International Journal of Electrical and Power Engineering 1 (4): 468-478, 2007

Integrated Software, for Impulse Voltages Estimation, in High Voltage Networks with Distributed Generation

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Abstract: In this research, was created functional software for quick calculation of impulse overvoltages caused from lightning incidents in electric energy distribution networks. Aim of the work is to facilitate the potential investors for the optimal installation place choice for Renewable Energy Sources distributed production. The application is practical because it obtains all data from already stored data in a geographic information system. Also it is accurate because of the using of ATP-EMTP, a powerful transient phenomena calculation program. In this study, they are presented the theoretical background, the tools that were used and an application for the prefecture of Laconia, Greece.

Key words: Distributed generation, renewable energy sources, impulse overvoltage calculation, ATP-EMTP, GIS

INTRODUCTION

The release of the energy market has made optimal network management, fast damage repair and continuous network extension for the connection of new producers or consumers of paramount importance. The improvement of electricity services underlines the need for the development of informed digital maps with user-friendly management combined with power flow programs and programs for the calculation of overvoltages and faults. The ultimate goal of such applications is the optimum exploitation of distributed production from renewable energy sources and reliable network extension due to the continuous addition of new product units and consumers.

In this cohort an interface between a Geographic Information System, which has been developed by the High Voltage Laboratory (Department of Electrical and Computer Engineering, University of Patras) for the study and designing of electric distribution networks that operate under high voltage of 20 kV (GIS-Zeus) and the ATP-EMTP. The aim of this interface, is the rapid and effective calculation of impulse overvoltage as a result of lightning incidents to installations of distributed production from renewable energy sources; in essence this program calculates the exact voltage waveform at the preferable nodes of the circuit.

The aim of the present study, is to provide the necessary theoretical foundation and the properties of the aforementioned interface followed by an example of its implementation on the 20 kV electric distribution network of Laconia Prefecture, Greece, where the installation of production stations by renewable energy sources is expected in the foreseeable future. Under this scope the current can function as the manual.

GEOGRAPHIC INFORMATION SYSTEMS AND THE ELECTROMAGNETIC TRANSIENTS PROGRAM ATP-EMTP

The free electric energy market requires excellent network knowledge, optimal economic exploitation, fast extension and direct damage repair. The electric networks are constantly extended due to the continuous addition of new loads and producers (small hydroelectric stations, wind parks and distributed generation of energy from renewable sources in general), rendering network follow-up with informed and distinct maps indispensable. Using conventional methods, this process involves the constant creation of new imprintings (traditional maps or sketches) in paper that require large operational costs, waste great amounts of time and effort and cause delays in the briefings and deceleration of investments due to delayed customer service. Obviously, this problem is intensified in regions where the network growth is rapid because of the increasing number of connections of new distributed generation plants.

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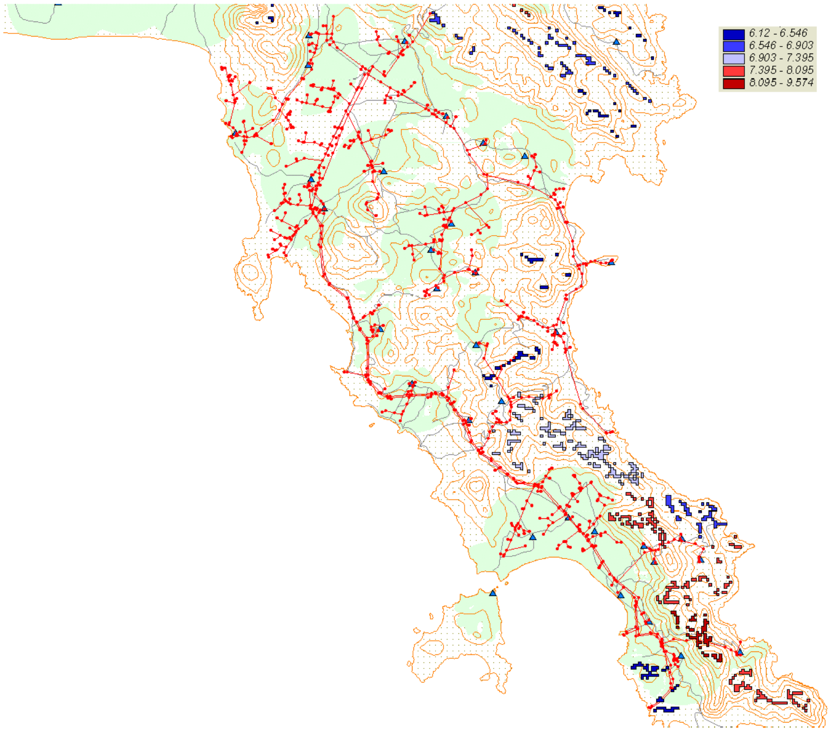


