0.21639 0.054155 0.0060926 0.013687 0.0060965 0.0025257]
\]

Because the load is constant, the risk value can be obtained from the outage table. For 480 MW, the risk take the value of 0.0018271. This value should be compared with a risk threshold defined by some regulator entity.

Case 2: System with a photovoltaic park

We consider the same system of the base case, but we exchange one of the 60-MW machines by a photovoltaic park with a maximum power of equal value. The wind farm has 10 units of 6 MW each, and = 24 failures/yr. We set µ = 0. Like it said before, it will be considered four power states for each unit, a=100%, b=70%, c=30% and d=0. The state transition rates are given by:
TABLE XIX
OUTAGE TABLE FOR CASE 2

<table>
<thead>
<tr>
<th></th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>580</td>
<td>0</td>
<td>1.0000000</td>
</tr>
<tr>
<td>574</td>
<td>6</td>
<td>0.0298739</td>
</tr>
<tr>
<td>568</td>
<td>12</td>
<td>0.0028506</td>
</tr>
<tr>
<td>562</td>
<td>18</td>
<td>0.00251191</td>
</tr>
<tr>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>480</td>
<td>100</td>
<td>0.001826864</td>
</tr>
<tr>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
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<td></td>
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TABLE XX
OUTAGE TABLE FOR CASE 3

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>600</td>
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<td>594</td>
<td>6</td>
<td>0.03020566</td>
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</tbody>
</table>

Case 3: Commitment of an additional conventional unit

One way to reduce the risk calculated at case 1, is the placement of a conventional service unit to increase the reserve. The unit has a capacity of 20 MW and has the same ORR value of the 60 MW unit.

TABLE XXI
OUTAGE TABLE FOR CASE 4

<table>
<thead>
<tr>
<th></th>
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<tbody>
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<td>.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For a 480 MW load, the risk is given by:

\[ R_a = 0.000304636 \]

For the second period, (10, 60 minutes), it will be necessary to obtain the risk values for t=10 minutes and for t = 1 hour, taking into account the inclusion of the RSU in the system.

TABLE XXII
OUTAGE TABLE FOR CASE 4 WITH T = 10 MINUTES

<table>
<thead>
<tr>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>620</td>
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<tr>
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<td>6</td>
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<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The risk value for t=10 minutes is: \[ R_{10\text{min}} = 0.000000868889 \].

TABLE XXIII
OUTAGE TABLE FOR CASE 4 WITH T = 1 HOUR

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>620</td>
<td>0</td>
<td>1.0000000</td>
</tr>
<tr>
<td>614</td>
<td>6</td>
<td>0.00305655</td>
</tr>
<tr>
<td>608</td>
<td>12</td>
<td>0.00319167</td>
</tr>
<tr>
<td>602</td>
<td>18</td>
<td>0.00285305</td>
</tr>
<tr>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>480</td>
<td>100</td>
<td>0.000003124688</td>
</tr>
<tr>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The risk value for t = 60 minutes is: \[ R_{1\text{hora}} = 0.000003124688 \].

\[ R_b = R_{1\text{hora}} - R_{10\text{min}} = 0.000003124688 - 0.000000868889 = 0.00000030378 \]

Finally it is possible to determine the new risk index of the system with a RSU unit.

\[ R = R_a + R_b = 0.00030767 \]
Therefore, the new risk value is lower than the value obtained in conventional system combined with the photovoltaic park.

VII. CONCLUSION

The aim of this study was to analyse the reliability of a generation system, using two methods, according to with all reliability indexes, namely LOLE.

For the long-term model, two approaches were taken. At first it was intended to study the impact of the photovoltaic units inclusion in a conventional system. With this inclusion, the LOLE value tended to decrease. This decrease is due to the fact that the installed power is not kept constant due to the addition of power from the photovoltaic unit, while the peak load is kept constant, which resulted in a significant increase in reserve power system.

The second approach is to analyse the impact on the electric system by replacing conventional units by photovoltaics units in order to realize the amount of the photovoltaic power that would be needed to add to keep the LOLE reliability index with the same value of the conventional system.

We can conclude that the ratio varies is irregular. For the 40 MW units, is not possible to replace them with photovoltaic units. This happens because the FOR value is not the same for conventional and photovoltaics units.

In a short-term study, we conclude that using a RSU unit will be the most efficient method to reduce the operational risk. It is quite an advantage to bet on photovoltaic generation to replace some conventional units to comply with and respect all levels of reliability without stopping feeding the expected load as well.

REFERENCES