CONSIDERATIONS FOR SELECTING CRITERIA FOR SAG QUALITY CLASSIFICATION AND STANDARD

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ABSTRACT

Good understanding of voltage sag characteristics can help all parties to solve the problems of this type of voltage variation. There is a clear need to confine and facilitate the electricity market by dictating standards and performance classification methods.

This research introduces principal guidance for establishing a sag evaluation, classification and standard. The reliability data are used in a voltage sag simulation to quantify and classify sags in different points in the network. A computation method, which includes short circuit analysis, is developed and used for modelling the network. The proposed method is applied on a large part of the distribution network in the city of Alexandria, the sag frequency per year is determined.

A voltage sag table is constructed which comprises types of sags and responsibility regions. A framework for voltage sag quality standard is presented.

The sag costs are determined from the number and type of installed equipment, voltage tolerance of those types of equipment and cost caused by equipment malfunction due to sags.

The sag cost table includes all types of the data required for determining the average cost per sag type per occurrence for a certain group of customers. This is considered the basic guidance used in constructing the sag criterion.

INTRODUCTION

Power quality is known to be as much an economical issue as a technical challenge. Voltage sag is one of the most prevailing power quality ailments known to cause wide-ranging disruptions with high economic losses. This is because many electrical loads are now incorporated with electronic devices that are highly vulnerable to voltage sags. Computers and all kinds of electronic controls and equipments are highly susceptible to fail or maloperate when subjected to such brief reduction in the voltage magnitude. In addition, modern industries rely much more on these automated equipments than ever before, and disruption to a single device may cause a cascading failure to the entire manufacturing process.

Every consumer is subjected to a voltage sag occurrence since faults cannot be totally avoided. In fact, the greatest losses will fall upon customers having sensitive equipment as PLCs (Programmable Logic Controllers) and ASDs (Adjustable Speed Drives).

Some of the voltage sag effects on such equipment are:

- PLCs malfunction, causing industrial process totally or partially shutdown.
- ASDs disconnection with consequent shutdown and production losses.
- Contactors and auxiliary relays dropout.
- Unexpected tripping of under voltage relays.

Although there are measures to mitigate against voltage sags, but they can be costly and in many cases, it has been difficult to justify their investments.

It is therefore imperative to evaluate the economic costs of such disruptions so that their severity can be fully comprehended and correction measures are justified.

The cost of a disturbance involves losses from lost production, idle labor and in certain cases damaged equipment. IEEE 1346-1998 provides some guidelines on how to calculate the cost incurred by such a disturbance. It stipulates the need to include the participation of management as well as financial, operational, maintenance and sales staffs to determine this cost. The potential economic cost needs to be carefully assessed in order to create a business case to the stakeholder, which can be different for different industries.

Voltage sags of different magnitudes affect devices to different degrees.

Voltage sag analysis is a very complex issue, since it involves a large variety of random factors, such as:

- Type of short circuits – three-phase faults are responsible for larger voltage sag magnitudes than single line-to-ground faults, although these ones are more frequent.
- Location of faults – transmission system faults are much more severe than distribution system ones, as a short circuit in a transmission grid is supposed to affect a larger area than in a distribution system.
- Protective system performance – the duration of voltage sag is directly related to the protective system performance i.e. the clearing times.

Studies for assessing effects of voltage sags on customers have gradually increased. These efforts are primarily divided into practical and theoretical approaches.

The practical approaches investigate the effects by monitoring customers, conducting experiments on customers' sensitive loads, and performing pertinent surveys. The theoretical approaches deal with methods to predict magnitudes, duration and frequency of voltage sags.

COMPUTATION PRINCIPLES

To obtain a better picture of power quality performance, Alexandria Electricity Distribution Company (AEDC) has initiated a research project to quantify and classify voltage sags.

The magnitude and duration of voltage sags are determined by fault simulation method in the distribution system of AEDC.

