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MODERN DISTRIBUTION POWER GRIDS

BY

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Abstract. A complex characterization of the modern distribution power grids is presented. Thus the present paper contains information about grids' structure, components and operation state. It focuses on the new tendencies regarding the grids components (electric lines and transformers) and on the operation state of the grids. The last part of the paper shows the situation of the Romanian distribution power grids, thus in order to underline the operation state of the grids, a study case is presented. The final chapter of the paper includes the conclusions concerning the modern distribution power grid and their future worldwide and in the Romanian area.

Key words: distribution grids; superconductors; operating state; power quality.

1. Introduction

The distribution power grids represent the parts of the power systems that distribute the electric energy from the nodes of the transmission power grids to the end users. They have a complex structure, different voltage steps and transfer a small amount of energy on short distances.

The modern distribution power grids contain the existing macro-grids

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and the new micro-grids. They include transformer stations, electric lines (ELs) of high, medium and low voltage, and auxiliary components necessary for protection, automation and measurement.

Macro-grids are characterized by a high level of dynamism due to the fact that they supply a great number of diverse consumers. Depending on the consumers that they supply, macro-grids are divided in three categories: urban, rural and industrial distribution grids.

Urban distribution grids contain high and medium voltage ELs connected in open or closed loop, low voltage ELs in radial, open or closed loop connections and the transformers from the stations and substations. In comparison with the urban grids, rural grids are simpler, since they have mainly medium and low voltage ELs in radial connection. The industrial distribution grids, in particular the ones that supply big industrial consumers, contain high and medium voltage ELs, which are connected in radial schemes (but a secondary supply line is provided if necessary).

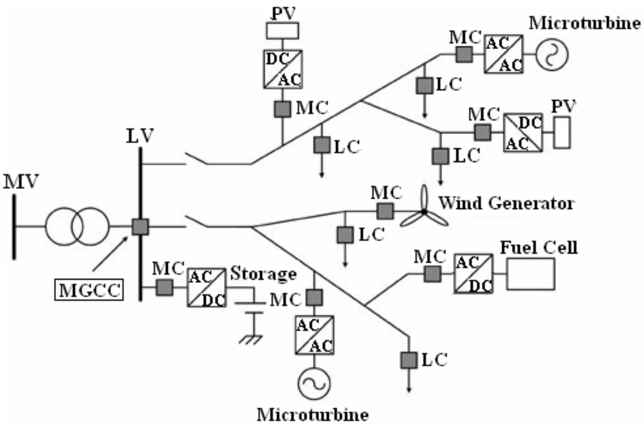


Fig. 1 – Power distribution micro-grid.

Micro-grids and smart-grids represent the new tendencies that meet the world's new energy policy that is to protect and mitigate the impact on the environment. Micro-grids are defined as the semiautomatic power grids that connect the power generation units and the corresponding end users. Each grid has a particular topology that depends on the consumers it supply. Most times, micro-grids are associated with the distributed generation, thus they are developed to work separately from the macro-grid they are connected with. On the other hand there is a permanent exchange of energy between the micro-grid and the macro-grid that is mainly influenced by economic factors. A micro-grid (Fig. 1) has the following three main features (Hatziargyriou & Asano, 2007; Lasseter, 2008; Hatziargyriou, 2009): particular structure developed in order to satisfy the power necessities; high power quality level and a high supply safety; it is seen as a compact unit by the macro-grid, and it has a minimum impact on this one.

A smart grid transmits the electric energy from the suppliers to the consumers using automatic digital control of the consumers' apparatus, in order to reduce the excessive power consumption and costs, and to increase the safety and transparency of the process. In other words, a smart grid is a modernized grid obtained by introducing smart meters, modern elements (to diminish the energy losses) or/and electricity production from renewable energy resources.

2. The Components of Modern Distribution Power Grids

The main components of the distribution power grids are the ELs and the power transformers. These are accompanied by auxiliary components like bank capacitors, reactance coils and FACTS (Flexible Alternative Current Transmission Systems).

