Long term interruption indicators for the Brazilian transmission system

Dalton O. C. Brasil*, Florisvaldo Martins, Dalva S. Araujo, George P. Wilson
ONS – Operador Nacional do Sistema Elétrico
Brazil

SUMMARY

Nowadays, the quality of electric energy supply has become even more important, at both national and international scenario. The National Electric System Operator, ONS, Brazil’s ISO, has among its functions, the responsibility for determining the actions through which the quality of electric energy at the border points of the main transmission network shall be maintained according to established standards, or reference values.

In this context, the Resolution no. 24 of the Electric Energy National Agency (ANEEL) issued in 2000, established continuity indicators for the border busbars of the main transmission network, which are the connection points to the generating and distributing companies (Gencos & Discos) and free consumers. The performance of these indicators must be verified and then published by ONS.

Regarding these indicators, this paper presents:

− Concepts and definitions of continuity indicators at the borders of the basic transmission network;
− Results of the survey of these indicators from 2000 to 2007, showing average values and related statistical distributions;
− Methodology applied to the establishment of reference values for the indicators, as well as corresponding results;
− Management analysis of these indicators covering the period from July, 2000 to December, 2006.

KEYWORDS
Power Quality, Transmission Network, Continuity Indicators, Long Term Interruptions, Control Points
1. Brazilian Electrical System

Figure 1 presents a general view of the Brazilian main transmission network. The subgroup of transmission lines, transformers, busbars and equipments with rated voltages 230kV and above and of non-exclusive usage, defines the Basic Transmission Network.

![Brazilian Transmission Network](image)

At the end of 2006, the Basic Transmission Network consisted of 83,545 km of transmission lines, 196,763 MVA of transforming capacity and 354 substations, with 306 of these located on the transmission system borders.

2. Continuity Indicators - Concepts and Terminology

Main Concepts:

- Control Point (CP): is an installation or group of installations, located on the borders of the basic transmission network with the connection assets of the accessing companies (Gencos, Discos, Free Consumers, Importers and Exporters). Due to rules set down by the Regulator, Tescos are responsible for all step-down transformations from transmission voltage levels (230 kV and above) to distribution levels (138 kV and below). The result of these rules is that the Basic Transmission Network borders and by consequence the Control Points location is frequently situated at the 138 kV or lower voltage levels (but always in a main grid substation). Figure 2 shows the application of this concept upon a border substation with a double bus scheme. In this case, two control points are defined (CP1 e CP2), each one of these being located on one of the substation’s buses.

- Service interruption of a control point: whenever it remains out of service (zero voltage) for a period equal to or higher than 1 (one) minute. Service interruption does not necessarily imply in load interruption to consumers.
Types of interruptions: interruptions are classified by cause and origin. Causes are classified as programmed or others. Programmed interruptions can be: maintenance interventions or reinforcement implementations. Other interruptions are non-programmed ones associated to accidents, emergencies due to equipment failure, natural phenomena, etc. Regarding the origin, they differ in being internal or external. Those classified as internal are caused by events internal to the Basic Transmission Network.

Indicators: the following continuity indicators were defined at each Control Point:
- FICP: the frequency of interruptions to the CP for a specific time-period;
- DICP: the total duration of interruptions to the CP in a specific time-period;
- DMI: the average duration of interruptions in a specific time-period.

From these individual CP indicators, average value global indicators are also calculated. Therefore, it is possible to compare these global indicators to those indicators previously recommended in the document Power Quality Indices and Objectives, a report of the workgroup C4.07/Cired of March 2004:
- SAIFI: System average interruption index (related to FICP);
- SAIDI: System average interruption duration index (related to DICP);
- SAIRI: System average restoration index (related to DMI).

3. Indicator survey

3.1 Methodology for carrying out the survey

The survey of the indicators is carried out according to an operational procedure where definitions, routines, periodicity and responsibilities are established. This procedure consists of:
- A record of all CPs containing information such as: substation name (location), voltage, bus configuration, initial operation date, among others;
- Data survey: transmission companies (Tescos) inform the regional operating centers of the occurrence of all interruptions of service to CPs, containing the cause, origin, description of the equipment associated to the origin of the event, date and time of the beginning and end of the interruption. This data is, then, transferred to the National Operation Center which checks their consistency and proceeds to their validation;
- Calculation of FICP, DICP and DMI indicators for each CP; calculation of the indicator average values (average values, separated by cause and origin of interruption, by voltage level, by bus configuration) which are then published by ONS.
3.2 Survey results

Figure 3 shows, over the period from 2000 to 2007, the annual global average values of FICP, (number of interruptions/year), DICP (hours/year) and DMI (hours/interruption), based on every CPs individual values, considering each interruption that occurred in the period. In 2007, there were 660 CPs in operation, with 2/3 of them located at 138 kV or lower voltage levels.

