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POWER SUPPLY INTERRUPTIONS MODELING

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Problemele şi daunele provocate consumatorilor datorită condițiilor de tensiune necorespunzătoare, a nesimetriilor de curent electric, a fenomenelor tranzitorii, a distorsiunilor armonice, a valorilor necorespunzătoare ale factorilor de putere, a golurilor şi întreruperilor de scurtă durată se regăsesc în costuri suplimentare substanțiale, in pierderile de producție şi materii prime, repornirea mijloacelor de producție, produse neconforme calitativ şi în întârzieri ale termenelor de livrare. La acestea se adaugă costurile necesare unei mentenanțe preventive suplimentare, necesare atingerii unor standarde înalte de performanță. Există, de asemenea, o tendință de a transfera responsabilitatea serviciilor de mentenanță dinspre mediul industrial către producătorii de echipamente. Măsurarea parametrilor de calitatea a energiei electrice este un instrument de lucru indispensabil în cadrul acțiunilor de mentenanță corectivă. Funcționări defectuoase ale unor echipamente sau instalații pot apărea fie datorită ignorării sau subestimării în faza de proiectare a unor abateri de la calitatea energiei fie datorită unor modificări ale instalațiilor. Cunoaşterea parametrilor de calitate a energiei electrice este utilă întocmirii planurilor de mentenanță preventivă, contribuind la reducerea costurilor de funcționare şi la o ameliorare a controlului acestor perturbații.

The problems and the damages caused to the customers owing the inadequate voltage conditions, current unbalances, transitory phenomenon's, harmonics distortions, inadequate values of power factors, dips and short time interruptions are founds in the substantial additional costs, in productions wastages and raw materials, restarting of equipments, low quality products and the delays of delivery terms. At all these things are added the additional preventive maintenance costs, necessaries for the high performance standards. There is, also, the trend to transfer the responsibilities of the maintenance services from the industrial environment to the equipments producers. The measurement of power quality parameters is an indispensable instrument for corective maintenance actions. The malfunctions of the equipments or installations can appear due to the discarding or underestimating in the designing phase of some departures form the power quality, or to some modifications of installations. The knowledge of the power quality parameters is very useful in the drawing up of preventive maintenance programs, contributing in this way to the reducing of operational costs and to the control amelioration of these perturbations.

Keywords: consumption center, customer, distribution operator, power supplier

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1. Introduction

The necessity to increase the competitivity, the large utilization of some equipments that are sensitives to the voltage perturbations or that generate harmonics, the opening of the energy market made from „power quality" a strategic subject from the point of view of the operation, maintenance and the management of the industrial and services sector, and equipments producers.

The most important probleme which preoccupy the distribution operator is the power supply assurance at the acceptable levels of continuity and quality. [1] Because an uninterruptible power supply is not feasible nor economically, nor technically, is accepted, into the exploitation agreement between customer and the distribution operator, a number of short and long time interruptions.

The continuity of power supply is illustrated by the following parameters [5]:

- Interruption time:

$$\Delta t_i = t_f - t_i \ , \quad [\text{s}] \tag{1}$$

where t_f is the moment of power supply return; t_i - power supply interruption moment;

- interruption frequency:

$$f_a = \frac{N_i}{T_r} \ , \tag{2}$$

where N_i is the number of interruption; T_r -reference time.

- the percentage or relative amplitude:

$$\varepsilon_g[\%] = \frac{\Delta U_g}{U_c} \cdot 100[\%] = \frac{U_c - U}{U_c} \cdot 100[\%] \ , \tag{3}$$

where U is the phase voltage residual value, and U_c – contracted phase voltage.

It must be specified that the interruption time is perceived in different ways by distribution operator and the user, bearing in mind that the moment of power supply reinstating on the busbar (value taken into account by the distribution operator) doesn't correspond with the production continuing at the parameters existents before the interruption (which is in fact interesting for the user). Between the two ways to identify the interruption time there are, usually, the important differences.

