Romanian Power Systems Engineering Towards EU Integration

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Abstract - The evolution of electric power system analysis methods followed the present technical problems and business needs of electric utilities in Romania, before EU integration. Present technical requirements and the current stage of power system analysis tools - are major subjects of the Romanian electric power engineering training. Training in Power Systems Transients and HV Electric Equipment requires a rich collection of computer applications on: transients and harmonic pollution on high- voltage transmission lines; non-linear equipment; non-linear consumers, etc. Such problems can only be taught to power engineers using due computer resources (hardware and software).

During its more than 50 years of activity, the Power Engineering Faculty continuously shaped its training system according to Romania needs and their dynamic, while its standard is competitive with the one in the developed countries. Department of Electrical Power Engineering (DEPE) trains the high quality specialists for the national field of power generation out of primary energy resources, power transmission and distribution to the consumers throughout the country.

Key-Words: - Power systems, training, computer applications, Fourier analysis, computer simulation, modelling

I. Introduction

The paper describes co-operation results between University POLITEHNICA of Bucharest and NTUA in up-dating applications of computer programming for successfully use in electric power engineering training. Ministry of Public Finance of Romania, through the Managing Authority for Community Support Framework, is guiding the training requirements, in order to accomplish the task of integration.

The Power Engineering School of Romania was founded in 1950 as the first, and nowadays, the largest one among the 8 similar faculties throughout the country.

As for NTUA of Greece, it already has a strong tradition in carrying research and development activity in the fields on all diverse aspects of telecommunications systems and techniques, computer systems and their applications in variety of implementations such as electric power systems, software and hardware engineering, control systems and biomedical engineering.

2. Present Structure of Power Engineering Faculty

Divisions:
Electric power systems, High voltage engineering and Electromagnetic interference, Power ngineering optimisation and informatisation, Electric power utilities, Electrical equipment and power system transients.

Laboratories: High voltage engineering, Electric power transmission and distribution, Electromagnetic compatibility, Electric power generation, transmission and distribution, Electrical equipment, Power system transients, Computating and optimisation, Electric power utilities, Electric power systems, Numerical methods in power engineering.

Research and Development: Inter-university national center for high voltage engineering and electromagnetic compa-tibility (TICEM), Engineering and management consulting center for continuous education (EDUPERCO).
Other facilities: Electric power micro-system model A.C. - D.C., Outdoor test area for 110 - 750 kV overhead transmission lines, Aeolian-induced vibrations test-stand for overhead line conductors.

3. EU-Integration of Romanian Future Power Systems Engineer

Power Engineering Faculty has always been interested in problems related to energy savings and efficient use, which led, by the year 1978 to the foundation of a new specialisation field, Industrial Power Utilities with the aim to provide the industrial large consumers with an appropriately trained engineer both for electric and thermal energy management, including in its curricula chapters devoted to higher efficiency of these activities and to the efficient use of energy, especially of the electric one.

Considering the geographic area covered by the national power system and the necessity to co-ordinate its control measures in certain nodes a special topic is the grid management via dispatching centres.

Power system deregularisation and the new energy market offer the condition for competition within the electric power field. As a result the power engineering training has to be reshaped to consider the restructuring activities specific to the present power system.

One of the major problems of power engineering is the quality of the energy supplied to consumers. The electrical power engineering students receive a special training in this field, dedicated lectures treating electric power quality quantifiers, as well as the due measuring methods and actions necessary to keep these within normal operation limits.

The present situation, which on an international scale includes a strong battle against environmental pollution, the study of the environment electromagnetic protection, of the TV and radio broadcasting protection, of the data-transfer protection, and of the electromagnetic field biological impact are well justified.

A sound training of the future electrical power engineers should also include the field of electric power end-use. The students are trained on subject like classic and modern electro-technologies aimed at an high-efficiency use of the electric power and at an energy low-content of human activities, as a whole. The evolution of electric power system analyses methods has paralleled the evolving technical problems and business needs of electric utilities. Technical requirements and current performance of power system analyses tools - advances in computer and software technology - are the powerful means to respond to the modern training in power systems.