As can be seen, the annual average values have steadily decreased over the years, with a tendency to stabilization, showing that the performance of the Basic Transmission Network has improved since 2000, two years after the Brazilian Electric Sector was restructured.

It is important to mention that the non typical results from 2002 show the effects of a large regional blackout which occurred on January 21st, 2002, affecting the Southeast and Middle-Western regions of Brazil. The severity indicator (system minute) related to this occurrence was estimated at 82 minutes.

Such results reflect the improvement of operational and maintenance practices, besides the increase of investments made on the Basic Transmission Network during this specific period. The evolution of transmission lines extension is shown in total kilometers in figure 4.

Figures 5 and 6 show, respectively, the results of FICP and DICP separated by cause and origin of the interruptions.
It may be observed on the previous figures that the duration of programmed interruptions shows higher values; meanwhile in the frequency this characteristic is inverted. It can also be seen that the contribution from the interruptions of external origin to the Basic Transmission Grid, vary over the years, being 15% the maximum value for the FICP, and 10% for the DICP.

Figures 7 and 8 present values of FICP and DICP grouped by voltage level and bus configuration.
It can be seen that the CPs showing the worst performances are those ones at voltage levels below 230 kV and tied to less reliable bus schemes.

3.3 Statistical distribution of FICP and DICP

FICP and DICP results previously shown are frequency and duration average global values. Figure 9 presents the statistical distribution of FICP and DICP values, considering the results of each CP in 2006. As can be seen, the statistical distribution is quite non-symmetrical.

3.4 Comparison to indicators of the distribution system

For the Brazilian distribution system, continuity indicators were established many years ago, and defined as:

- DEC (Equivalent duration of interruptions per customer) – indicates the average number of hours that a customer is without service and is calculated on a monthly or yearly basis;
- FEC (Equivalent frequency of interruptions per customer) – indicates the average number of times that a customer is without service and is calculated on a monthly or yearly basis.

It isn’t possible to compare FICP/DICP and FEC/DEC indicators directly, excepting for radial transmission systems, where an interruption of the CP leads to the complete interruption of the supply to the Distributor, and consequently to a load interruption. However, for a preliminary referential analysis, figure 10 presents a comparison between the annual average values of the indicators FICP to FEC, as well as DICP to DEC.
As a result of this comparison, it is possible to say that transmission system interruptions contribute roughly with less than 10% of all interruptions that affect distribution customers.

4. Reference Values

The development of reference values for the indicators FICP and DICP followed two different paths. At the time, the historical data base for CPs at 230 kV and over was relatively small, so predictive values were calculated individually for each CP which were then grouped together, following certain rules (12 groups resulted). For CPs at the lower voltage levels, the historical data base was considered sufficient to define statistical reference values based on specific criteria. [4]

The predictive values were calculated based on reliability evaluations. The calculation consists of the modeling of each CP location, taking into account the substation bus scheme, the number of breakers and disconnectors, voltage level, etc. so that it represents the environment of the CP as closely as possible. The modeling also includes the number of transmission circuits, directly connected to the bus, capable of maintaining voltage to the CP and also those whose failure or outage might cause its interruption. For radial systems the calculations take into direct account the reliability of the infeed circuit, going as far back as necessary until a multicircuit bus is encountered.

The modeling methodology evaluates the reliability of the location as the total sum of the combination of statistical indices of all the involved components’ performances, based on the analysis of the average in-out process and operation-failure-repair cycles, where the average times and indices for failure and repair of each component are defined as a starting point.

It must be observed that systemic events, such as a regional blackout, are not considered, bearing in mind the complexity associated to its modeling.

For the definition of the twelve CP groups (CPs ≥ 230 kV) the main factors considered were: the bus scheme, the number of bays (lines, transformers, etc.) and the voltage level. Regarding voltage level, two subgroups were created: 230 kV and 345 kV and above. The following bus schemes were considered: triple bus, double bus, main and transfer bus, ring bus, breaker and a half. For the three
first schemes, where the number of bays exerts a significant influence on the results, two subgroups in each were formed: one with up to six bays and another with over six bays.

On the other hand, the performance of CPs below the 230 kV voltage level are mainly influenced by the characteristics of the Basic Transmission Network at the site where the CP is located, as well as the features of the associated distribution network.

Consequently, the possible combinations of three factors were taken into consideration:

− Redundant or non-redundant infeed transmission system;
− Redundant or non-redundant step down transformation;
− Radial or grid distribution system connected to lower voltage bus or buses.

