# Power quality in automatic restoration systems using stand alone generators

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***Abstract* – The aim of this paper is to give an introduction to automatic restoration of voltage techniques and technology. There is also basic generator power quality test presented, with specification of typical small power stand-by usage. All the tests were taken with Fluke 345 PQ meter. Introduction concerns also basic European Directives for power quality measurements and requirements.**

## I. INTRODUCTION

Lately automatic restoration subject become very important. Reasons for this to happen are economic, political and technical. For economic we could find: to big power demand factor for production of energy ratio, negligence in maintenance cost predictions and demanded high interest rate on each level of energy market. For political reasons we can try to find more restrictive energy quality directives, too big pressure on low energy price (depending on the market energy price is national or free). And at the end we can describe technical reasons which in many cases are partly technical because of their origin in one of the above groups. For instance low maintenance expenditure effects with many failures in the network, though insulators and lines have defined lifetime often this period, due to other important works, is being exceeded. Another technical problem comes with load factor in the grid. Many faults are due to reactive power unbalance, involving generator under-excitation, sustained overvoltage, and switched capacitors/reactors. Other which are partly connected with those were problems due to load and generation unbalance, including responses to sudden increases in load and under-frequency load shedding including lack of black-start capability, problems with switching operation, line overloads and control center coordination. [2]

To prevent consequences of failures many systems are equipped in fast disconnectors and automatic restoration system with auto reclosing procedures (for over-head lines) or which is also common (mostly for private usage) with standby source able to work instead of mains supply. Typical AR system is presented on fig. 1.

[1] We can distinguish two groups of AR systems. One will be created by systems using evident stand-by source, which are often working with some flat period (with break after failure). These systems are using some stand alone generators (e.g. petrol [III.] or diesel generators, batteries and other energy storage devices). The other group will be systems using hidden stand-by source, so called reserve power source which is designed to fulfill requirements of full load even if one of the supplying lines is cut off. In this system there are no breaks in supply and during normal stable work lines are only loaded with 60-70% of theoretical capacity, but during failures there is possibility to overload system even with more than 30 % over the maximum nominative power capacity.

What is important when talking about Automatic Restoration are operation times (also as a factor of division). Main times of interest are:

- operation time, the time between the detection of failure and restoration of voltage (full or partial depending on characteristic of the system),
- cut-off time, the time when there is no power supply in secured circuits.

There is also difference on the cycle depending on the failure character. If AR is being activated because of CB operation on main supply we are talking about *shorter cycle*, else if AR is activated by the detection of voltage collapse (e.g. swell or sag) we are talking about *full cycle*, which is bigger than cut off time.

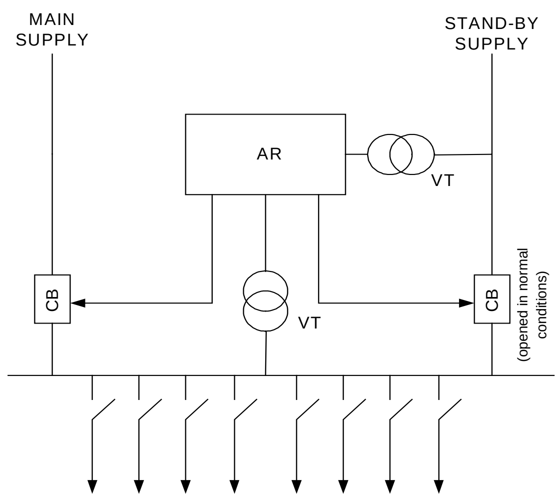


Figure 1. Typical evident stand-by AR system [1]

Of course both mentioned times must be coordinated with other system operation times like protection operation times of both plant and distribution/transmission networks as well. During automatic restoration also number of electric motors needed to be taken into account, when time of operation is being chosen.

Often after voltage restoration we can observe in the system with connected electric drives voltage drop due to associated inrush current, then torque drop because of voltage drop, motors stall and as a consequence either tripping of motors protection, bus bar CB or another operation of AR. To eliminate these faults two restrictions were introduced. First is the level of AR power, which should be sufficient, second is that motors are allowed to restart only with respect to their inrush current ( can't make voltage drop  0,7 $U_{AR}$ ). [2]

## II. Directives

Most important documents that influence automatic restoration parameters as well as detection parameters are standards and normalizations. For Poland these papers are, (taken from European Council Directives)[3] PN-EN 50160 "Parameters of supplying voltage in communal distribution networks", PN – IEC 60038 "Normalized voltages IEC". For other countries respectively are being used 96/92/EC "Concerning common rules for the internal market in electricity", and the 89/336/EEC with add-ons 92/31/EEC and 93/68/EEC "Electromagnetic Compatibility Directive". Regulations concern general requirement factors as frequency, voltage deviation, shaping of voltage and content of unwanted harmonics related to base harmonic and overall time of failures in circuit.