Fig. 1a: GIS map and medium voltage (20 kV) distribution lines in prefecture of laconia, Greece

Taking into account the aforementioned points, the electric companies are driven to the development of applications that organize and record the necessary information with modern solutions of informational technology. Such programs are described on the whole as GIS. The science of geography describes the objects and overlays the information of the surface of the ground; essentially it is a frame of knowledge format. A GIS is an analysis and projection system of geographic information. This information can be drawn in the form of maps, parcels of geographic information (tables) and results of calculation analysis. The GIS systems practicality stems from the fact that data management is organized in layers.

The GIS is often confused with the maps (http://www.mapinfo.com/). The maps however, are only one from the three GIS subsets. Comprehensively, the GIS is comprised of:

- The database of the geographic data.
- Map creation: These systems offer dynamic mapping creation and provide functions that can determine the relations among the various elements on the surface of the ground.
- Model creation: Using individually adapted tools, they can provide geographic information management and conclusion exporting.

Moreover, various GIS systems are available that provide an array of different functions that can be adapted to the individual needs of each user. For example, if the objective is simple area mapping, imprinting of geographic information is adequate. But if the objective comprises network study and conclusion export of steady and transient condition, the electric information and apparatus characteristics imprinting is also required.

The GIS program developed by the High Voltage laboratory (Psalidas *et al*., 2005) fulfils the purpose of creating a complete system that can both record a medium voltage network for simple mapping production and at the same time perform complex studies on the calculation of network condition. Network digitalization is essential for recording all the necessary ground and electric elements (Fig. 1a and b).

The following layers have been selected to be stored in electronic format (Agoris *et al*., 2004):

- The political map of the studied region
- The region wind potential
- The contour lines
- The aquatic flows
- The road network
- The electric network
- Lightening curves of the area

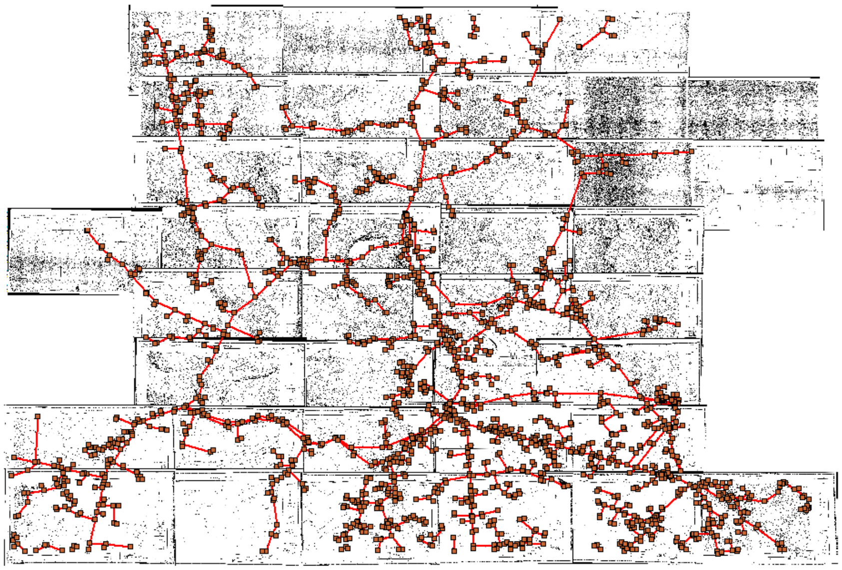


Fig. 1b: GIS map and medium voltage (20 kV) distribution lines in prefecture of arta, Greece

Table 1: Medium voltage lines technical characteristics

line_type_nan	Material name	D	Insulation	Resistance	mmH_m	mmF_m	Comments
3*16ACSR	ACSR	0	0	1.268	0.422	0	
3*35ACSR	ACSR	0	0	0.576	0.397	0	
3*35AAAC	AAAC	0	0	1.071	0.393	0	
3*95ACSR	ACSR	0	0	0.215	0.334	0	R,X Times SE Ohm/km
3*185AAAC	AAAC	0	0	0.204	0.337	0	
3*70AAAC	AAAC	0	0	0.562	0.37	0	
3*35NHKBA	NHKBA	0	0	0.576	0.1	0	Den exoume sygrkrimena stoixeia

The electric network, which represents the most important part for this application, includes the nodes and the lines. Each node includes the following information:

- Node type (branch, change of line type, end node, earth node, production, Low Voltage, Medium Voltage).
- Region
- Area
- Network owner
- Main or secondary
- Main line
- Nominal voltage
- Insulation level
- Observations
- Medium voltage load
- Active power
- Reactive power

The electric characteristics (per length ohmic, inductive and capacitive resistance,) have also been recorded for each type of line (Table 1).

