PILOT SYSTEM FOR HARMONIC EFFECTS ATTENUATION OF POWER ELECTRONICS AND POWER FACTOR IMPROVEMENT

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***Abstract**: The paper refers to a mobile pilot-equipmen, open system, with possibilities to be re-configured and extended, designed for measurements, tests, qualitative and quantitative assessments on two levels within LV electric power distribution substations.*
At the level 1, measurements and assessments on the electric parameters quality and energy consumptions are made, measurements for improving the network parameters and making more efficient the consumption are set, the compensation pilot equipment is pre-configured. At level II, there are performed tests for quantitative determinations with the pilot equipment for power factor automatic compensation, and for demonstrating the ability to make more efficient the energy by compensating the harmonic effects and reactive power absorbed by the consumers within 380 V, 50 Hz three-phase network.

1. INTRODUCTION

The increased use of power converters, adjustable-speed drives, electronic devices, etc., contribute to the excessive distortion of voltage and current wave-forms due to harmonics. This created the need for an accurate method for the measurement of the power components in the presence of distortion [3]. When designing this equipment, the most advantageous variant is taken into account, so as the savings got by removing the energy losses, concretized in the reduced value of electric energy consumption bill provide the shortest period of the investment redemption. The investments for energy efficiency and quality entail the mounting of new systems and technologies or the re-engineering of the existing equipment, requiring substantial funds. The previous analysis of the system and energy consumption, on the basis of which the saving strategy and necessary measurements for improving the system quality are adopted, provides the investment success [1], [2].
Within this framework, ICMET Craiova, R-D National Institute in electrical engineering field, developed by the R-D national program « CALIST », a method for electrical network analysis, completed with a pilot equipment for power factor compensation for LV networks.

2. POWER QUALITY

The problems related to power quality are the object of an European Norm, EN 50160, issued by CENELEC (European Committee for Electrotechnical Standardization) and treats the characteristics of low and medium voltage electrical products. The most frequent electrical disturbances on the distribution networks are mainly the following: frequency variation, delivered voltage amplitude variation, slow voltage variation, fast voltage variation (called flicker), no-voltage, short time interruptions, long time interruptions, transient overvoltages, harmonics.

The harmonics contribute to the increase of Joule effect losses in electrical conductors, leading to the diminution of the installation power factor and affecting the equipment connected to the electrical installation and determining the decrease of the life time. It should be noticed, additionally, the high price of the electric energy consumption bill, caused by the harmonics generated within an electrical installation, in fact a result of the diminution of the installation power factor. The limitation of harmonic pollution is concretized by a continuous concern of distributor and user. On one side, the electric energy distributor is an essential supplier of electric power quality, having a distortion as low as possible. On the other hand, the electric energy user is the only one insuring that the identified polluting loads do not contribute to the degradation of the mains voltage and will not be detrimental to the operation of other receivers.

The limitation of the harmonic currents is mentioned in the electromagnetic compatibility rules. IEC norms 61000-3-2, 61000-3-4 and 61000-3-6 specify the limits for harmonic emission which should be met.

In Romania, the limits of an assymetric and shapeless frame in electric networks are normalized by PE 143/94 of RENEL – Power Services Supply.

The pollution from the distribution network will be detrimental to the good operation of all consumers connected to this network.

The values imposed to the harmonic voltages cannot be exceeded, for assuring a proper operation of the receivers. At the electric energy supplier, the harmonic coefficient will not exceed the values specified in Table 1.

These values represent the particular coefficient calculated depending on the 50 Hz fundamental, knowing that the total ratio of voltage harmonics (THD_U) does not exceed 8% within a low voltage distribution installation.

Harmonic order	Ratio (%)
3	5
5	6
7	5
9	1,5
11	3,5
13	3
15	0,3
17	2
19(1)	1,5
21(2)	0,2

Table 1.- Compatibility level for particular voltage harmonics

(1): related to odd harmonics, not multiple of three;
(2): related to odd harmonics, multiple of three;

Global report of voltage harmonics	**Consequence in harmonic terms**
$THD_U < 5\%$	Non-existent problems in most of the cases
$5\% < THD_U < 7\%$	Emergence of problems in solid equipments
$7\% < THD_U < 10\%$	Harmful short-term effects
$THD_U > 10\%$	Certain long term harmful effects

Table 2. Consequences for typical value of global report of voltage harmonics

2.1. HARMONIC EFFECTS

One can consider that the disturbances caused by harmonics influence in two ways the electrical apparatus and equipment:

- Instantaneous effects, due to the distortion of the waveform and to the resonance phenomena, and regarding the sudden release of circuit-breakers and automating relays, material destruction (e.g. capacitors); the disturbance of the regulators cause also a decrease of the installation power factor

-Long term effects, generated by the capacitor and conductor heating effect, causing a premature ageing of materials and additional losses within the electrical rotating machines and transformers. The encountered problems are, in general, of thermal nature and affect the life time of the equipment. The summing up of the effects generated by harmonics on equipment is done in Table 3.