So base values are:

- For frequency grid values for synchronized connected circuit requirement is:
  - 50 Hz ± 1% for 95% time during usage period
  - 50 Hz ± 4/-6% for the remaining period

  *For other circuits 95% period can use threshold ±2%, and for 100% period ±15%*
- For voltage, average value with sampling time 10 min. should be:
  - 95% of these values should be 230/400 V ± 10%
  - 100% of these values should be in range of 230/400 V +10%/-15%.
- For harmonics normalization is shown in table 1:

TABLE 1
Admissive values of harmonics in LV/MV networks

| odd harmonics | | | | even harmonics | |
|---|---|---|---|---|---|
| multip. of 3. | | not multip. of 3 | | Harm. order | Rated volt.[%] |
| Harm. order | Rated volt.[%] | Harm order | Rated volt.[%] | | |
| 5 | 6 | 3 | 5 | 2 | 2 |
| 7 | 5 | 9 | 1,5 | 4 | 1 |
| 11 | 3,5 | 15 | 0,5 | 6..24 | 0,5 |
| 13 | 3 | 21 | 0,5 | | |
| 17 | 2 | | | | |
| 19 | 1,5 | | | | |
| 23 | 1,5 | | | | |
| 25 | 1,5 | | | | |

European Directives are also using THD factor (total harmonics distortion) which cannot exceed 8% for networks with nominal voltage level beneath 110kV and 3% for networks with nominal voltage level above 110kV.

## III. Laboratory Tests

The goal of laboratory test was to examine the behavior of simple power generation unit as a stand-by power source. Device chosen for testing was 1-phase generator powered by no-PB petrol engine produced by NUAIR POLSKA Sp. z o.o. The nominal power is 0,65 kW and the maximum power is 0,78 kW. More specific data are listed in table 2.

Not like other big machines, this one is provided with manual starter, which is useless with auto power restoration control system, but will give overview of advantages and disadvantages of stand-by power source commonly used for fulfilling needs of simple small countryside household – typically most unsecured in power supply.

Before the tests started there was found a problem with the load. The idea of the tests was to create environment which will be similar to real conditions. On the other hand, reduction of the influence of inductances and capacitances was necessary. Decision was made to take 0,5 kW halogen lamp as a load, which is almost 100% resistance and will not cause big inrush currents during start procedure. Additional researches were performed with 2 computer (laptop) power supply adaptors, to verify compatibility with energoelectronic devices.

The measurements and transients where recorded using FLUKE 345. All the data was transferred directly do the computer using software provided by the producer. The lamp was connected through special socket with splited input wires to ensure reliable usage of current clamps. For the purposes of the test 5 connection's of FLUKE inputs were used – 2 current clamps, 2 voltage probes and 1 PE wire.

The measurements were dived into three parts. All began with cold startup. Cold startup can be understood as starting the generator from temperature below 0ºC. Such strict parameters were taken to simulate hard winter conditions – the result from pre-test is the smooth behavior during start from temperature above 15ºC.

In first part after starting the generator, there was up to 10 seconds of idle work and then the load was connected. Difference between first and second part is joined with duration of idle work – in second section it was increased to 2-3 minutes, this time was sufficient for engine to get to the nominal work temperature. The last part was very similar to second, but the load was changed to two computer power supply adaptors connected in parallel.

From all attempts listed below values and transients were taken:

- Current RMS,
- Voltage RMS,
- Total power,
- cosφ,

- Total harmonic distortion (THD) parameter.

TABLE 2

NPEGG780 STAND-BY POWER SOURCE DATA

| | |
|---|---|
| Rated power | 650 W |
| Maximum power | 780 W |
| Nominal voltage | 230 V |
| Output | 1-phase socket |
| Protection | Over current (5 A) |
| Engine rotation speed | 3000 rpm |
| Engine power | 2 HP at 3000 rpm |
| Capacity of fuel tank | 4,2 l |
| Maximum continuous work length | 6 h |
| Level of noise | 57 db (7 m away) |
| Weight | 17,5 kg |
| Dimensions | 328x325x337 (mm) |
| Engine type | Two stroke |

## *A. Cold startup, 10 seconds of idle work*

This attempt will show if generators powered with petrol engines are able to withstand load demand during power system voltage collapse. Performances of generator after cold start were poor. Just after the startup value of RMS voltage is going up to almost 300V – this transient lasts maximum 3 seconds, but usually ends after 1 second. Then the voltage level is stabilizing, till the moment of connecting the load. After connecting the load, the RMS value goes up to 250V. Almost all of the attempts finished after 15-20 seconds, because the generators could not withstand the load demand and stopped working. Figure 2 shows voltage RMS value transient.

Value of cosφ was constant – 1 for non-load period and 0.98 for load period. Just before the generator stopped it started to decrease.

Current level was stable (2,1 Amps), only during switching period reached 2,2 Amps but this limitation was only due to small power of cold generator, normal conditions were presented in [B].