According to voltages interruption time, it can be done the following clasification of the events (IEEE-1159-95) (fig. 1):

-short time interruptions: instantaneous (0,5 periods- 3 seconds) and temporal (3 seconds-1 minut)

-long time interruptions, having a duration superior than 1 minute.

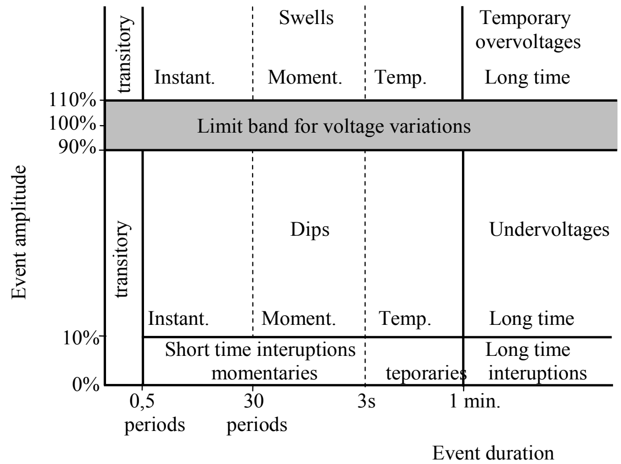

Fig. 1 – Events classifying according to IEEE 1159-1995 Standard.

Considering the scheduling as classifying criteria, the interruptions ca be:
-scheduled, the customers are announced before doing any programmed actions into the distribution network;
-accidentals, caused by the permanents or temporary faults, generally produced by external events, equipments faults etc.

The interruption indicators (performance indicators regarding the service reliability), are defined relative to the frequency, to the interruption time or simultaneously.

According to the interpretation way of the power supply interruption it can be define:

-indicators for power supply system;

-indicators for the customer supplying.

The difference between the power supply system indicators and the customer supplying indicators consist in the fact that all the reports are made relative to the number of the customer (interrupted, deserved or affected) in comparison with the system indicators which are made relative to the number of the incidents.

2. The dips and the short time interruptions origins

The main causes of the dips and short time interruptions are retrieved in the phenomena which determine the apparition of fault currents. These currents cause voltage drops in the electrical network, whose amplitudes decrease proportional to the distance to perturbation source.

A dip can be the connection result of some electrical motors [2] [8], having big starting currents, or of the clearing of some faults, appeared in the electrical network, by the relay protections and automations [7]. In the last situation the dip time is equal with the operation time of the protection.

The short time interruptions are, generally, the results of the clearing of the network faults by the reclosers or ARC (automatic closing of the reserve), the customers being submits of a dips and/or short time interruptions succession, caused by the existence of an intermittent arc, followed by automatically reclosing in order to clear all semi permanent and transitory faults [3].

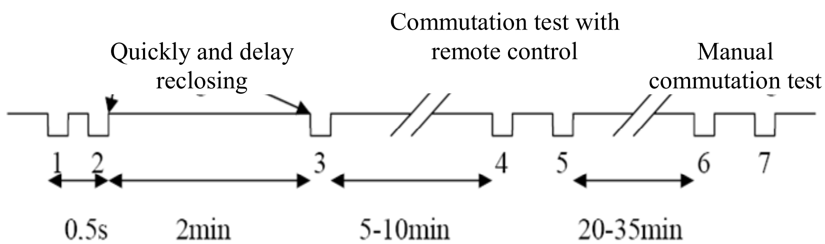

Fig. 2– The dips succesion.

The long time interruptions are the results of the definitive insulation of a permanent fault outcome of the relay protections working, being necessaries reparations or replacing of some components before energizing. Those are determinates, specially, by an inadequate configurations of network power supply, by the low performances of the equipments, as well by the inexistence of some specific maintenance procedure of the installations.

3. The dips distribution

The characterization of a power system from the dips point of view can be made by the determination of a dips distribution [4]. For a low voltage customer, the evaluation of dips distribution can be made indentifying the network areas in which the fault appears: the transport systems, medium voltage distribution systems and low voltage distribution networks.