Voltage sag is commonly described by two essential characteristics, namely sag magnitude and sag duration. Therefore, analysis and assessment of voltage sag necessarily require the knowledge of the voltage sag characteristics, the statistical information of voltage sag occurrence, and the information of the sensitivity of important loads within the facility.

In AEDC, there is a large amount of reliability data for components available from the fault-monitoring program. The reliability data can be used in a voltage sag simulation to calculate the expected frequency, depth and duration of sags at various locations in the network.

The computation method was applied to a large part of the medium voltage distribution network in Alexandria City. This distribution network is connected to the 66 kV transmission grid by four transformers, 66/11 kV, 25 MVA each.

The HV side of each transformer is wye connected, with the neutral solidly grounded. The MV side is wye connected, with the connection to ground through an impedance that limits the available line to ground fault current to 500 ampere or less. From the substation, main feeders are extended to ten distribution points. Each distribution point has six to eight outgoing circuits. Each circuit feeds eight to ten distribution transformers that are ranging in size from 300 to 1000 KVA and convert the MV to 380/220 volt.

Medium voltage cables are aluminum conductor, XLPE, armored, solid dielectric of sizes 240 mm^2 and 400 mm^2.

The network is modelled using a developed software which offers a complete short-circuit analysis. The probability of the types of faults was taken as:

- Single phase to ground faults 60% probability.
- Two phase to ground faults 20% probability.
- Three phase faults 20% probability.

To compute the annual number of voltage sag events, failure rates are calculated for all cables and bus bars. The total number of failure events is calculated by adding the failure rates of all cables and bus bars in the network.

Voltage sag appears on the equipment terminal as long as the protection equipment allows fault current to flow.

The duration of the events depends on the protection setting. In the modelled network, over current protection relays were used exclusively. Typically, the total clearing time can be determined by adding the circuit breaker clearing time (3-5 cycles) to the relay operating time. The relay operating time depends on its time/current characteristic curve.

All events are recorded in a voltage sag table. The sag frequency is equal to the failure rate of the short-circuit event.

The resulting voltage sags at the substation bus bar are shown in table 1. We can also present these figures in the form of a 3D-plot (Fig. 1)

TABLE 1- Sag frequency in number per year for substation bus.

Sag depth	Sag duration in seconds				
(%)	0.0 < 0.2	0.2 < 0.4	0.4 < 0.6	0.6 < 0.8	≥ 0.8
10-20	0	0	0	0	0
20-30	0	0.18	0	0	0
30-40	0	0	0	0	0
40-50	0	0	0	0.05	0
50-60	0	0.283	0	0.897	0
60-70	0	0.044	0	0.306	0
70-80	0	0.2	0.1	0.55	0
80-90	0.15	0.7	0	0.5	0

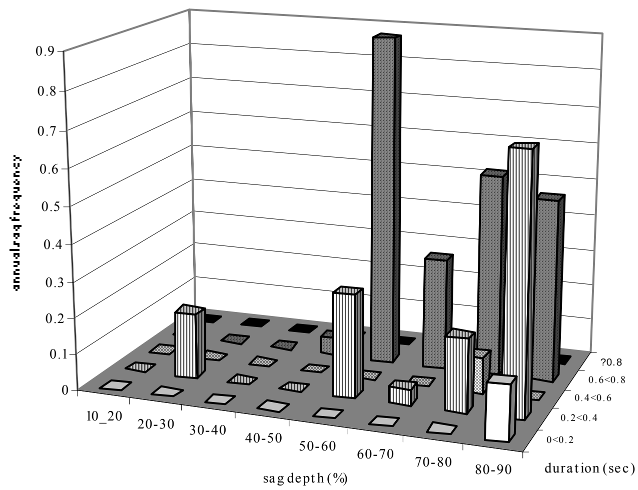

Fig. 1 Sag profile for substation bus.

An estimated sag frequency of 3.96 sags/year was obtained. This is in good agreement with the data measured through the large-scale power quality monitoring program which showed an average of 4.3 sags/year.