The proposed application was developed in order to achieve minimum renewal times of electric map and at the same time to record all the essential information to perform network studies. The load flow analysis is materialized using the program PSS/E, while the transient situations are studied using the EMTP-ATP (ATP-EMTP Rule Book; http://www.eeug.org).

For the resolution of transient phenomena the EMTP is used, a powerful but at the same time complicated program. The program of electromagnetic phenomena analysis EMTP has its roots in Bonneville Power Administration (BPA), collaborator of American Service of Energy, USA. EMTP have been developed using government funds for more than one decade, dedicated for free distribution. In 1984 became an attempt was made to trade the program and consequently BPA was excluded from further development of EMTP. By that time, a non publication commercial of EMTP, the ATP, was created. The ATP is distributed without authorization fees from those users that do not participate to the EMTP trading.

ATP is a universal program system for digital simulation of transient phenomena of electromagnetic as well as electromechanical nature. With this digital program, complex networks and control systems of arbitrary structure can be simulated.

ATP has extensive modeling capabilities and additional important features besides the computation of transients. It has been continuously developed through international contributions over the past 20 years.

Trapezoidal rule of integration is used to solve the differential equations of system components in the time domain.

Non-zero initial conditions can be determined either automatically by a steady-state phasor solution or they can be entered by the user for simpler components.

Interfacing capability to the program modules TACS (Transient Analysis of Control Systems) and MODELS (a simulation language) enables modeling of control systems and components with nonlinear characteristics such as arcs and corona. Symmetric or asymmetric disturbances are allowed, such as faults, lightning surges and any kind of switching operations including commutation of valves.

Frequency response of phasor networks is calculated using Frequency scan feature.

Dynamic systems can also be simulated using TACS and MODELS control system modeling.

GREEK ELECTRIC NETWORK

The electric network is separated to the transportation and distribution lines (http://www.desmie.gr). The installations of RES distributed generation are installed to the medium voltage distribution network, which is the reason that this study was implemented on 20 kV distribution lines of medium voltage.

The first overhead high voltage transportation lines of Greek interconnected system were manufactured in 150 kV and were simple circuit. In the 60's decade the double circuit transportation lines were developed.

Around 1969 the use of 400 kV lines was studied and around 1972 the network of 400 kV that is constituted by simple and double circuit overhead lines was developed. The networks of 400 and 150 kV are interconnected with autotransformers. In selected cases transportation lines of 66 kV in Crete and Rhodes were manufactured. This policy is used up to now.

Medium voltage distribution networks before 1970 functioned in the voltage of 15 kV throughout the country, with the exception of Athens the region that functioned in the 22 and 6.6 kV. The 20 kV distribution voltage network, that is currently used, was standardized in 1970 for economical harmonization with the European standardizations reasons.

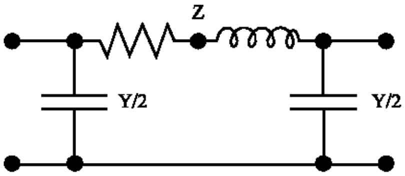


Fig. 2: Single phase equivalent for distribution lines

The major part of distribution network functions in the 20 kV. In the remainder parts that function in lower voltage (15 kV) equipment of 20 kV is being installed aiming at the progressive upgrade to the 20 kV voltage.

The standardization of 20 kV voltage for the medium voltage distribution networks throughout the country led to the adoption the Basic impulse Insulation Level (BIL) of 125 kV. All the medium voltage networks are three phase, three conductors.

The standardized nominal voltages of operation for the Greek electric network are:

- Transportation network: 400 , 150 and 66 kV.
- Medium voltage distribution network: 20 and 15 kV.
- Low voltage distribution network: 380 V/220 V (400 V/230 V).

The medium voltage network is constituted by conductors of three categories that are selected depending on the prevailing needs. Thus ACSR conductors are used in all cases of nominal loads in regions with normal corrosiveness. The Cu conductors are used in regions with intense corrosiveness, mainly coastal but also regions with intense industrial pollution. Finally the tortuous cables are used in forestation regions, in coastal regions with frequent faults with Cu conductors, in mountainous regions with large ice volumes and in special cases for safety reasons, protection of the environment and at forestal areas.