The recorded dips by a customer can be describes by a distribution cumulative function:

$$F(u,t)_k = \sum_i^n \sum_{ft} \left(\lambda_{i,ft} / u_k \le u, \Delta t_{i,ft} > t\right) , \tag{4}$$

Where $\lambda_{i,ft}$ the frequency of a *ft* type fault in the *i* position; u_k – the voltage drop recorded at a low voltage customer, in the node *k* node, $\Delta t_{i,ft}$ – the dip time caused by the *ft* fault in the *i* position.

Because of the different characteristics of a dip according to fault type which induce them, is necessary to determine the frequency of each type of fault.

The λ_i faults frequency, in a certain point of a network can be the results of faults such as: single-phase, bi phase, tri phase, with or without earthing. Thus, the calculus relation is:

$$\lambda_i = \sum_{ft} \lambda_{i,ft} = \sum_{ft} \frac{p_{i,ft}}{100} \cdot \lambda_i \quad (5)$$

,

Where $p_{i,ft}$ is the frequency of a ft type fault. The $p_{i,ft}$ parameter satisfies the follows relations:

$$0 \le p_{i,ft} \le 100\% ;$$

$$\sum_{ft} p_{i,ft} = 100\% . \quad (6)$$

4. Case study: The evaluation of the power supply interruptions costs for an industrial platform

The analyse make reference to an industrial platform, by a 110/20 kV station, supplied by two 110 kV lines.

Each line is connected to a 110/20 kV transformer block, with the following main characteristics:

- the nominal power S_{nt} = 20 MVA;
- the primary nominal voltage U_{np} = 120 kV ± 10 × 1,25%;
- the secondary nominal voltage U_{ns} = 20 kV;
- the primary nominal curent I_{np} = 96,2 A;
- the secondary nominal curent I_{ns} = 577,4 A;
- the short-circuit voltage u_{sc} = 8%;
- windings configuration YNyn0 (d).

The both transformers HT/MT supply the 20 kV bus bar, sectional, each transformer, supplying, in the normal configuration, one of the two sections. In the normal working both sections are independents.

On industrial platform, choose as the study case object there are three factories: plane glass factories (float line), whose consumption centers are represented by the 20/0.4 kV substations (positions 1-12 from table 1) and that are dedicated to supply the mains sections of the lines, coater line (positions 13 and 14 from the table 1) and the industrial gases factory (nitrogen and hydrogen).

The main consumption centers from the 20 kV QMT interconnections station, who's unifilar is presented in the figure no. 1, are presented in Table 2.

The 20 kV distribution centers is composed from for sections, two sections are principals (A1 and A2 are secondary (B1 and B2), separated in the normal working by the coupling breaker ICMTA1A2.

Table 2

The mains consumption centers of the industrial platform

No.	Consumer	Power [kW]
1	Transformer 1 composition (TBA 1)	310
2	Transformer 2 composition (TBA 2)	200
3	Transformer 1 furnace (TBT1)	130
4	Transformer 2 furnace (TBT2)	140
5	Transformer 1 float –annealing lehr heating up(TCT1)	650
6	Transformer 2 float–annealing lehr heating up (TCT2)	570
7	Transformer 1 float area(XBT1)	150
8	Transformer2 float area (XBT 2)	170
9	Transformer 1 warehouse and cutting line (MBT1)	320
10	Transformer 2 warehouse and cutting line (MBT2)	100
11	Transformer 1 utilities (SBT1)	360
12	Transformer 2 utilities (SBT2)	145
13	Transformer 1 coater factory (COT1)	850
14	Transformer 2 coater factory (COT2)	1100
15	Industrial gases factory (FG)	3700

