ANALYSIS AND FIELD TESTS OF THE INFLUENCE OF HARMONIC COMPONENTS FOR PROTECTION RELAY CURRENTS ON SINGLE-WIRE EARTH RETURN SYSTEMS

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ABSTRACT

The purpose of this study is to asses the influence of current harmonic components (mainly third-order components) on the operation of a three-phase sub-transmission system at 34.5kV, which employs as predominant load Single-Wire Earth Return (SWER) Systems, the detailed analysis of which is observed in some of Copel's feeders.

The disconnection of feeders ensuing from neutral overcurrent caused by opening the automatic reclosers that protect circuits that predominantly feed SWER systems has occurred at a certain frequency. Normally, this occurs due to the difficult load balance between the phases of the three-phase system. Thus, neutral trip adjustments have reached high stages, which affect the sensitivity and reliability of the protection system.

The attempt to discover the cause of the aforementioned disconnection occurrences led to performing field tests and measuring endeavors, whereby it was possible to observe an extremely high third harmonic current, which is addressed in this study. That situation increased abruptly at certain hours of the day, and when the neutral current phase was added, it would result in a higher neutral module than for currents corresponding to the other three phases.

INTRODUCTION

The source of the strong third harmonic current increase were the hundreds of single-phase transformers (19.053/254-127V) that would reach the point of saturation via the increase of the near-nominal tension, which was hindered by low load, causing many transformers to run on empty.

The increase of non-linear loads connected to the power system has been a source of great concern and of a series of studies and discussions about that issue. Much attention has been given to the evolution of the use of electronic loads.

However, some electrical equipment generates harmonic distortions, which have been employed from the beginning of the practical applications of electricity and electromagnetism, e.g. saturable devices. Transformers, motors, generators and reactors, among others, are included in this category. Harmonics are specially generated due to the non-linear characteristics of steel [1]. Although the transformers' magnetizing current displays high harmonic distortion, it is typically below 1% of the nominal current at full load. Power Distribution Companies that have feeders with hundreds of transformers might display significant harmonic distortions caused by transformer over-excitation, due to tension or load stage variation.

The case under study addresses operational problems caused by the over-excitation of small and many single-phase transformers that feed predominantly rural loads.

Phenomena observed are conducive for a broad field of studies on the quality of power applied to the case at hand, referent to the filtering of neutral current signal registered by the recloser relay, which enables the equipment to differentiate current failure to ground over-currents caused by the third harmonic component.

SINGLE-WIRE EARTH RETURN - SWER

In order to enable the proper understanding of the quality of energy addressed it is necessary to provide some details on the Single Wire Earth Return (SWER) system that prevails within the electric energy distribution system (34.5kV sub-transmission) in the area where the study was carried out.

Those systems are used to feed low potency loads, which are typically for rural consumers located scores or even hundreds of kilometers far from the load stations.

The option and motivation to implement this system is the low cost when compared to the construction of medium tension distribution networks using just one cable and isolator, where the ground itself plays the role of the conductor of return current, as well as low rural consumption that do not pose at the short and medium term the perspective of a consistent increase of actual consumption.

The single-wire system is a sole metal conductor connected directly to one of the phases of the three-phase line, using the ground as the current's return path. Distribution transformers that are fed by it have the primary package connected between the conductor and the ground, as per Figure 1.

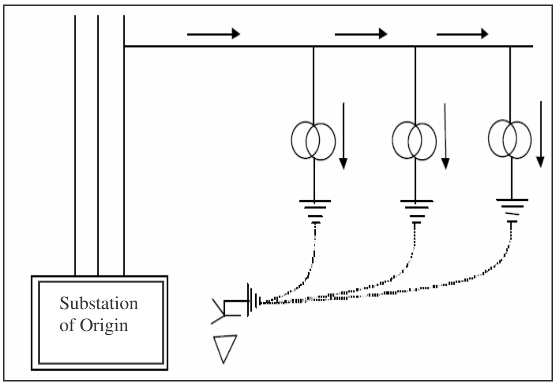

Figure 1 – SWER system at Copel

Of the three SWER (single-wire) in [2]: Insulated, Duplex and Non-insulated, Copel uses the Hybrid Non-Insulated system that employs a three-phase conventional network as the main line, with or without a multi-grounded neutral and neutral solidly grounded at the origin. Ground return single-wire networks leave the main network to feed rural transformers.
Copel is an energy distribution concessionary that detains one of the largest SWER systems in Brazil, with over 63,000 consumer and connections totaling over 25,000 Km of overhead distribution lines, implemented since 1967.

CONFIGURATION UNDER STUDY

The sub-transmission system with 34.5kV rate of tension under study is located in the central region of the State of Paraná.
Source substations include three-package transformers and the energy injection points for the sub-transmission and distribution system operating under the regular radial mode, see single-wire diagram in Figure 2).