The harmonic currents flow through conductors and electric apparatus, generating harmonic voltages on the self impedances of these components, according to Ohm law. Thus, the current harmonics are the source of voltage harmonics.

DISTURBED EQUIPMENT	DISTURBANCE TYPE
Rotating machines	Additional heating; pulsating torque causing mechanical stability losses at motors; noise increase
Transformers	Additionally losses; saturation risk if the harmonics are even
Cables	Ohmic losses (notice, in a neutral cable within the three-phase network); premature ageing of insulation (by Joule effect); additionally dielectric losses Aluminium cable corrosion in case of even components and direct current; skin effect
Computers	Disfunctionality (pulsating torques of the magnetic support driving motors)
Communication devices	Interferences
Remote control devices Protection relay Fuses Thermal circuit-breaker Circuit-breaker for maximum	Operation and sudden release
Power capacitor	Heating, ageing
Energy meter	Measuring errors
Industry electronics	Operating fault related to the waveform (switching, synchronization)

Table 3-Types of disturbances generated in case of harmonic pollution on the electric network

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For quantifying an electrical installation in terms of harmonic pollution, the ratio of voltage harmonics, which will be revealed at the secondary terminals of the distribution transformer, can assess if within the considered installation there is or there is no pollution. On the other hand, harmonic current measurement enables the determination of the sources of disturbance on an electric network. The harmonic current measurement is a solution when it is necessary to detect and locate the sources of harmonics and to establish a diagnosis on such faults.

2.2 EFFECTS OF A LOW POWER FACTOR

The distribution of electric energy with low power factor has the following consequences:

- ***High absorbed current***: e.g. for cos φ = 0.5, the current through the load will be twice the necessary one, and for cos φ = 0.9, the current will be only 10% higher than the necessary one.
- ***Increase of loses by Joule effect*** ; these losses can be found in all the circuits: connection cables, distribution transformer windings, control and protection devices.

For the same transmitted active power, the power factor increase means the main current decrease.For a given cable, the losses are proportional to square current.

- ***Voltage loss increase***, leading to an insufficient power of supplying the consumers, at their turn the receivers undergoing a capacity decrease.

At a low power factor, it corresponds a high voltage drop at the transformer terminals, which could lead to a decrease of the voltage value in the distribution system, sometimes even below the imposed limits, and to a faulty operation of consumers.

- ***The installations cannot be used at their entire capacity*** , resulting a high depreciation of the costs. These are important especially for the distribution transformers. A transformer is much better used when the load power factor is close to unit.

3. SOME ASPECTS CONCERNING REACTIVE POWER COMPENSATION

3.1. SITUATION ON NATIONAL LEVEL

At present, there are designed and manufactured, at request, installations for power factor compensation. The assessment of the maximum capacity of the compensation battery and step values is made on the basis of the consumptions recorded in the bill for electric energy consumption and measurements made in the network.

The method has disadvantages:

- the recorded consumption are not always the real ones;
- measurements and records with the network analyser, or with similar apparatus, are made for a limited time period and, in most cases, the most disadvantageous operating moments from the manufacturing flow (a correlation between the moment when the measurements are made and the most disadvantageous situations from the manufacturing flow, in terms of the power factor, harmonics, unbalance between the phases or system dynamics is very difficult to obtain) are not caught, for an analysis of the network state as real as possible;
- the possible inadvertences between project and reality, regarding the reactive power necessary for compensation and its variations are found only when putting into service, after carrying out the installation.

During this stage, the correction of the installation implies additional costs for :

- supplying with new equipment, if the installation was sub-sized
- giving up to some of the equipment and providing with another ones, if the value of the steps does not correspond with the system dynamics, in this case the power factor oscillating permanently, without reaching the prescribed value
- remaking the metallic construction of the block if it is exceeded the power threshold it was sized for
- changing both the compensation solution and the equipment, if the maximum weight of the harmonics exceeds the considered level .

All these disadvantages and technical aspects are accompanied by negotiations regarding the allocation of additional funds to the initial contract, appearance of beneficiary distrust in the installation manufacturer, and many other unpleasant aspects, the desired technical-economic impact coming too late.

3.2. SITUATION ON WORLD LEVEL

On world level, companies such as: Chauvin Arnoux/Enerdis - France, Siemens - Germany, Schneider Electric - France, General Electric - USA, Circutor - Spain are focused on modernizing the measuring principles, also on using small overall dimension transducers, endowed with local “intelligence”, increasing the equipment facilities with functions of electrical event records, simultaneously with the achievement of electrical parameters records for long time periods, possibilities to analyse the electrical power quality.