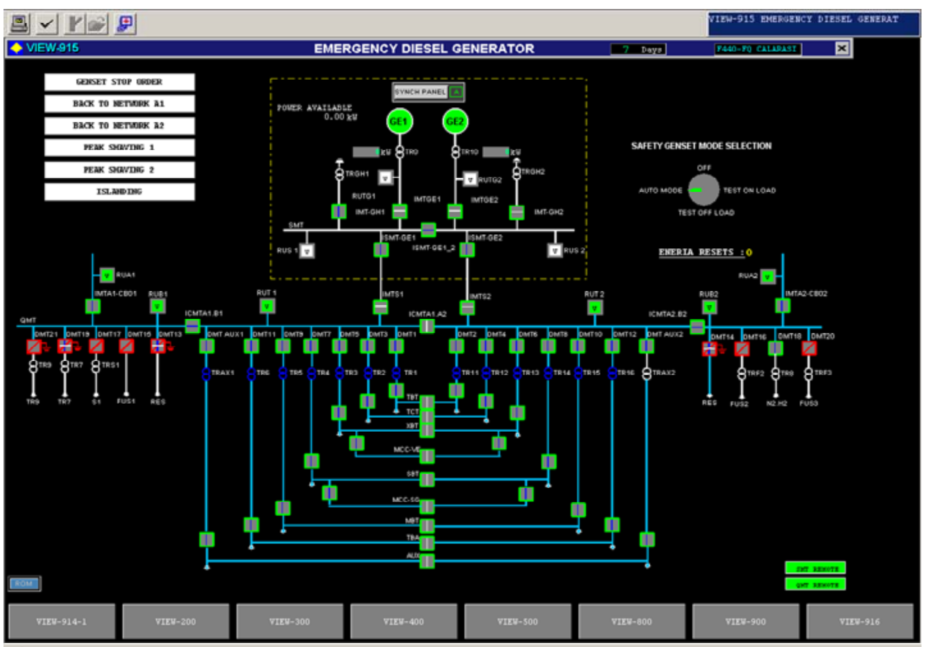

Fig. 1 – The single line diagram of the 20 kV connections stations

Each consumption center is supply by two transformers 20/0,4 kV, which are working simultaneously all the time and who are supplies from the each of the branches thus creates:

- the branch 1: sections A1 and B1;
- the branch 2: sections A2 and B2;

An exception from the presented supplying rule is the industrial gases factory who is supply by a single transformer 20/0.6 kV.

The power supply interruptions during the 2008 year are considered:

- a scheduled interruption, designed to the emergency power supply system testing, having as effect the total interruption of power supply for 15 minutes. Restarting the technological process of the industrial gases factory is made after 20 minutes from the voltage restoration, the total interruption time being 35 minutes.

- the accidentals interruptions were caused by working of some protections, as follow of the transitory events. Table 3 shows the accidentals interruptions distribution and the average time of each interruption:

Tabelul 3

The accidentals distribution during one year

Post	TBA1	TBA2	TBT1	TBT2	TCT1	TCT2	XBT1	XBT2
Nr.Int.	2	3	2	3	2	3	2	3
Durata medie [min]	15	15	15	15	15	15	15	15
Post	MBT1	MBT2	SBT1	SBT2	COT1	COT2	FGI	MBT1
Nr.Int.	3	3	2	3	2	3	8	3
Durata medie [min]	15	15	15	15	15	15	20	15

With the aid of calculus relations for the SAIFI, SAIDI, ENS and AIT are obtained the values from table 4.

