EARTH-FAULT ANALYSIS OF THE MEDIUM VOLTAGE NETWORK GROUNDED WITH LOW VALUE RESISTANCE

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INTRODUCTION

Different types of distribution network neutral grounding have always been attracting power engineers attention provoking discussions about their good and bad properties. Basically, problems exist mostly in medium voltage systems, where various types of neutral grounding are used, such as: ungrounded, effectively grounded, reactance grounded, resonant grounded, low resistance grounded etc.

The 110 kV power network of Elektrovojvodina is effectively grounded, whereas 20 kV network is grounded via a 40 Ω metal resistor. The earth fault current is limited to 300 A.

In order to increase the network reliability a proper choice of neutral grounding type is to be made. When it is done the fault analysis and appropriate maintenance measures have to be undertaken to reduce the earth fault number.

Digital recording devices with a resolution of up to 64 points during a period of 20 ms with 16 analogue and 32 digital channels are used for analyzing distribution network components. The current and voltage waveforms are recorded by analogue channels, while the digital channels are used for monitoring protection and switching devices. Data obtained by using this equipment give a complete view of events and enable fault analysis.

The arc is the most frequent phenomenon during faults. It is eliminated by switching off the power supply. The objective of autoreclosing (AR) is to restore power line supply after a dead time, during which the de-ionization takes place. Since the arc is not a stationary phenomenon, it generates current and voltage harmonics in the network.

The harmonic analysis of the recordings made by these devices is still in its initial phase and its goal is to determine the pattern of transient and permanent earth faults, as well as other types of faults.

The paper presents and discusses results of harmonic analyses for different cases of earth faults obtained by using the Fourier transform (FT) method and with the help of a program developed at the Faculty of Electrical Engineering in Belgrade. Also, directions of further development are discussed.

FAULTS IN A 20 kV NETWORK

Earth faults are the most frequent faults in the 20 kV network of "Elektrovojvodina". These faults represent approximately 80-90% of the total number of faults. 5% of all faults are phase-to-phase earth faults, which are the result of transforming an earth fault into a phase-to-phase fault. This occurs when an earth fault, at one point in the system, causes an increase in the phase to neutral voltage at other two "healthy" phases. This voltage increase causes an earth fault at other two phases of the same of some other line. Thus we have a phase-to-phase earth fault. The remaining faults are phase-to-phase and three-phase faults without earth faults and these faults are mostly permanent.

Detecting a fault in a medium voltage network is simple because 20 kV networks have radial power supply. Overcurrent relays are used for detecting faults. The setting of the operating value for this protection depends on the characteristics of overhead and underground lines, the network length, as well as on the resistance of 20/0.4 kV substation groundings.

The 20 kV line protection in "Elektrovojvodina" was conceived so that it consists of the following types of protection: instantaneous overcurrent protection (J>>), definite time overcurrent protection (J>) and earth fault protection (Jo>). Most protection devices are of the electromechanical type while there are also the more recent types of static protection. In addition to this, each 20 kV line is also equipped with an AR with two reclosing shots i.e., with an autoreclose open time of 0.3 sec and 180 sec.. Due to the mentioned phase-to-phase faults with an earth fault, which are most often of a transient character, the AR activate all types of protection. The success rate of AR is high i.e., the number of transient faults amounts to 80%.

THEORETICAL DISCUSSION

Earth faults on 20 kV voltages differ from higher voltage faults based on several significant characteristics. The first characteristic is that the 20 kV earth fault current is limited to 300 A, while its real value is determined by the position of the short-circuit. The value of the current of the high voltage earth fault depends only on the position of the short-circuit. The characteristic which is significant to us for calculating the current and the characteristic of medium voltage earth faults is that medium voltage earth faults have an impact only on a local level i.e., their impact is not felt on adjoining high-voltage substations.

So far, examinations of 20 kV network faults have indicated several causes of faults. In these examinations the first fact taken into consideration was that the 20 kV network is versatile in character i.e., it is mostly an overhead system, while in larger cities, it is an underground system. Its great versatility is also based on the insulators used, including both the method of installation (suspension and post insulators) and various levels of insulation: from 17 kV (transitional period from 10 kV to 20 kV) to 35 kV (for 35 kV voltage lines). The most frequent causes of faults are birds who by landing and flying off the conductors or posts cause earth faults. This is especially the case on terrains where there are no forests, which is also characteristic of the greater part of Vojvodina. Other causes are dirty insulators, due to birds and dust, and overshooting, due to a little moisture. The remaining faults are lightning impulses faults of the TS (transformer substation) 20/0.4kV and so on.

A joint characteristic of both types of faults is the appearance of an arc. The arc is a significant factor of the fault because both the value of the earth-fault current and the success of AR depend on the arc parameters. It is to be expected that all these faults will be followed by the appearance of an arc. The difference between electric medium voltage and high voltage arcs is in their length.