Figure 2 shows the configuration of the system under study.

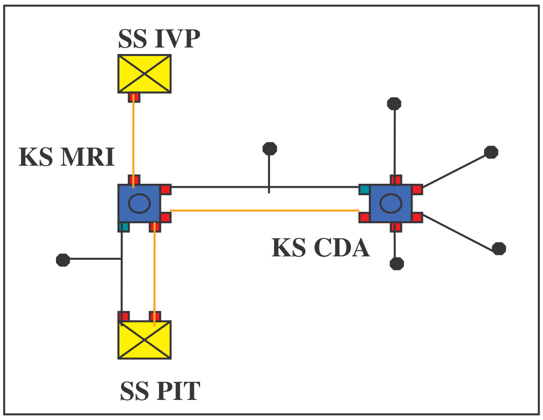

Figure 2 – Configuration of the System under Study

MEASURING THE QUALITY OF ENERGY

Measuring Equipment

Two digital recorders of parameters for electric energy quality were used to carry out the measuring, Reason Tecnologia model RQE-II.. Analogical signal acquisition is carried out at the 11520 HZ (192 points per cycle) acquisition rate.

Figure 3 shows the equipment above described.

Figure 3 – Energy Quality Analyzer

Equipment Installation

Two types of measuring equipment were installed to try to assess the high rate of disconnections by neutral over current.
Equipment # 1 was installed at KS Manoel Ribas, where it exits to Cândido de Abreu (Rio Quieto feeder, SS Pitanga source), neutral current signal. Tension signal was removed from the tension busbar fed by the Ivaiporã source to ensure that in the case of shutdown the measuring system would not be turned off as well.
Equipment # 2 was installed at KS Cândido de Abreu where it exits to the Tereza Cristina feeder. (as per Figure 4).

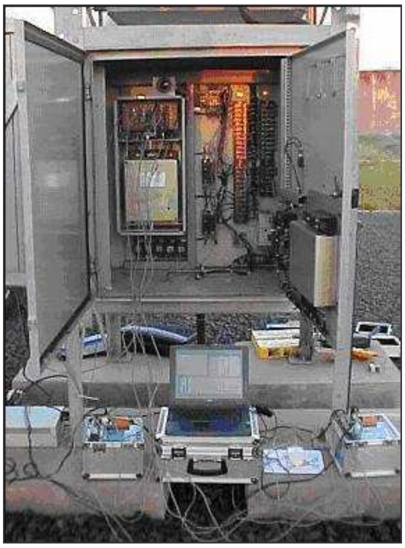

Figure 4 – Measuring Equipment Installed on the Electronic Control Recloser.

One of the options to monitor neutral current on 34.5 kV equipment, where in may cases this access is unavailable because those reclosers usually have only 3-TC phase, is to use a flexible TC installed outside the reclose, as shown in Figure 5.

Figure 5 – Installation of neutral flexible TC on recloser ESV 3810 with Electronic control

VERIFIED OCCURENCES

On the first day of the assays during installation and operation testing the following oscillographies were registered, as per Figure 6:

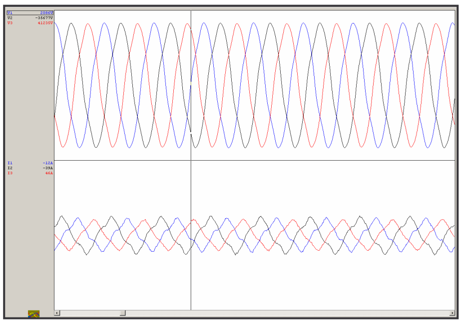

Figure 6 – MRI - Post Installation Tension

- MRI - post installation tension and current:

  - 6.03% THD mean tension
  - 19.2% THD mean current

Detail in Figure 7 shows the highest neutral current in other phases, whereby 60 HZ phasers are near the balance point.

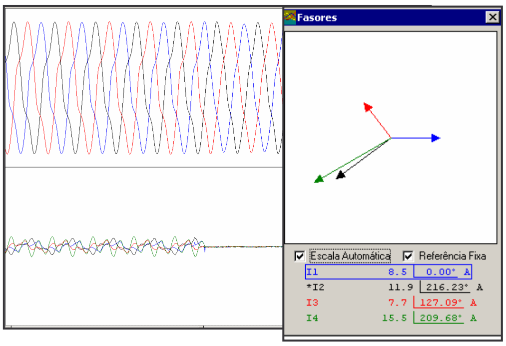

Figure 7 – Oscillograph and Phasers - CDA First Open

On the second day when assays were run, the same measuring was carried out, with the difference that neutral activation increased considerably for both Reclosers.

Figure 8 and Figure 9 show the Oscillography and Frequency Spectrum current -CDA last operation.