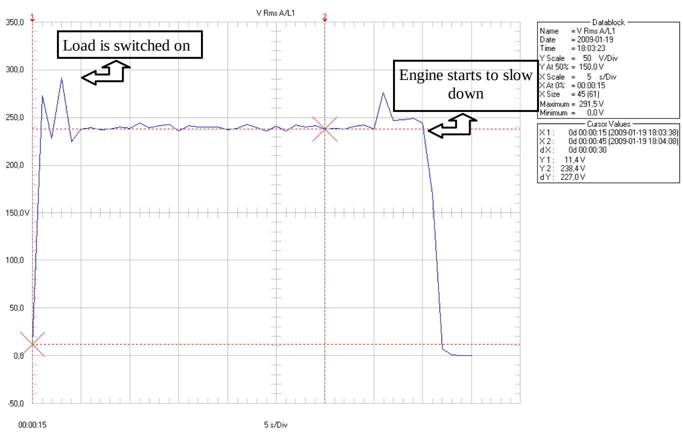


Figure 2. Voltage RMS transient for cold engine [A]

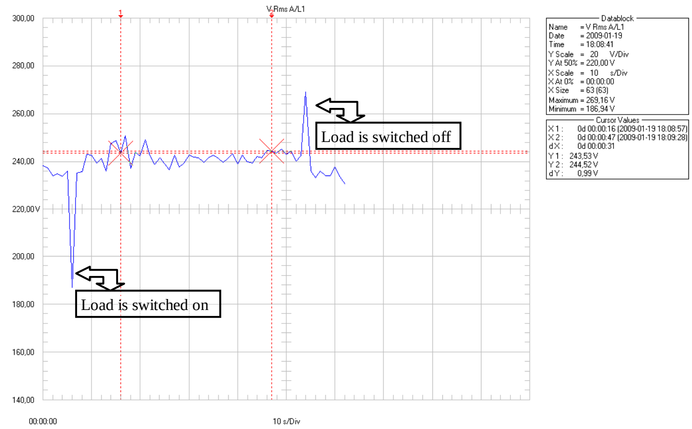


Figure 3. Voltage RMS transient for warm engine [B]

## *B. Cold startup, 2-3 minutes of idle work*

The pre-test trials showed that the engine needs time to stabilize its work. Basing on this knowledge next part tests were performed after reaching the work temperature. After this time the voltage level of idle work was about 230V, so it was similar to parameters decelerated by the producer. After switching on the load, there was o big voltage decrease, down to 186V. The drop duration was short – less then 1 second. During work voltage average value was 240V. The transient is not stable – it is oscillating around average value. Transient of the voltage RMS value is shown on figure 3.

The current level, like while first part, was stable (2,1 Amps). The peak during load switching operation reached 3,3 Amps, which is significant for other connected devices.

Value of cosφ were constant – 1 for non-load period and 0.98 for load period. Only changes were registered when the load was connected – 0,58 for switching on and 0,91 for switching off operation.

During this part the THD parameter was measured. It is giving overview of harmonic content in signal. The parameter is defined as the ratio of the sum of the powers of all harmonic components related to the power of the fundamental frequency, as in

$$THD = \frac{\sum \text{harm. powers}}{\text{fund. freq. power}} = \frac{P_2 + P_3 + P_4 + ... + P_{40}}{P_1} [\%]$$

The acceptable level of this coefficient is 20% (for separated LV networks, including up to $40^{th}$ harmonic). Obtained value from measurements is in range – around 17% for non load period and slightly above - 21% for load period. The producer of the generator does not give the THD value for the unit.

### C. *Computer power supply adaptors*

The aim of last part was only to check if power source is able to work efficiently with normal household devices. The most interesting values, from investigation point of view, were THD and reactive power.

Unexpectedly THD value for 2 devices connected, was very low – 2.5%.

As expected reactive power was twice bigger then active power – 90 Var. This is the result of AC-DC converter.

All other measured parameters were on expected level:

- voltage 235 V,
- current 0,42 A,
- active power 43 W.

## IV. SUMMARY

The tests were performed to prove abilities of stand-by power sources. Second topic, which should be taken under consideration, is the control of reserve power source – it should be 100% automatic. The basic requirement for generator is the electric starter. From the second view not all the devices and machines connected can be connected to second power source, the best example are the engines due to inrush currents.

Designer of control systems should pay attention to the temperature of the engine. As it was shown during laboratory tests it is strongly connected with efficiency and work stability. It can be noticed that during switching load procedure on cold engine, the peak voltage is lower, it is probably connected with dose of fuel and poor performance of cold engine – larger dose allows engine to work against provided load.

During cold start, control system could take as a control variable the value of cosφ – it was observed that it is decreasing while the generator is not able to withstand the load demand. This theory needs further investigation.

The main problem of small generation units is the power quality, which is decreasing in proportion to load. If the receivers are sensitive to harmonic content, then they can not be used.

The tests showed that even small generator unit can be used as stand-by power source. What is more, if there is no need of continuity of supply, the control system can be replaced by manual control – the blackout (operation) time will be extended to few minutes.

## REFERENCES


[1] prof. B. Miedziński " Lecture materials for System Opaeration and Security". Wrocław 2008 (not published).

[2] D.Glover, M. Sarma, T. Overbye Power System: Analysis and Design. Fourth edition (International Student Edition), USA 2008 by Thomson Corp.

[3] Edward Siwy, *„Dostosowywanie przepisów polskich w zakresie jakości energii elektrycznej do wymogów Unii Europejskiej"* Instytul Elektroenergetyki i Sterownia Układów, Politechnika Śląska, Gliwice