Table 4

The interruptions indicators for one year

Consumption centers	Consu su- mers No.	Interrup- tion num- ber	Power [kW]	SAIDI Min/year	SAIFI	ENS [kWh]	AIT [min/year]	Undelivered energy cost [euro/year]
TBT A	1	3	130	64	4	97,5	152,0455	5,655
TCT A	1	3	650	64	4	487,5	152,0455	28,275
SBT A	1	3	360	64	4	180	152,0455	10,44
XBT A	1	3	150	64	4	75	152,0455	4,35
MBT A	1	4	320	64	4	240	152,0455	13,92
TBA	1	3	310	64	4	155	152,0455	8,99
COT 1	1	3	800	64	4	400	152,0455	23,2
TBT B	1	4	140	64	4	70	152,0455	4,06
TCT B	1	4	570	64	4	285	152,0455	16,53
SBT B	1	4	145	64	4	72,5	152,0455	4,205
XBT B	1	4	170	64	4	85	152,0455	4,93
MBT B	1	5	100	64	4	50	152,0455	2,9
TBA	1	4	200	64	4	100	152,0455	5,8
COT2	1	4	1100	64	4	550	152,0455	31,9
FG	1	9	3700	64	4	12309,9	152,0455	713,9742

For the calculus of the indicators presented in the table 3 were taken into account the following aspects:

The electrical energy that was spent during the analyzed period was 52397 MWh; all the interruptions were happened in the normal working conditions (table 2).

With the exception of the situations when the interruptions have affected only the industrial gases factory, consequence of the protection functioning, the others interruptions were affected simultaneously all the consumers supplied from the same branch, conducing to stopping of float, coater and industrial gases factories productions.

The restoration of the normal functioning and the productions interruptions costs during power supply interruptions are indicated in table 5.

Table 5

Financials loses caused by the production interruptions

Factory	The normal functioning reestablishing time [hours]	The total time of the production interruption [hours/year]	The production loses costs [euro/hour]	The total cost of the production interruption [euro]
Float line	0,75	7	8350	58450
Coater line	3	18	1500	27000
The industrial gases factory	1	12	1200	14400

Observations:

The evaluation of the interruptions indicators was based on the recordings made during the 2008 year;

The undelivered electrical energy cost during the interruptions (the loses of the power supplier) were calculate at the average price of the electrical energy on the 2008 year, being 58 euro/MWh;

The calculation of the production loses costs were based on the averages prices of final products, specifics for each of the three factories on the 2008 year;

The reestablishing time of the functioning nominal parameters has a statistic character, based on the experience accumulated in each of the situations.

It can be observed that the interruptions productions damages, which are the consumers' damages, are substantially greater than the loss of the power supplier, consequence of the undelivered energy.

5. Conclusions

Given that electricity supply interruptions cause damage both directly and indirectly, their proper evaluation requires a detailed knowledge of energy consumer behavior, and is a prerequisite in the adoption of appropriate measure to mitigate them [9], [10] and [11].

The competitive increasing necessity, the largely using of some equipments which are sensitive at the voltage perturbations or generate perturbation, the market opening made from "the power quality" a strategic subject from the operation, maintenance and management of industrial sector but also from the equipments producers point of view.

The problems and the damages caused to the consumers because of the inadequate voltage conditions, dips and short and long time interruptions determine substantial additional costs. The costs of those perturbations are retrieved in the raw materials and a production loses the restarting of production means, inaccurate products from the quality point of view and the delivery time delays. At all this, it can be added the additional preventive maintenance costs, necessaries to approach a high performance standards.

The short and long time power supply interruptions quantifications on interruptions indicator allow the realization of some comparative analyses, indented to illustrate the real significance of a such as power quality problems for a production flow.

Annexe

For a dips complete characterizations on the reference duration, presently, according the SR – EN 50160 recommendations, it operates with the amplitude-time matrix [6] (table 1)

Table 1

The monitoring matrix of dips and voltage interruptions

Duration Δt_g (s) / U/U_c	0,01 … 0,02	0,02 … 0,1	0,1 … 0,5	0,5 … 1,0	1…3	3…20	20 … 60	60 … 180
> 1,1								
1,1… 0,9	t_{real}/T_r							
0,9… 0,85								
0,85… 0,7								
0,7… 0,4								
0,4… 0,1								
0,0								

A.1. Indicators for the power supply system

For the short and long time interruptions characterization from the distribution operator are used the folowing indicators:

SAIFI (*System average interruption frequency index*) – it indicate the interruption medium number into the electrical network per year.

$$SAIFI = \frac{\sum_{i=1}^{n} N_i}{N_c}[\text{interruption/customer}] \qquad (7)$$

Where N_i is the number of all the customer interrupted for more than 1 minute in *i* interruption;

N_c – the total customer number; n – total interruptions number.