- 31.3% THD mean tension
- 163.7% THD mean current

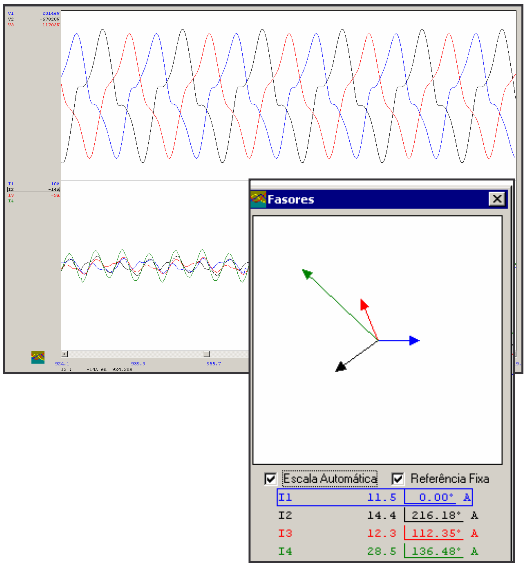

Figure 8 – Oscillography and Phasers - CDA Last Open

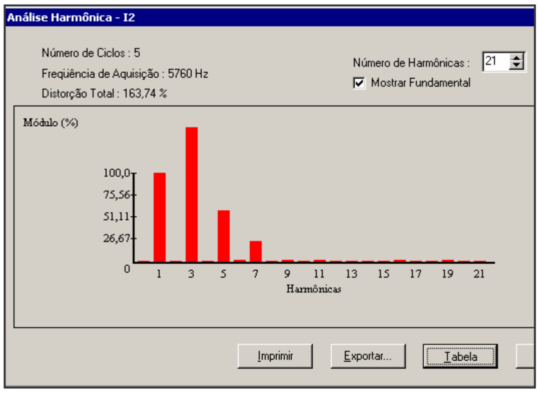

Figure 9 – Frequency Spectrum Current of CDA Last Open

RESULT ANALYSIS

Recorded oscillographies and other measurement findings were assessed as follows [7]:

- -High rate of current harmonic distortion on two measuring points.
- -High rate of third-order harmonic current, predominant on other components.
- -Automatic recloser operations upstream or downstream from the point of installation cause the

required neutral current unbalance to anticipate shutdown.

- -Third harmonic current was higher when it changed from the high load to the light load period (after ten o'clock pm, becoming critical during the small hours).
- -During critical periods, neutral current checked surpassed the efficient value on modules compare to other three-phase currents.
- -The system's RMS (root means square) tension was higher at the points of measuring, reaching values above 34.5 kV nominal tension.

In face of those findings, it can be partially concluded that the higher level of tension on the combined system and the load regime at certain periods were responsible for the considerable generation of harmonic currents observed. The most significant third order component increased the neutral current progressively causing successive shutdowns at the two points that were measured.

The following points underwent a comprehensive analysis:

- - Assays were run on single-phase transformers that evidenced saturation for limit tension at their nominal value, increasing the rate of harmonic distortion to higher tensions.
- - The higher tension level for the new configuration was observed for the three following reasons: Capacitation effect for a longer line, lack of consumers on that line (drop of tension decrease) and tension increase at the system's source substation.

CONCLUSIONS

Despite having been implemented at Copel in the 60s, the single-wire earth return phase and later studies on the third harmonic component for single-wire transformer current, this case clearly shows the evolution of a specific problem that was and still prevails on sub-transmission systems, displaying only variations of intensity.

This study plainly shows the effect on electric energy concessionaries when there is a significant increase of non-linear loads.

The growing trend to use non-linear loads should be carefully addressed and scheduled for the near future. That study will be a major challenge for professionals involved in developing electric energy distribution systems.

The acquisition of single-wire transformers should be carefully taken into account when acquiring single-wire transformers, which will not compromise cost versus the quality of energy.

Tension Regulators and Automatic Reclosers should be able to carry out the acquisition of electric parameters at the rate required for calculations of high order harmonics [6].

That type of equipment is already being acquired by Copel, which is requesting as part of the specification the inclusion of assays on the reception in order to check if the microprocessed equipment includes filters for the harmonics and maximum tolerated values, which will not lead to the false performance of the protections system [5].

A second study addresses the project and execution of a medium tension passive filter that is used to attenuate third harmonic currents, the immediate benefits of which are the decrease of loss and the improvement of the system's capacity factor.

Given the goal established by national administration to universalize electric energy supplying, establishing deadlines and the respective fines when supplying mainly rural consumers located at distant regions, many concessionaries that still use the SWER system are starting up their implementation feasibility studies. Concessionaries that already use that system display a trend towards large growth. Hence, this study can be used as a recommendation for which topology and equipment should be used.

Acknowledgments

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