In 1996, Idaho Power companie started a program for correcting the deficiencies from its local field of reactive power compensation and they carried out a method for the optimal control of the capacitor banks; on the basis of this concept, they achieved a pilot equipment. The pilot equipment was integrated with the working systems in a large area of Boise county. 44 distribution substations have been controlled with the pilot station for correcting the reactive power.

4. PILOT SYSTEM

This method, by means of which the distribution system is tested with the pilot equipment, with a view to adopting the strategy of making more efficient the energy and to taking the necessary measures for improving the system quality, provides the detailed knowledge of the condition of electric energy distribution system and solutions following to be adopted, the basis for a proper assessment of the fund for putting into practice, credibility for the clients, accuracy and reliability of the designed and manufactured products [4].
Thus, the pilot method and equipment, being mounted at the customer, will offer complete and accurate data necessary to develop economic engineering analyses, to set the opportunities for the investments of making more efficient the energy, to draw up feasibility studies, energy balance etc.
The mobile pilot method and equipment, in open system, with possibilities to be reconfigured and extended, is designed for measurements, tests and qualitative and quantitative assessments on two levels in LV distribution substations. At the level I there are made measurements and assessments in the consumer's electrical installations, regarding the quality of electrical parameters and consumption levels: measurement and recording of voltages, currents, power factor, harmonic weight, waveform, disturbances, flicker with network analyser, waveform processing with special software for harmonics of unlimited order, result analysis and comparison with the norms and recommendations in force, setting of measures for improving the network parameters and making more efficient the consumptions, pre-configuration of the pilot equipment itself. At the level II, there are performed tests for setting qualitatively and quantitatively the solutions for improving the power factor by the pilot equipment intended for being mounted to different beneficiaries, for: quantitative (maximum capacity of the battery, capacitor step values) and qualitative (dynamics of consumption variation, adjustment of the regulator sensitivity and delay times at step switching in/switching out) determinations by prescribing and configuring diversely the numbers and values of the capacitor steps, proving of energy efficiency by automatic compensation of the reactive power absorbed by the consumers from the 380 V, 50 Hz three-phase networks, with the equipment let to operate at the consumer for an mutually agreed time period. The method of pilot equipment use has many advantages, because
- it extends the storage capacity, it increases the measurements and records performing period of the network analyser, by connecting and communicating with a Laptop;
- the laptop has an analysis , interpretation and fast decision program implemented, regarding the results of the mesurements and compensation solution within the analysis system and a special software for processing the waveform and analysing the unlimited order harmonics
- the pilot equipment for power factor compensation is pre-configured on the basis of the previous results and system parameters, is mounted in the system; repeated settings and adjustments with tracking in operation are made, then the equipment is configured with the equipment from reserve as regards the step values and the maximum necessary capacity, until the installation fulfils all the requirements of the tested system The Pilot equipment

Fig. 1. Pilot equipment

remain in operation for a sufficient time, covering all the operation states characterizing the manufacturing flow of the consumer, with continuous tracking;
- the conclusions are a designing theme or directly an order, with well-defined parameters for the compensation equipment specific to the consumer's tested distribution point

The main technical characteristics of the pilot equipment are:
- rated voltage network – 3x400 V (440V), 50 Hz
- maximum capacity - 394 kvar, at 3x400 V
- (installed power 474 kvar, at 440 V – over-dimensioned condensers for networks with the maximum pollution degree of 25%)
- capacity harmonics compensation with detuned reactors (pollution degree 25% ÷ 60%) – 87,5 kvar
- maximum number of steps automatically controlled by a varmeter regulator with microprocessor - 12
- modular construction, configurable according to the requirements of the tested placed
- a cubicle for two modules fitted out with compensation batteries, enabling the extension of the block for the third compensation module
- the compensation modules are detachable
- maximum capacity of the compensation modules:
    - module 1 : 44 kvar (400 V), for fine control, in 4 steps
    - module 2 şi 3 : each one 175 kvar (400 V), in 4 steps

The detuned reactors, especially designed for compensation installations of the power factor with condenser batteries used in harmonic polluted networks, are being introduced into the compensation circuit only if the analysed network has a harmonic pollution degree ranging from 25% to 50%. In such situations the capacity of the battery is limited to 87.5 kvar.

5. CONCLUSIONS

The accomplishment of measurements for networks analysis and determining the network pollution degree is absolutely necessary before introducing it into the condenser batteries distribution system in order to compensate the power factor; establishing the type of compensation installation - with standard or over-dimensioned condensers, with over-dimensioned condenser and anti-reasoning coils or reasoning filters, will be made according to the degree of the network harmonic pollution. A condenser battery that does not obey to the degree of harmonic pollution at the mounting place leads to an enhancement of their non-expected effect and to the destruction of the compensation circuit's equipment.

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