A new problem that is to be very soon considered is the energy saving by the small consumers (the private ones, the ones in agriculture, small industrial workshops, public services) whose weight in the national energy balance tends to become significant in the new economical structure of Romania.

4. Teaching Activity and Scientific Research

The complexity of the power generation, transmission and distribution implies a special training of the human resources that are expected to be efficient in exploiting the existing modern installations and equipment. Some numerical data could provide a first-glance image of the national power system.

The power transmission is performed using overhead (mostly) and underground lines that sums up to 155 km of 750 kV lines, 4 400 km of 400 kV lines, 3 570 km of 220 kV lines and 18 000 km of 110 kV lines (out of these lines, 280 km are underground lines).

For power distribution, 101 450 km of 10 kV overhead and underground lines are used (13.050 km of underground lines), 6 821 km of 6 kV underground lines and 168 350 km of 0.4 kV lines (46.053 km of them being underground lines).

The installed power in transformer substations is equal to 71 300 MVA, while the one installed in transformer points is equal to 23 200MVA. In training the Electric Power Engineering graduates the present problems of all the exploiting, managing and planning branches of the national power system are considered.

The complex process of restructuring and deregul-arisation get special attention, as well as the perspective link with UCTE network. As a result, the lectures offered to the students accordingly cover a wide spectrum of modern topics. As an example, we can cite here the topics on static stability and the transient stability of electric power systems, which - due to their large extent and the problems implied by their control - are among the most complex systems created by human activity.

Special studies are devoted to the present problems of insulation co-ordination, considering also the very fast transient voltages and the modern equipment for over voltage protection e.g. zinc oxide surge arresters.

Considering the length and the importance of the transmission lines, a special attention is devoted to the modern technologies applied in electric power engineering field, that include power electronics.

Such modern equipment includes FACTS (Flexible Alternative Current Transmission Systems) circuits, which offer the opportunity of improving the power system controllability (power flow, voltage level, and frequency). The HVDC (high-voltage direct current) transmission lines are also considered, including the "back-to-back" converter substations which could prove especially appropriate for the future link of the national power grid to the UCTE one.

The large number of the electric utilities and the important size of the installations required to supply them impose that the study of the distribution networks should be of a special interest in electrical power engineering training.

Last-hour achievements within the field of informatics are also present in the curricula for future electrical power specialists. Among them, a special attention is devoted to AI (artificial intelligence) techniques: Expert systems, Neural networks, Fuzzy systems and Decision trees, that are used when optimising the national grid operation and forecasting its evolution.

5. New Training Items in Modelling HV Processes

The harmonic pollution of the consumers is a very actual problem for the specialists working in Power System engineering. That why our training in Industrial Power Utility is sustained by modelling and simulation of this processes. When non-linear loads exist, like switching power supplies, transformers, that saturate, capacitors which charge to peak of the supply voltage and converters used in drives, the characteristic of the load is dynamic. As the characteristic of the load changes, the frequency of the current will change.

That changing current and resulting complex waveform is a result of these load changes. A fixed load characteristic and changing AC line voltage characteristics can also result in a complex current waveform. The percentages of harmonic current will always be a percentage of the fundamental current. The presence of harmonic currents will not increase the demands on the electrical system on the basis of current amplitudes, but on the basis of the additional heating that can occur in electrical components not designed to handle the affects of higher frequency currents. Computer applications (digital simulations of the due processes) are used to determine the transient voltage/current waveform.

With converter-type power equipment or other non-linear components (MOV's), highly distorted waveshapes can occur. For each particular configuration, the harmonic content can be identified, allowing for a systematic study of network-equipment interference, considering particular data for voltage sources, switching type and network components.

The Fourier Series defines the individual values for the harmonic currents in each case. Special components are identified to economically control harmonic distortion within general guidelines.

The influence on the harmonic propagation on overhead transmission lines operating in unbalanced power systems is studied according to the influence of different components.

