Indices for Assessing and Measuring Short and Sustained Interruption to Quantify Power System Performance

Le Viet Tien, Nguyen Viet Linh, Tran Dang Khoa
Department of Electrical Power System
Hanoi University of Science and Technology
Hanoi, Vietnam
tien.leviet@hust.edu.vn, nguyenvietlinh.eee@gmail.com, trankhoa.hust@gmail.com

Abstract—This paper presents the main results of a benchmarking survey for Northern Power System in Vietnam to measure the Power Quality and Reliability in regard to short and long-term interruption. The survey was conducted in 28 provinces and cities divided into four groups to compare: mountainous vs. delta areas and industrial vs. agricultural areas. The evaluation of power quality is based on reliability indices SAIFI, CAIFI as well as RMS voltage variations indices SARFI. Although the comparison of such indices was the main issue, several other issues were analyzed to assess which phenomena are most complained by customers and the customers’ solutions. The study has resulted in the collection of database for Vietnamese electrical engineers and experts to have a good picture and raise the awareness of Power Quality.

Keywords—power quality survey; short interruption; sustained interruption; SAIFI; SARFI; CAIFI; power quality solution

I. INTRODUCTION

Good Power Quality (PQ) was seen as the ability of utilities to provide a uniform constant magnitude sinusoidal fundamental frequency voltage. In the Digital Age, the increase in critical loads and electronic equipment has put our electrical network under the PQ pressure. PQ phenomena such as sags, interruptions, and harmonic distortion can cause high losses and increase the economic feasibility of industry. Therefore, it is important to evaluate such problems. For the majority of customers, short and sustained interruptions, due to their frequency and ensuing process reboots and resets, actually may be the greater issue which is easy to record. In this paper, the evaluation of PQ data will focus on the issue of interruptions through PQ indices.

To enable commercial and industrial customers to assess the reliability and quality of performance of the system network, several projects were carried out (e.g. PQ survey in Europe, EPRI DPQ Project… [1-2]), and some standards were developed for PQ performance requirements.

This world development is now being applied to the Northern Power System of Vietnam, as initiated by Vietnam Electrical Engineers Association (VEEA) in 2011 for the first time to obtain the benchmark and statistic values of PQ data at grid level. In fact, before the project was launched, PQ had not become the attractive topic of many Vietnamese electrical engineers and experts. To be more precise, there were no official papers of PQ topic from Vietnamese engineers. In addition, many Vietnam technological universities which are expert in electrical power system do not contain any course about PQ in undergraduate syllabi. Therefore, the objective of this paper is to raise PQ awareness and establish the solid base for the improvement of the regulation in electricity market of Vietnam.

II. INDICES OF LONG TERM AND SHORT TERM INTERRUPTION

A. Long-term Sustained Interruptions (Reliability Indices)

In engineering application, according to IEEE 100 [3], reliability is the probability that a device will function without failure over a specified time period or amount of usage. For customers, the term “reliability” means that uninterrupted power supplied to customers’ facilities at minimum costs [4].

Reliability statistics and indices are the primary benchmarks used to evaluate service quality as well as track the performance of the utility or a region or a system. This explains why the reports of reliability indices are required from investor-owned utilities. To illustrate, with the quantification of reliability indices, the regulatory trend will determine whether the performance is penalized or rewarded. Since there are many more short duration events where voltage has generally dropped to 0 for around 1-5 minutes, these indices are capturing the gross issues. IEEE standard 1159-1995 defined a sustained interruption as a reduction in the RMS voltage to less than 10% of nominal voltage for longer than 1 minute [5]. The occurrences of sustained interruptions mean that the processes of power restoration have been failed, so it is required for manual intervention or equipment repair.

Based on the IEEE Standard 1366-2003 [6], there are several indices are used to benchmark reliability such as SAIFI, SAIDI, and ASAI … Most countries use SAIFI, SAIDI, and CAIDI to evaluate the reliability of power system...
because they stress the operation of the worst performing circuit. In Vietnam, it is preferable to use SAIFI, SAIDI and MAIFI, and Vietnam Electricity (EVN) has the regulations, which can be seen in the table below.