It is a known fact that the arc is a non-linear "element" of the electrical power system i.e., it has variable resistance. As such, it introduces harmonic disturbances to fault voltages and currents. This fact enables us to conclude whether or not the fault is with an arc based on the presence of higher harmonics. The contents of higher harmonics compared to the standard also indicates the size of the arc.

Digital processing of the fault current and voltage has been applied in this paper using the FT method based on two assumptions. Initial examinations of the faults indicated that a standing DC component was not present. This component appears when the line in fault is switched off and during reclosing time, which is not significant when analyzing the nature of the fault. Also, due to relatively high resistance during the neutral state (40 Ω), the time constant of fault is small, which is also why there is no standing DC component. It has been stated earlier that these faults do not have a significant effect on the entire electrical distribution system, thus there will also be no changes in the frequency. It is known that the FT algorithm is sensitive to network frequency deviations from the nominal value, thus it does not apply to high voltage faults.

Continuity and periodicity of the voltage and current fault function are primary assumptions, which enable the use of FT in harmonic analysis. The procedure is carried out in such a way that for each current and voltage duration period, we have 20 discreet values representing input data for the calculation. For example, for voltage we have a series of n elements:

$$v(t_1),\ v(t_2),\ v(t_3),\ ..v(t_i),\ v(t_{i+1}),... ,\ v(t_n)$$

Since we have 20 instantaneous voltage values for each duration period, this means that the difference between t_i and t_{i-1} is equal and amounts to 1 msec.

To exit the program, for each input data a signal is broken down to a sum of individual harmonics i.e.:

$$v(t_i) = V_0 + \sum_{k=0}^{M} V_k \cos(k\omega t + \theta_k)$$

Where:

- M is the highest order of harmonics used to break down the given signal,
- k is the index of individual harmonics,
- ω is the frequency of the primary harmonic,
- V_0 is the standing DC component,
- $V_k = \sqrt{A_k^2 + B_k^2}$
- θ = arctg($-B_k/A_k$)
- $A_K = \dfrac{2}{T}\int_0^T v(t)\cos(k\omega t)dt$
- $B_K = \dfrac{2}{T}\int_0^T v(t)\sin(k\omega t)dt$

The significance of analyzing the size of the arc during a fault lies is evaluating the possibility of eliminating the arc during dead time i.e., evaluating whether or not the fault in transient or permanent. This cannot be performed using relays that are momentarily present in the network (electromechanical and static), but it is possible by using a new generation of relays (numerical) containing computers, and by adequately programming this device.

ANALYSIS OF TRANSIENT FAULTS

It was stated earlier that the number of transient faults is far greater than the permanent, thus in this fault examination there were many more such faults. In the analysis, input data were broken down to the 5th harmonic. During the examination of transient faults two types of transient faults were obtained:

1. Faults with an arc only at the beginning of the fault, while during the duration of the fault and up to the moment when the circuit breaker is open, there is no arc. An example of such a fault is given in Fig. 1. The Figure shows current and voltage waveforms on the medium voltage side of the transformer. The Figure does not show the tapping current with a fault due to practical reasons i.e., there is not a great number of analogue inputs in the digital recording device. Figures 2 and 3 show harmonic analyses of voltage and current in the case of this fault. The diagrams represent the percentage value of individual harmonics of the total signal.
2. Faults with an arc, which is successfully de-ionized during dead time. An example of such a fault is given in Fig 4., while Fig 5 and 6 show harmonic analyses of current and voltage in the case of this same fault.

By reviewing Fig 2, 3, 5 and 6 and numerically analyzing the data obtained through a harmonic analysis, the following conclusion were made:

– the appearance of higher harmonics, and thus an arc as well occurs during the duration of two to three periods (approximately 50 msec) before the protection are operated on the appearance of fault current;

– in the case of the first type of transient fault after the arc appears (20-40 msec), it begins to stabilize and disappears;

– in a great number of cases there is also a standing DC component of the fault current, which is characteristic of high voltage faults and prevents us from using the FT method for a more detailed fault analysis;

– switching transients, at the closing time of the circuit breakers, are also accompanied by a more intense presence of an arc;

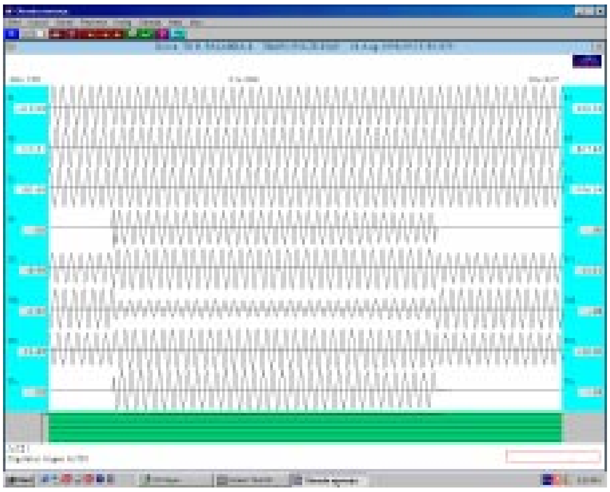

Figure 1.