The ELs describe the assembly of electric conductors, devices and constructions necessary to assure the electricity distribution. They include ELs with voltages until 110 kV, electric installations and measurement equipments. There are two major categories of ELs: overhead lines and underground lines. The main elements of the ELs are the conductors, which are used isolated (cables) or unisolated (mono-wires or multi-wires) made of copper, aluminium or steel–aluminium mixtures. Most of overhead lines are un-isolated; the usage of isolated ones supposes the conductors to have an isolation resistant to the aggression of the environment factors. The underground lines includes only cables that are used for caring especially medium and low voltages in situations where overhead lines cannot be used, *e.g*. urban agglomerations.

The new tendencies in the electric energy transport and distribution fields are represented by the usage of cryogenic conductors, which eliminates the limitations of present conductors (power losses, over-heating, etc.). The functioning of these conductors is based on two phenomenons namely

a) Hiperconductivity – at temperatures lower than 90 K, the conductivity of aluminium grows over ten times its normal value. The cables constructed by this principle are named *cryo-resistive* cables;

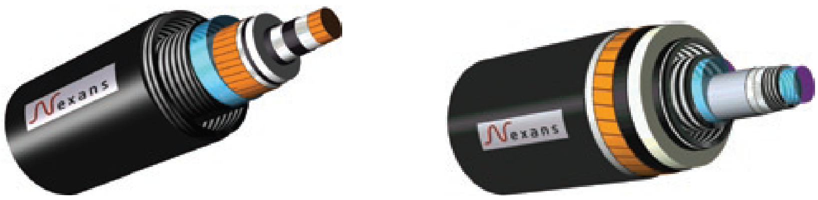
b) Superconductivity – the use of some materials (Nb, NbSn) at temperature of some Kelvin degrees determines the electric resistivity to incline to zero. These kinds of cables are the *superconductors*.

In the present, superconductors are divided in two categories: LTS (low temperature superconductors), that are made of metallic alloys and HTS (high temperature superconductors), which contain oxides of different material (Minervini, 2009). From the active conductors' numbers point of view there are mono-axial and tri-axial superconductors (Yagi *et al*., 2009; Shimoyama *et al*., 2009). LTS are characterized by the fact that the conducted material is cooled with liquid helium. These installations had appeared in the 1960s and in the present they have been abandoned because the cooling system is much too complex and expensive, and the functioning optimum temperature is around several Kelvin degrees (Shimoyama *et al*., 2009). Lately, the cooling system was replaced with one based on liquid nitrogen that offers the advantages of being cheaper, accessible and un-pollutant.

HTS contain conductors made of many layers of superconductor material, which is based on two ceramic composites: Bismuth strontium calcium copper oxide (BSCCO) and Yttrium barium copper oxide (YBCO). HTS conductors are covered by an isolation called *dielectric*. Concerning the cooling system of the cable's dielectric, the HTS cables are cold and warm. In the case of cold HTS the dielectric and the conductors are cooled with liquid nitrogen. These kinds of superconductors have a special construction, so they don't release electromagnetic field and their inductance is very low. Fig. 2 presents the images of superconductor cables.

The warm HTS cables (Fig. 2 *b*) have a simpler construction and they are cheaper than the cold ones, but they are not so shielded, and the dielectric has the environment temperature.

The main advantage of the superconductors is their very low electric resistance, which determines lower power and energy losses, and, consequently, a higher current density and a bigger quantity of electric energy transported than the classic one that are used now.



a *b*

Fig. 2 – HTS cable: (*a*) cold, (*b*) warm (Superconducting Cable System, 2011).

Worldwide there is no superconductor cables used in exploitation, but only in experimental projects at medium and high voltage (Yagi *et al*., 2009; Shimoyama *et al*., 2009).

The power transformers realize the static transformation of the a.c. electrical energy main parameters by keeping the same frequency; they are used to raise or drop the voltage level. In the distribution grids there are used especially power transformers that drop the voltage level (Cziker & Cziker, 2006).

The main transformers components are the windings and the magnetic core. Windings are made of copper or aluminium wires with circular or rectangular cross-sections. The magnetic core is realized of cold or warm laminated silicon steel or thin laminations of amorphous steel. In Table 1 are presented the material features of the amorphous steel lamination in comparison with the conventional one (used in the Romanian distribution power transformers).