<table>
<thead>
<tr>
<th>Momentary events in MV transmission (events/100 km/year)</th>
<th>Permanent events in MV transmission (events/100 km/year)</th>
<th>Permanent events in substations (events/100 units/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>3.6</td>
<td>1.8</td>
</tr>
</tbody>
</table>

In this paper, for reliability indices to quantify sustained interruptions, the authors use SAIFI and CAIFI. IEEE Standard 1366-2003 [6] defines:

SAIFI: System Average Interruption Frequency Index is the number of times during the period of analysis that the average customer sees a sustained interruption. The number is typically on the order of 2–3 for all interruptions, and 1–2 excluding major storms.

\[
SAIFI = \frac{\text{Total number of customer interruptions (sustained)}}{\text{Total number of customers served}} \tag{1}
\]

CAIFI: Customer Average Interruption Frequency Index, which is less common than SAIFI, gives the average frequency of sustained interruptions experienced by customers who had at least one interruption during the period. It is noticeable that this is a measure of “If someone was interrupted at least once, how many net interruptions have we seen?”

\[
CAIFI = \frac{\text{Total number of customer interrupted}}{\text{Number of customers who had at least one interruption}} \tag{2}
\]

If there is a large difference between CAIFI and SAIFI, it means outages are concentrated in only certain parts of the system or on certain customers. This could be due to poor design, poor maintenance, differences in the weather among areas of the system, or just plain bad luck, and further investigation will be required to determine cause and cure.

From the formula (1) and (2), note that for any one system and period

\[
SAIFI \leq CAIFI \text{ and } CAIFI \geq 1
\]

Also, the ratio SAIFI/CAIFI is the fraction of customers who experienced at least one interruption in the period.

B. RMS Variation Performance (Short-term Indices)

As mentioned above, reliability indices area applied in historical analysis to evaluate operating experience and reveal trends or patterns, expose problems, and indicate how and where reliability can be improved. They are used in predictive analysis to evaluate how well proposed solutions are likely to solve the identified problems. In fact, sustained interruptions are only one type of RMS variation.

Long before, some utilities had been required to report certain indices to regulatory agencies. The standard also defines indices quantifying momentary interruption performance, which quantifies another very important type of RMS voltage variation. Even though momentary and short interruptions, which are due to clearing of temporary faults and reclose operation, are not mentioned in the traditional reliability indices, they affect many end-user classes. Therefore, the developed RMS variation indices are designed to aid in the assessment of service quality for a specified circuit area.

In order to assess the service quality for a specified circuit area, it is the most effective to utilize the RMS variation indices, which may be applied to systems of varying sizes, from a single feeder or customer to a utility’s entire distribution system. As a result of this scalability, values can be calculated for various parts of the distribution system and compared to values calculated for the entire system. In these indices, some properties are useful to quantify such as the frequency of occurrence, the duration of disturbances, and the number of phase involved.

The susceptibility of various customer devices and processes to RMS variations differs [8]. Some devices are only susceptible to the magnitude of variation while others are easy to be influenced by both the magnitude and duration. Accordingly, there are several indices presenting assess RMS variation magnitude and the combination of magnitude and duration such as SARFI, SARFI, and SARFI, ... This paper uses SARFI (System Average RMS Frequency Index), which gives the average number of short-interruption events over the assessment period, per customer served [9]. A SARFI value is obtained by means of the following expression

For a single site:

\[
SARFI = \sum_{i=1}^{n} \frac{N_i}{N_f} \tag{3}
\]

Where \(n_i\) is the number of customers’ response, \(N_i\) is the number of customers experiencing an event (short interruption for this case) and \(N_f\) is the number of customers served from the section to be assessed.

For an entire system:

\[
SARFI = \sum_{k=1}^{N_k} \frac{N_k,SARFI_k}{N_f} \tag{4}
\]

Where \(n_k\) is the number of load locations, \(N_k\) is the number of customers served from location \(k\) and SARFI is the value for location \(k\). The calculations in this paper are based on the assumption that there is only LV demand according to customers’ reports, and the distribution of event is uniform in every node.
III. ANALYSIS AND RESULTS

This section presents the results obtained through the collection of the data gathered in questionnaire which was detailed in the other paper of the authors [9]. In other words, these results take the advance step of the afore-mentioned paper.

The values on the figures reflect the analysis of the replies to the questionnaire. Actually, these values depend primarily on data collected from the reports of customers, not real measurements.