SAIDI (*System average interruption duration index*) – it indicate the medium time of an interruption for the customer serviced by the DO

$$SAIDI = \frac{\sum_{i=1}^{n}(N_i \cdot D_i)}{N_c}[\text{ system minute/customer}] \qquad (8)$$

Where D_i are the inerruption times (minutes), in the *i* interruption.

ASAI (*Average service availability index*) – it is defined as the ratio between the total number of customer hours how the distribution service was available and the total number of customer hours how the distribution service was required. The total number of customer hours how the service was required it's obtained by multiplying of yaerly medium number of serviced customers by the DO by 8760.

It can be calculated with the relation:

$$ASAI = \frac{AD - ENS}{AD} = \frac{8760 - \frac{SAIDI}{60}}{8760} \qquad (9)$$

Where *ENS* is undelivery energy because of the power supply interruptions [MWh/yaer]; AD – the actual yearly consumption of electrical energy for the energetical system- without the own technological consumption [MWh/year].

ASUI (*Average service unavailability index*)

$$ASUI = \frac{ENS}{AD} = \frac{\frac{SAIDI}{60}}{8760} = 1 - ASAI \qquad (10)$$

ASIFI (*Average system interruption frequency index*)

$$ASIFI = \frac{\sum_{i=1}^{n} S_i}{S_t} \qquad (11)$$

Where S_i is the interrupted power at the *i* interruption [kVA]; S_t – the total power in function (instaled, conected) [kVA].

ASIDI (*Average system interruption duration index*)

$$ASIDI = \frac{\sum_{i=1}^{n} S_i \cdot D_i}{S_t}[\min] \quad (12)$$

A.2. Indicator at the customer level

CAIFI (*Customer average interruption frequency index*) – it show the average number of interruptions/interupted customs during one year. It can determined from the relation:

$$CAIFI = \frac{\sum_{i=1}^{n} N_i}{N_{ca}}[\text{interruptions/afected customers}] \quad (13)$$

Where the N_{ca} represent the total number of the afected customers during the analyzed periode.

CAIDI (*Customer average interruption duration index*) – it alow the evaluation of the power supply inerruption average duration during one year.

$$CAIDI = \frac{\sum_{i=1}^{n}(N_i \cdot D_i)}{\sum_{i=1}^{n} N_i} = \frac{SAIDI}{SAIFI}[\text{minutes/interrupted customers}] \quad (14)$$

MAIFI (*Momentary average interruption frequency index*):

$$MAIFI = \frac{\sum_{m=1}^{M} N_m}{N_t} \quad (15)$$

Where *M* is the total number of the short time incidents(momentary);N_m – the number of the customers interrupted for short time (under 1 minute), at each interruption *m;* N_t –
the total number of the customers supplyed from the analyzed electrical network.

UNIPEDE recomand the folowing indicators, for the power supply service quality, analyzing from the undelivery energy point of view to the customer because of the inerruptions:

AIT (*Average Interruption Time*) is a performence parameter, defind from the voltage disparitiy to the re-establishment, wich it calculated with the relation:

$$AIT = 8760 \cdot 60 \cdot \frac{ENS}{AD}[\text{minutes/year}] \quad (16)$$

Where *ENS* is the undelivered energy because of power supply interruptions [MWh/yea]; AD – actually yearly consumption for the energetical system-without the own technological consumptions [MWh/year].

The processed indicators supply valueble informations regardind the the performence of the electrical network served by the distribution operator and the transport operator, informations wich can be uses into the probabilistic aproach of a distribution network reliability studies. The corect determination of those indicators can be made owing to the existence of some data base and an informations flow regarding the power quality.

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