Table 1
Comparison between the Characteristics of the Classic and the Amorphous Steel Lamination

	Classic silicon steel lamination			Amorphous steel
	in general	other types		
		Max 0.3	LASER 0.23	
Thickness, [mm]	0.18...0.35	0.3	0.23	0.025
Volume, [kg/dm^3]	7.65			7.18
Saturation induction, [T]	2.04			1.56
Lamination coefficient, [%]	93.5...96.6	96	94.8	< 82
Inner tensions sensibility	smaller			bigger
Open circuit losses, [%]	60...120	100	65	25...35

The new tendencies in the transformers construction field are to use superconductor wires for windings and amorphous steel laminations for the ferromagnetic core. At present, the superconductor windings are in the experimental stage, but the ones with amorphous steel cores are used in exploitation. Their main advantages are the mitigation of the iron losses and of the magnetic core size.

Bank capacitors are used to provide the needed reactive power in order to raise the grids power factor. Reactance coils have the role to limit the fault current that can appear in the distribution grid, in order to maintain the voltage between the admissible limits.

The new trend, concerning the fault currents limitation, is to use superconductors. Such a device is called *fault current limiter* and its working is based on superconductor wires cooled with liquid nitrogen at very low temperatures.

FACTS technology offers the possibility of raising the quality and efficiency of the distribution process by minimum investments and without being necessary to replace the existing components (Sivanagaraju & Satyanarayana, 2009). FACTS usage assumes the intensive exploitation of the ELs by increasing the transport capacity more close to their thermal limit. FACTS devices are (Eremia, 1997): Static VAR Compensators; thyristor – controlled capacitors or series reactors; thyristor – controlled phase angle regulators; unified power flow control regulators; advanced FACTS, whose running is based on of special components like GTO (Gate Turn Off) and MCT (MOS Controlled Thyristor).

3. The Operation of Modern Distribution Power Grids

The distribution grids supply an increasing number of domestic consumers, whose repartition on the three phases cannot be controlled, this fact causing unbalanced operation of the grid. On the other hand, there are many industrial consumers that include bi-phase and three-phase unbalanced loads, which determine an unbalanced three-phase system of currents. This system of currents causes an unbalanced system of voltages with which the end users connected at that time to the distribution grid are supplied.

In the present, in the modern industry, about 50% of usual industrial devices are based on frequency converters, switching sources and electronic ballasts. Due to their nonlinear characteristics, these loads inject in the distribution grids harmonic and/or interharmonic currents and voltages that distort the current and voltage waveforms and negatively influence the grid.

In the distribution grids appear different transient events that determine the appearance of voltage dips and over-voltages. These events are characterized by short duration (less than 3 sec.), but they cause great variations in the supply voltage amplitude, thus affecting the end users and grid's components normal functioning.

In practice, the harmonic distortions and the unbalance determine a steady state that is characterized by unbalanced three-phase systems of non-sinusoidal currents and voltages. In this power environment, different events like voltage dips and over-voltages that cause a transient operating state and more serious negative effects appear and determine the modern operating state of the distribution grids.

4. The Romanian Modern Distribution Power Grids

The Romanian power distribution grids are primarily macro-grids that include ordinary ELs and transformers. The feature that makes them modern is the operating state that is non-sinusoidal and unbalanced and influenced by transient disturbances like the ones presented above. In order to underline the situation of the distribution grids, a study case was realized. Thus, different measurements have been made in an urban grid, which supplies an assembly of block with flats.

The studied distribution grid contains the following components: cables with $3 \times 240 + 120$ mm^2 cross-section, 65 m in length, which make the connection between the substation and the common coupling point; ACYABY cables with $3 \times 150 + 70$ mm^2 cross-section, 100 m in length, which supply the flats.

The measurements have been made during 4 days, at the LV busbar of the substation that connects the assembly of flats and the principle medium voltage feeder. After the data were processed, the graphics from Figs. 3,...,6 have been obtained. The graphic from Fig. 3 shows the variation of the currents mean values, while the one from Fig. 4, the unbalance quality indicator time variation.