Among these the following components should be mentioned: power transformer (actual turn ratio, connection diagram, short-circuit impedance), overhead lines (phase angles and neutral conductor size, layout, lengths, short-circuit impedance, capacitance (when needed), capacitor bank (voltage rating, VAr rating, configuration), generator (subtransient impedance, configuration), loads (linear: watts, power factor, composition, balance and nonlinear: expected level of harmonic current injection, magnitude and phase angle)

.The *Discrete Fourier Transform* (DFT) is usually used in an harmonic study since the measured data is always available as a sampled time function. Fourier analysis can be applied using DFT.

Modelling advantages. The most important advantages coming out the modelling and simulation methods are:

- the possibility to vary any of the circuit parameters, having the possibility to notice their influence on the problem analysed;

- the possibility to modify the disturbing character of the consumer and its effects on the resonance phenomenon;
- the possibility to modify the compensation power;
- the precision for introduction system of input data.

5.1. Non-Sinusoidal Regime Modelling

Electric networks operate under favourable conditions in case voltage and current obey very simple. In AC networks, the current and voltage are expected to be sine waves. Any deviation leads to the presence of supplementary currents and voltages having a higher frequency, which can lead to rated normal regime alteration, both inside that network, as well as in its neighbouring networks

Throughout the network, the harmonic sources and the harmonic regime generated can be the triggering phenomenon for high level overvoltages and high currents, which can lead to insulation sparkover or breakdown or conductor overheating. And it is to be stressed that all these effects originate in high order harmonic voltages and currents, due to deviations from the expected sine waves.

Power transformers and high voltage are well known sources for high order harmonics, especially when their core is operating under saturation conditions. Magnetic saturation of the steel core is the main cause for a strong distortion of the current and voltage waves. Under a sinusoidal voltage applied to a winding, the absorbed magnetising current will have a pointed waveshape, a proof that its harmonic content is very rich.

The same situation is identified when strongly non-linear elements are presents within the network. For instance, it is known that corona discharge on the conductors of high-voltage (HV) and very high-voltage (VHV) lines is characterised by a rapid rise of the discharge current as soon as the voltage increase over a critical value.

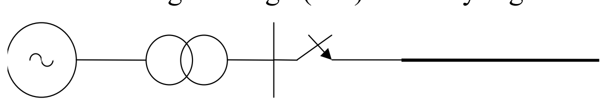

Fig. 1, *a*. Equivalent circuit for the power system.

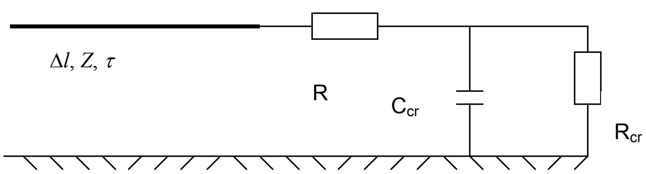

Fig. 1, *b*. Corona discharge model.

It is this fact that explains the existence of high order harmonic current and voltages on transmission lines.

Numerical simulation can be employed to anticipate the problems caused within the power system by the harmonic components and estimate the procedures to control them.

In order to determine the value of harmonic distortion, each component of the system has to be modelled as being frequency dependent. Recommendations are formulated for modelling the components (harmonic sources, transport and distribution lines, filters and condenser units, power transformers and different loads) and the electric network.

A harmonic study base can be established when modelling every component type:

- Harmonic sources are the most important element when simulating the harmonic regime. Harmonic currents can originate in a certain number of sources, including static converters, arc furnaces non-linear motors, computer networks, etc. The input data for database can be obtained experimentally or from reported data within specialised literature.
- When studying the harmonic regime in case of transport and distribution lines, it is particularly important to consider their frequency dependency. Capacitive and inductive mutual coupling of lines with different rated voltage have also to be included into the model, since high frequency couplings could result in resonance regimes within lower voltage lines or within telecommunication lines.