In association with power demand ranging from 1 to 16 MVA, a total of 28 provinces and cities from four areas were considered valid for this survey study. Four areas are divided into two pairs for comparison, which are: plateaus vs. plains, and industrial vs. agricultural areas.

A. Plateaus vs. Plains

According to customers’ reports from each area, figure 1 shows the distribution of different indices being calculated, from the formula (1) – (4). As can be seen, in general, the indices of plains are higher than that of plateaus. In other words, the interruptions in plains are more frequent than in plateaus, which is mainly due to the fact that the plains have higher load density.

Compared to plains, the distribution of indices in plateaus is more uniform, clearly perceived with CAIFI. It is implied that in plateaus, when interruptions occur, most provinces and cities will be interrupted simultaneously while the interruptions in the plains are less concurrent. In other words, the spread of interruptions in the mountainous areas is more severe. This is explained that for many big cities, especially areas which have a large number of essential loads, the continuous energy distribution is prior.

Another noteworthy feature is that the gaps between CAIFI and SAIFI of plains are overall huger in comparison with plateaus. The wider these gaps are, the lower the percentages of customers who experienced at least one sustained interruption are. This reflects on the fact that the grids of mountainous regions are older, so with high probability, long interruptions occur many times at the same node.

B. Agricultural vs. Industrial Areas

The next figure illustrates the comparison between agricultural and industrial areas. The values of indices are shown in a general perspective based on the average answers.

![Figure 1. The values of indices: Plateaus vs. Plains](image1)

![Figure 2. The values of indices: Agricultural vs. Industrial areas](image2)
Taking into account the answers provided, there are several remarks below.

Overall, for all groups, both the values of SARFI and SAIFI fluctuate between 0 and 1. However, SARFI is generally greater than SAIFI, meaning that short interruption is the dominant event. To be more precise, short interruption occurs in all surveyed provinces and cities while some places did not report any sustained interruption.

CAIFI of industrial areas is remarkably greater than CAIFI of agrarian areas while the values of SAIFI for both regions are approximate. This means that industrial areas have lower probability of long interruptions occurring many times at the same node although both areas may be supplied by the same networks. In this case, the main reason is that since a large number of essential loads concentrate on industrial areas, it is strictly required to clear any faults on power systems as perfect as possible rather than farming regions.

In addition, for the reasons of larger load density, the SARFI values of industrial zones are slightly higher, which means short interruptions somewhat occur more than agricultural areas.

C. Customers’ Solutions when PQ Disturbances Occur

The graph below describes the proportion of load in each area covered by different types of redundant or mitigatory solutions.

On average, backup generators, which prove to be most effective in case of long interruptions, are the most preferable solutions. Industrial areas have the highest frequency of different PQ solutions.

In plateaus, there are a large number of “no solution” reports because of the lack of electrical equipment and PQ experts. Compared to farming regions, for the reason of maximum reliability in the toughest applications including manufacturing, machining, or automation processing, voltage stabilizers account for significant proportion in the industrial areas. In those cases where the backup supply is unnecessary, such stabilizers perform higher efficiency in electrical and superior protection than UPS (uninterruptible power supply).

D. Customer’s Complaints about Quality Services

In the survey, for the evaluation of Quality Services, the customers were also asked to report which PQ problems were mostly complained. The average answers to this question are on the figure 4.

Based on the graph, it is obvious that most customers did not complain about PQ problems, meaning that they were satisfied with the Quality Services. Additionally, as explained above, both short and sustained interruptions are the most complained events. Noteworthy is the fact that customers also much complained about voltage sags and swells in industrial and agriculture areas.

IV. CONCLUSIONS

This paper presents a method of evaluation a power system performance through different indices. According to the information collected, and as already shown by the analysis carried out, this approach is simple and easy to become widely used in different sites and systems because these indices depend only on the number of events.
However, for such indices, all information of time and duration is lost, hence there is no incentive to reduce fault-clearing times. For SARFI with the formulas (3) and (4), the use of the system average makes it less appropriate as a system index than as a site index. The use of SAIFI and CAIFI is under the assumption that all customers are the same size, which represents a theoretical interpretation of interruption probability for the system. Accordingly, the use of such indices may not be accurate when some deeper analysis is required.

This pioneer and innovative study allowed to have a picture on the problematic of PQ disturbances and showed that there is still a considerable amount of pressure to do in terms of mitigation technology dissemination in national power system in Vietnam.

REFERENCES