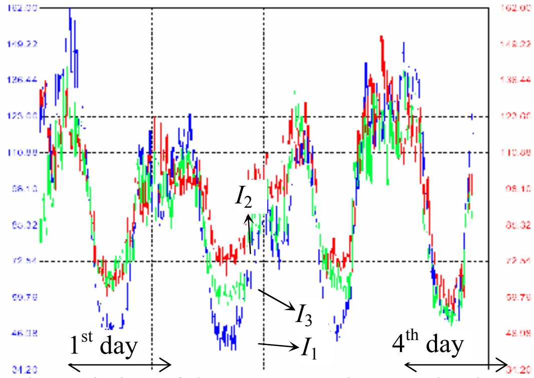


Fig. 3 – The variation of the currents values on the three phases.

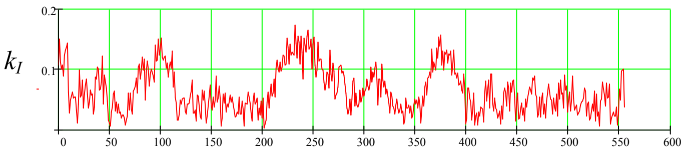


Fig. 4 – The variation of the current unbalance factor.

The power quality indices that characterize the non-sinusoidal state have been determined based on the currents values on each phase; but in Fig. 5 are illustrated only the currents from phase L3.

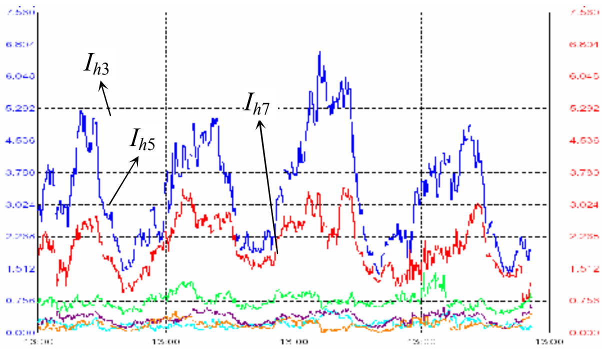


Fig. 5 – The variation of the current harmonics values on the L3 phase.

The time variation of the THD (Total Harmonic Distortion) for currents is illustrated in Fig. 6.

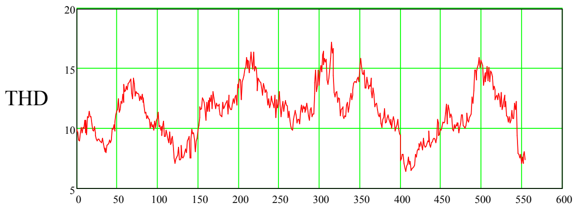


Fig. 6 – The variation of the THD for current on the L3 phase.

5. Conclusions

The modern distribution grids are characterized by three features: (i) a combination of the old existing installations and new ones, which are based on the infield innovations and introduced in order to increase the efficiency of the distribution process; (ii) an operation state that is non-sinusoidal and unbalanced on one hand, and on the other hand it is influenced by a great number of non-stationary disturbances (voltage dips, over-voltages, etc.); (iii) a high level of automation.

The study case above described underlines the modernity of the Romanian distribution grids that supply many consumers, which inject electromagnetic disturbances. This fact has as effect an operating state of the grids that is unbalanced, non-sinusoidal and influenced by voltage dips and over-voltages.

Considering the above presented aspects, the future distribution grids will be mainly represented by micro-grids (in the case of small localities), but there will be a mother macro-grid that will connect all of them. They will contain revolutionary components that will raise the grids efficiency and consequently the existence of electromagnetic disturbances will be controlled.

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REȚELE ELECTRICE MODERNE DE DISTRIBUȚIE

(Rezumat)

Se efectuează o caracterizare complexă a rețelelor electrice moderne de distribuție; ea conține informații legate de structura, componentele şi regimul de funcționare al rețelelor. De asemenea se pune accentul pe prezentarea noilor tendințe privind componentele şi regimul de funcționare al rețelelor de distribuție. În ultima parte a lucrării se prezintă un studiu de caz privind regimul de funcționare al rețelelor de distribuție din România. Ultimul capitol include concluziile legate de problema rețelelor electrice moderne de distribuție şi viitorul lor pe plan mondial şi în arealul românesc.