PROPOSED CLASSIFICATION OF SAGS

The organizational changes occurred in the electric sector in the majority of the countries around the world have modified many technical and economic approaches in relation to such sector. This is especially true when it comes to service quality.

Because the economic optimum for network companies in most countries differs considerably from the socio-economic optimum, there is a clear need to confine and facilitate the electricity market by dictating standards and performance classification methods.

Different types of faults will result in different characteristics of voltages during the disturbance.

The voltage characteristics will depend on the fault type, the system characteristics between the fault and the measurement location (especially transformer connections), and other factors such as load characteristics and unbalances in the system impedances.
In developing rules for classifying different types of voltage sags, tolerances must be applied to account for the unbalances that can be introduced by the system and fault characteristics.

Evaluation indices

Generally, the sensitivity of the equipment to voltage sags can be expressed by the tolerance curve. Two popular equipment tolerance curves - namely the Information Technology Industry Council (ITIC) curve and the SEMI F47 curve – are shown in Fig. 2. Each point on the curve indicates how long this piece of equipment is able to ride through certain voltage sags. The first curve, ITIC curve, was formerly called the Computer and Business Equipment Manufacturer Association (CBEMA) curve. It represents the voltage variation tolerance requirements of information technology equipment as defined by the Information Technology Industry Council. On the other hand, the second curve specifies the voltage sag immunity of semiconductor manufacturing equipment. It is widely used by semiconductor vendors in evaluating their needs for protection against voltage sags. As these curves are characterized by the sag magnitude and duration, a proper representation of the system performance in terms of these parameters is needed in order to evaluate the consequences of voltage sags. It is therefore necessary for the voltage sag performance presentation format to commensurate with that of the equipment's voltage sag immunity specifications.

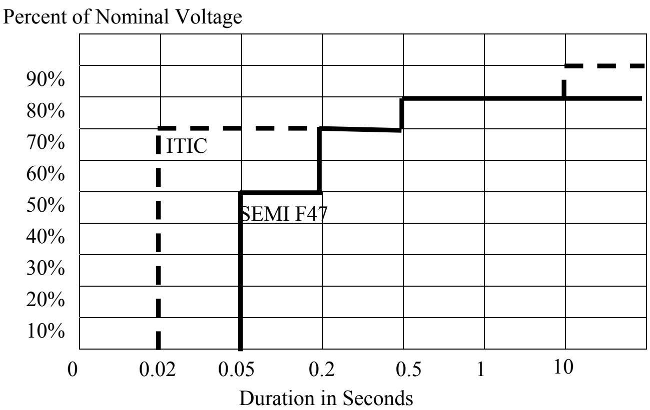

Fig. 2 Example of tolerance curves.

Generalized indices are customarily used to describe the performance of power-supply systems.
Similarly for voltage sags, indices such as system average rms variation frequency Index ($SARFI_X$) and its subsets of system instantaneous average rms variation frequency Index ($SIARFI_X$), system momentary average rms variation frequency Index ($SMARFI_X$), and system temporary average rms variation frequency Index ($STARFI_X$) are the frequently used indices. The subscript "x" denotes the range of voltage sag magnitude to be considered when computing the respective indices. These indices are useful to give a general impression of the supply voltage sag performance. However, as voltage sags are characterized by magnitude as well as duration, for a more accurate assessment, other more specific ways of presentation are needed.
A straightforward way for quantifying the number of voltage sag events is through a table with magnitude and duration ranges.