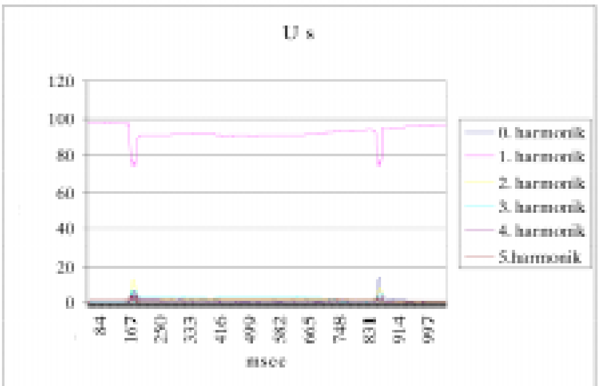

Figure 2.

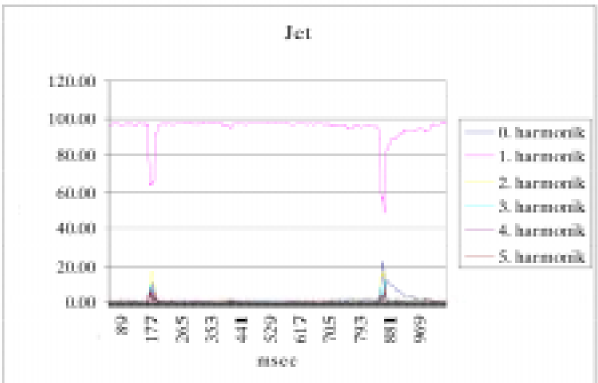

Figure 3.

– current running through a neutral point of the power transformer, as well as the residual line current are not suitable for fault examination through a harmonic analysis because their value during normal operation is nearly zero, thus more time is needed for a steady process;

– a harmonic analysis was performed on recordings that registered transient phenomenon with 20 points during a duration period, which satisfies an analysis at the 5th harmonic level. This is an important note based on the fact that most of the numerical protection devices today work with this resolution.

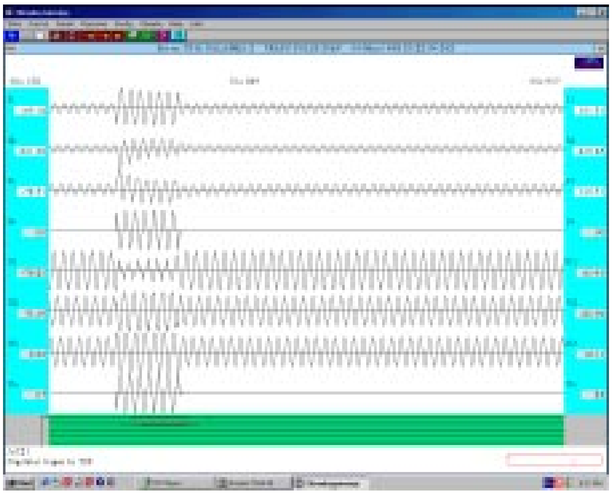

Figure 4.

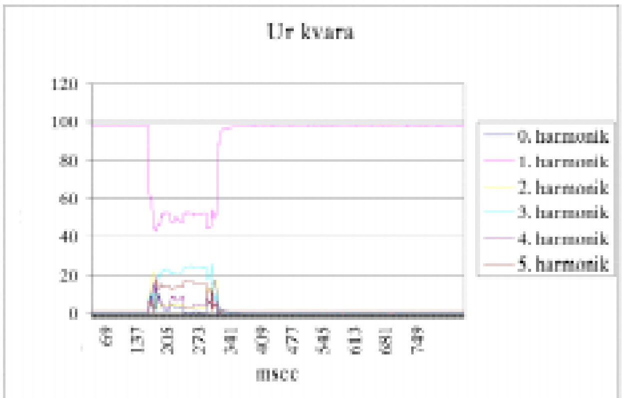

Figure 5.

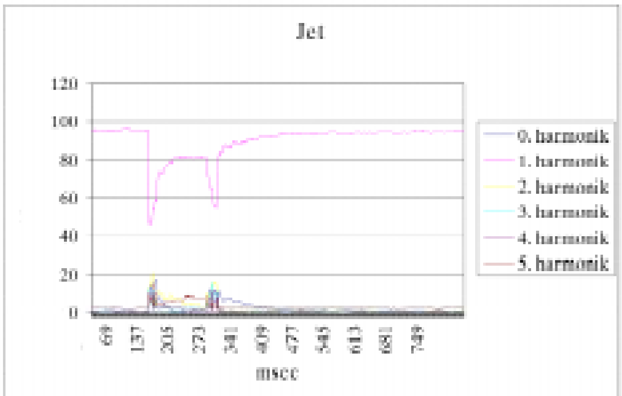

Figure 6.