There are three possible modelling procedures for these effects:

- a linear model can be adopted for short lines, with the impedance considered as a linear function of frequency;
- a simplified model for long lines could employ a linear model with lumped capacitive parameters at both ends;
- the preferred model is the one including a non-linear impedance model, which considers the components with distributed parameters, skin effect, etc (Fig.1).

The difference between a linear and a non-linear model can be traced in Figures 2 and 3.

Power transformers operating in a saturated regime are modelled as harmonic sources, the process of nonlinearity generation being liable of a more detailed modelling by examining the flux and current waveshapes, as well as the hysteresis curve.

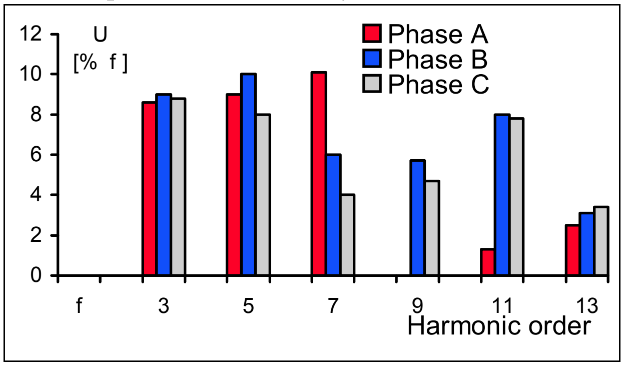

Fig. 2. Fourier analysis
(linear characteristic, non-symmetrical regime).

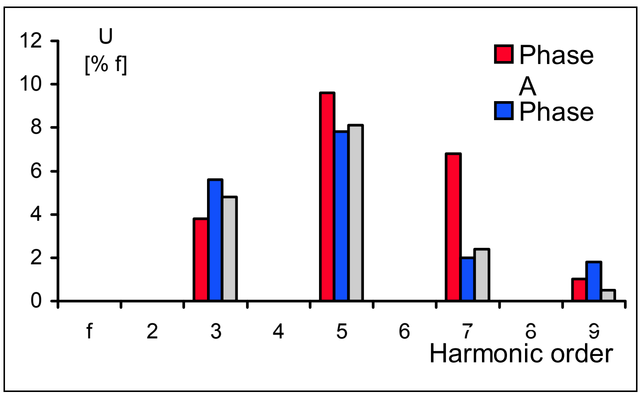

Fig. 3. Fourier analysis for a circuit including a generating unit, a power transformer, a 400 kV transmission line and a load (non-linear)

5.2 Saturation Harmonics on Long Transmission Lines

A. General properties

Transformer core saturation could - in certain cases – result in voltage escalations, as a result of the presence of high order and low order harmonic components, which could be of follow-up and resonance type.

The group of follow-up harmonics are high order harmonics (with frequencies that are multiple of fundamental power frequency), of odd order, with frequencies that are 3, 5 7, … times the fundamental one (f_s = 50 Hz). The cause responsible for their presence is the non-sine wave of the magnetisation current for a voltage higher than the rated value.

High order odd harmonics are possible under certain circumstances, with high amplitudes only in

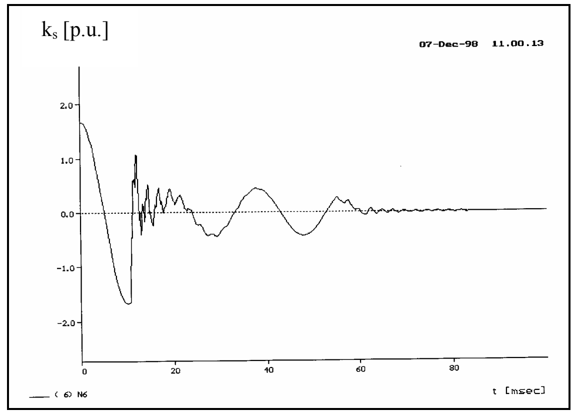

Fig. 4 . Voltage waveshape for 750 kV network, for single phase ground fault (phase A) and reclosing on remanently charged line, considering the magnetisation curve of the transformer;
(line node, k_s = 1,8, detail for 0 – 100 ms).

case the specific frequency of the circuit is close to the one of the considered harmonic. Resonant harmonics are only identified in case these two values are equal.