Of all the possible combinations three were selected as being able to cover all present situations:

− Redundant transmission + redundant transformation + grid distribution system;
− Redundant transmission + redundant transformation + radial distribution system;
− Non-redundant transmission + redundant or non-redundant transformation + radial distribution system.

The range covered by the reference values for FICP and DICP resulting from these groups are shown in the following table. It is worthwhile mentioning that such reference values are only applied to outages classified as other interruptions. Rules and values for programmed interruptions are, at this moment, still under consideration.

<table>
<thead>
<tr>
<th>Voltage level</th>
<th>Groups</th>
<th>FICP (range of values)</th>
<th>DICP (range of values)</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥ 230 kV</td>
<td>12</td>
<td>0,100 – 0,670</td>
<td>0,100 – 1,530</td>
</tr>
<tr>
<td>&lt; 230 kV</td>
<td>3</td>
<td>0,220 – 8,000</td>
<td>0,100 – 2,640</td>
</tr>
</tbody>
</table>

5. Management

Indicators of any type only have a reason to exist, if they are useful in detecting variations in performance, that may be considered acceptable or not, and therefore initiate and/or support corrective actions if necessary. With this in mind, initially, the values of the indicators (annual and historical) for each CP are calculated and compared to their respective reference values. At this stage, any CP that showed indicator values above their respective reference ones must have their performance analyzed in detail.

Subsequently, all CPs selected are evaluated, through an analysis of each recorded event, aiming at the detection of possible common or repeated causes of the indicator’s overcoming the reference value. At this stage, the traffic light concept is adopted through the application of a set of classification rules. Green stands for the CPs whose performances are considered satisfactory, even though one of their indicators may have overcome a reference value. Yellow identifies those CPs that even having an unsatisfactory performance, do not require any immediate or additional remedial action, but must remain under close surveillance. Finally, red identifies those CPs with an unsatisfactory performance and which demand immediate and/or additional corrective actions.
The table below shows the final results of the evaluation process on the CPs’ performance for the year of 2006.

<table>
<thead>
<tr>
<th>CP</th>
<th>green</th>
<th>yellow</th>
<th>red</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥ 230 kV</td>
<td>197</td>
<td>14</td>
<td>11</td>
<td>222</td>
</tr>
<tr>
<td></td>
<td>(30.3%)</td>
<td>(2.2%)</td>
<td>(1.7%)</td>
<td>(34.1%)</td>
</tr>
<tr>
<td>&lt; 230 kV</td>
<td>276</td>
<td>109</td>
<td>44</td>
<td>429</td>
</tr>
<tr>
<td></td>
<td>(42.4%)</td>
<td>(16.7%)</td>
<td>(6.8%)</td>
<td>(65.9%)</td>
</tr>
<tr>
<td>TOTAL</td>
<td>473</td>
<td>123</td>
<td>55</td>
<td>651</td>
</tr>
<tr>
<td></td>
<td>(72.7%)</td>
<td>(18.9%)</td>
<td>(8.4%)</td>
<td></td>
</tr>
</tbody>
</table>

6. Other indicators

In this item, some other indicators, also applied in Brazil to evaluate the performance of the Basic Transmission Network, are presented.

The “Robustness Indicator” is obtained from the ratio between the amount of disturbances without load interruptions and the total amount of disturbances over the system in a specific time period. The results for the Basic Transmission Network, from 2001 to 2006 are shown in Figure 11.

![Figure 11 – Robustness Indicator](image)

Another performance indicator is the “Severity Indicator” (system minute) obtained from the ratio between the energy not supplied by the maximum demand of the system in a specific period. Figure 12 shows its results from 2000 to 2006.

![Figure 12 – Severity Indicator](image)
7. Conclusion

In the process of surveying and managing the continuity indicators, it can be observed that a significant improvement of the annual performance has occurred, both in DICP and FICP. For the FICP the improvement has been extremely positive, with steadily decreasing values shown: from 1.65 in 2000 reaching to 0.54 in 2007 (the exception being 2002 = 2.03 as a consequence of the blackout of 21st January). Regarding DICP, the evolution was from 2.83 to 0.49 in the same period. Such results reflect the investments made in the Basic Transmission Network, over the same time period.

According to the 2006 survey results, it can be seen that 72 % of CPs were classified as green, 19 % as yellow and 9 % as red, demonstrating a good overall performance of the Brazilian Basic Transmission Network.

The dynamics of the evolution of the electric system, as well as possible regulatory adjustments, demand permanent efforts regarding the monitoring and improvement of the management process of the Continuity Indicators.
BIBLIOGRAPHY