PERMANENT FAULTS

Permanent faults are characteristic of an arc which does not succeed in de-ionizing during dead time, thus resulting is an unsuccessful AR. Most of these faults usually develop into multi-phase faults. Typical examples as a permanent arc with current and voltage diagrams on a transformer bay as well as a harmonic analysis of current and voltage for this fault are given in Figures 7, 8 and 9. The analysis given for transient faults is also present in these faults, but there is a higher percentage of higher harmonics and thus, a greater arc, which does not succeed in de-ionizing during dead time and due to this, we are faced with a permanent fault.

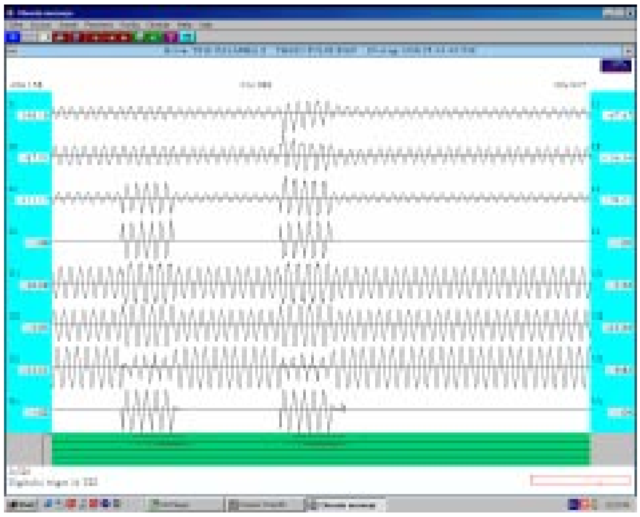

Figure 7.

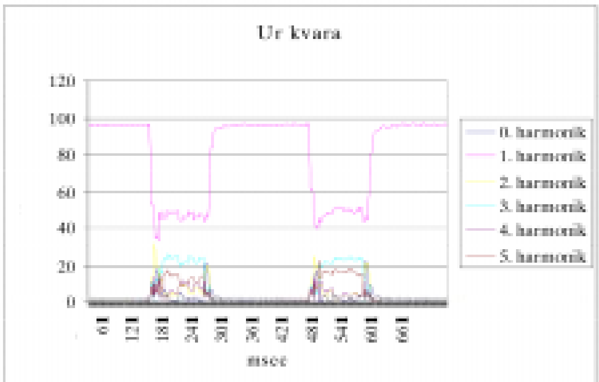

Figure 8.

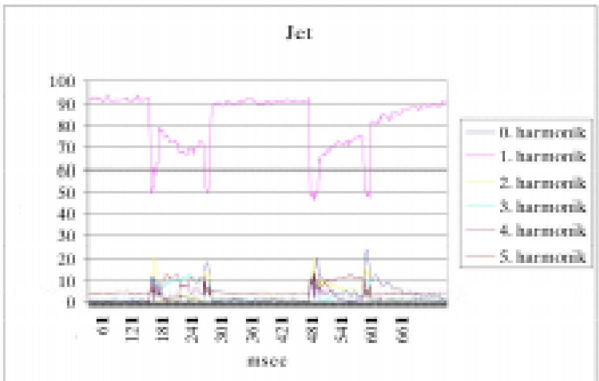

Figure 9

CONCLUSION

In analyzing single-phase faults, the FT method is not completely applicable when analyzing the success of earth faults. Transient earth faults without an arc represent a problem. In the case of metal connections, there is also no arc and the assumption is that these faults are permanent, thus we are not 100% certain when it comes to this analysis. An earth fault without an arc also brings up the question what kind of fault has no arc, but is transient. This question represents a future direction in fault research regarding 20 kV networks, at which time other methods for finding the arc value will be examined.

By examining these faults an idea surfaced that further research should not only move in the direction of determining the character of the fault, transient or permanent, but also in the direction of determining the cause of the fault base on the shape of the curves.

BIBLIOGRAPHY:

1. M.B. Djuri}, V.V. Terzija,"A New Approach to the Arcing Faults Detection for Fast Autoreclosure in Transmission Systems", IEEE Trans. on Power Delivery, Vol. 10. No 4, October 1995, pp 1793-1798.
2. M.B. Djuri}, Z.M. Radojevi}, V.V. Terzija, "O klasi numeri~kih algoritama za za{titu nadzemnih vodova razvijenih u vremenskom domenu", Elektrodistribucija, God. 26, Septembar 1998. broj 2. str. 122-130.