B. Study results

The resonance components are only present in case specific frequency of the circuit (considering the saturation) equal to the considered harmonic component /1/. The circuit containing the tripped line (together with the supply source) is a complex oscillatory circuit, with a certain content of specific frequencies. This is why, in general, a resonance is possible for two frequencies, e.g. the 2nd and the 5th ones. But, such situations are not likely to occur /2/. In most cases a

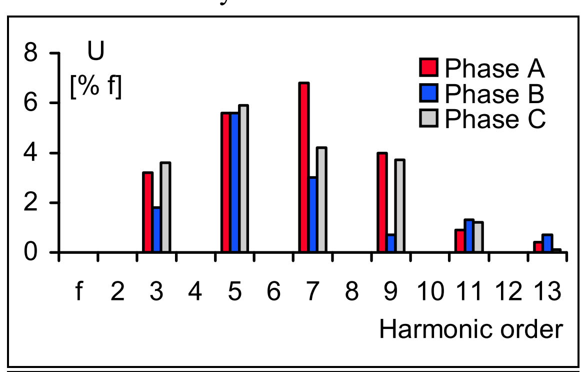

Fig. 5. The effect of modelling high frequency coupling.

single frequency is dominant in the voltage waveshape and for this resonant conditions are generated.

A model study of the different circuits including long lines reveals that most of the cases present voltage escalations dependent on the presence of the 5th, 7th, 2nd components or the presence of the $f_s/3$ sub-harmonic component.

For a long line switching-in the first specific frequency, as computed without considering the core saturation, is of the order of $(1,4 \div 2,5)f_s$, favouring thus the appearance of 2nd or 3rd harmonic components. /2, 3, 6/. But 3rd order harmonic component is but rarely present as a result of two main reasons:

- The first main reason is the primary, delta-connected winding of the transformer. It is equivalent, thus, to a low inductance shunt for triple frequency; an exception is the low power transformer, having a high inductance tertiary winding.
- The second reason is a consequence of the fact that for considerable amplitude harmonics to appear it is necessary a power frequency voltage escalation on the branch representing the magnetic circuit. In case the first specific frequency is close to $3 f_s$, then the voltage escalations are insignificant.

The sub-harmonic resonance was closely examined by the time the first VHV transmission line was constructed. An analogue model study /7/ revealed stable sub-harmonic components with large amplitudes, caused by the nonlinearity of the reactors (whose magnetisation curve could by described using a third degree polynome). The occurrence of these oscillations in real conditions was excluded on the basis of the diminished nonlinearity of the reactors and of the design of a proper substation circuit and proper location of the switching equipment.

The method is used to study the 2nd and 5th harmonic components specific for the follow-up and resonant frequencies, using an interface designed by the authors.

6. CONCLUSIONS

There are very important facilities in Electrical training using computer simulation, for the teaching staff and for the students too:

- the increasing of applications number;
- finding out easier conclusions using more examples;
- efficient individual work, for each type of studied problem;
- a better systematisation of methods to apply;
- an efficient learning and revision;
- better possibility for the teacher to verify the systematic study and the quantity of the assimilated information;
- high flexibility of the study;
- organise demonstration tests, individual research;
- expandability of the model, an easy integration of the new problems;
- the elimination of the descriptive and old-fashioned methods in training;
- the decreasing the solving time.

The modelling is successful used to understand better the Electromagnetic Compatibility problems, as well as the impact of the consumers (harmonic pollution) on the equipment and the environment.

The digital modelling of the above mentioned problems leads to a better understanding of complex EMC topics and the accomplishment of EU requirement regarding energy and environment.

As well, major tasks in government teching policy are to:

- promote EU training co-operation;
- contribute to the further development and establishment of a common approach and harmonized training programs;
- implement training courses;
- support the coordinated EU training policy in the field of nuclear power; enhance the training co-operation with other international organizations

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