Generalized sag table

The sag density table can be obtained through monitoring or some form of stochastic estimation. From monitoring, almost all the characteristics can be captured and their statistics can be readily obtained. The same data can also be obtained through computer modelling and simulation of the fault events, considering the action of protective relays and the behavior of generators, motors and other loads. With sufficient details, all the characteristics and corresponding statistics can also be realized.
A simple, efficient and consistent method that can be used for classification and representation of voltage sags is proposed.
The method uses the "magnitude / duration" approach. This performance summary may provide useful information about the voltage quality for comparison of different locations and systems.
Table 2 illustrates the proposed presentation of sag performance, termed as the "generalized sag table". Columns are divided into four ranges, rows are divided into three groups. Intersections of columns and rows then determine cells or sag types (ST).
Group I represents the area where the responsibility for preventing damage due to these sags is with the equipment manufactures. Group II represents the area where a balance has to be found between the customer's willingness to pay for quality or mitigating equipment, network investment costs, possibilities for risk financing, etc. Group III represents the area where the equipment cannot be expected to ride-through. It is the responsibility of the utility to minimize the number of these sags.

TABLE 2- Sag types table.

Group	Magnitude%	Duration (seconds)			
		0-0.05	0.05-1	1-10	10-60
I	70-90	ST_{11}	ST_{12}	ST_{13}	ST_{14}
II	50-70	ST_{21}	ST_{22}	ST_{23}	ST_{24}
III	10-50	ST_{31}	ST_{32}	ST_{33}	ST_{34}

SAG STANDARD

The method used for the sag standard is by defining limits for the average occurrence per each sag type per year.
Table 3 shows an example of a proposed sag criterion based on data gained by AEDC distribution power quality project over a period of 10 years.

TABLE 3- A proposed sag criterion table.

	0-0.05 s	0.05-1 s	1-10 s	10-60 s
70-90%	-	-	8	6
50-70%	5	2	1	0.5
10-50%	1	0.8	0.7	0.3

As shown in table 3, it is not possible to define limits for sag types ST_{11}, ST_{12}.
Assessing the economic value of voltage sags for distribution companies is not a simple task.
The economic assessment of voltage sag requires information about the consequences of expected voltage sags on the performance of industrial processes.
In order to determine whether the equipment will trip/malfunction or ride-through the sag of specified magnitude and duration, expected voltage sags are compared with the sensitivity of process equipment connected at a given bus. This procedure requires preparing a sag performance chart for a particular bus in the system and coordination of the customer's equipment responses with these voltage sags on a single graphic display. For this purpose, the precise information about the equipment sensitivity is required for the accurate quantification of their nuisance trips due to voltage sags.
The cost data have to be aggregated in a way that allows a quick determination of the expected cost per year for any customer from a particular customer group.
The sag cost table fulfils all these requirements. It combines all kinds of data to calculate an average cost per sag type per occurrence, for each particular customer group.
Table 4 shows an example of the sag cost table based on rough estimates in (LE) carried out by combining information provided by the customers from different categories.

TABLE 4- An example of a sag cost table.

	0-0.05 s	0.05-1 s	1-10 s	10-60 s
70-90%	-	-	7	16
50-70%	38	50	75	130
10-50%	600	800	1000	1600

The sag cost table is the principal guiding data to be used in establishing the sag criterion. The higher the sag costs, the lower the acceptable number of sags per year should be.
The maximum acceptable costs per year due to voltage sags are obtained from the multiplication of the number of sags from the sag criterion table by the corresponding sag costs from the sag cost table. This is called the sag performance index (SPI). A voltage sag standard table could then be constructed which includes the individual SPIs.

CONCLUSION

Power quality can be evaluated only through mutual interactions between the power supply system and equipment connected to it. Accordingly, power quality assessment procedure should include both the information about the power supply system performance and the information about the equipment sensitivity. Furthermore, these two sets of information should be expressed and represented in such a way that they can be easily compared. Without this direct comparison, precise assessment of costs associated with power quality disturbances (economic evaluation) and need for power conditioning simply cannot be determined.
This paper presents a method for characterizing and presenting system voltage sag performance data.
The classification method presented is validated against sag data measured/recorded in actual power systems and against data obtained in computer simulations. It is shown how expected number of voltage sags can be calculated and simply presented (with inclusion of fault rate statistics).
The sag standard and the sag classification are targeted towards the network utilities. They should try to reduce the amount and the severity of the voltage sags. The customer on the other hand remains responsible for managing his sag coordination process.

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