The choice of overhead line conductors' cross-section is governed by technical restrictions that are related to the largest permissible intensity (thermal load), to the largest permissible voltage fall and to the mechanic tenacity of the line. Following the above restrictions, optimal cross-section is considered the one when the cost of overhead line is entirety minimized. The total cost of the overhead line is calculated from the summation of manufacturing, exploitation and load and energy losses costs.

An overhead line can be simulated by the single phase equivalent (Fig. 2). The capacity and the induction of all overhead lines mainly depend on the line geometry and the conductors' distances from each other and minimally on the conductors' cross-section.

For the standardized provisions medium voltage overhead lines, line capacity is 10 nF km^{-1}. The induction and the ohmic resistance of lines are described in Table 1.

LIGHTNING AND OVERHEAD DISTRIBUTION LINES

Lightning incidence: The following data were drawn from (IEEE, 1997). Lightning occurs during rainstorms, snowstorms and other natural phenomena. However, in most areas, rainstorms are the primary source of lightning. Storms produce intracloud, cloud-to-cloud and cloud-to-ground lightning. Although intracloud lightning is most frequent, it is cloud-to-ground lightning that affects overhead distribution lines. During a storm, power interruptions are caused by wind and lightning. Interruptions caused by wind, trees and damaged equipment are sometimes assumed to be caused by lightning, which will make the number of lightning-caused interruptions appear artificially high. In most areas of the world, an indication of lightning activity may be obtained from keraunic data (thunderstorm days per year). The keraunic level is an indication of regional lightning activity based on average quantities derived from historically available ground-level observations. A more detailed depiction of lightning activity may be obtained from lightning Ground Flash Density (GFD) maps, which are created from information obtained via lightning-detection networks.

Lightning-location systems and flash-counter networks have been deployed all over the world. With enough experience, these networks may provide detailed GFD maps. GFD maps will provide more detailed and accurate thunder data compared to available information. Location systems also provide measured quantities that are more useful and detailed than keraunic data. In addition to providing the frequency of lightning, networks can also provide the date, time and location, number of strokes, estimate of peak stroke current and polarity.

In some areas of the world, these systems have or are close to having enough data (7 years at a minimum) for design purposes. GFD maps are currently being used for distribution line design, estimating lightning-caused flashovers and for many other types of lightning analysis.

The reliability of a distribution line is dependent on its exposure to lightning. To determine exposure, the annual number of flashes per unit area per unit time is needed.

The GFD may be estimated from the keraunic level using Eq. 1.

$$N_g = 0.04 T_d^{1.25} \text{ [flashes/km}^2\text{/yr]} \quad (1)$$

Where: T_d is the number of thunderstorm days per year (the keraunic level).

Another Estimate of GFD may be obtained from thunderstorm hour records, as shown by:

$$N_g = 0.054 T_h^{1.1} \quad (2)$$

Estimates of average GFD may also be obtained directly from lightning-detection network data or from flash counters. If enough years of data are available, identification of regional variations is possible.

Lightning and lightning-caused interruption rates have considerable year-to-year variation. The historical standard deviation for yearly measurements of lightning activity ranges from 20-50%.

Estimates of GFD for a small region such as 10×10 km have a larger standard deviation of about 30-50%. Larger regions such as 500×500 km have a smaller standard deviation about 20-25%.

In areas with lower levels of lightning activity, the relative standard deviation is higher.

With such large standard deviations, it takes many years of data collection to accurately estimate the mean values. This is especially true when using ground flash data for a localized region or estimating lightning caused interruption rates on a distribution line from outage data.

Lighting strokes to overheads lines and structure height: Lightning may have a significant effect on a line's reliability, especially if its poles are higher than the surrounding terrain. More flashes are collected by taller structures. The flash collection rate N, in open ground (no significant trees or buildings nearby), is estimated by Eriksson's equation.

$$N = N_g \left(\frac{28h^{0.6} + b}{10} \right) \quad (3)$$

Where:

h : Is the pole height (m);
b : Is the structure width (m);
N_g : Is the ground density (flashes/km^2/yr);
N : Is flashes/100 km/yr.

For most distribution lines, the structure width factor b is negligible.

From Eq. 3, if the pole height is increased by 20%, the flash rate to the overhead distribution line would increase by 12%. Note that a distribution line may collect many more flashes than would have been predicted by the 4×H model (IEEE, 1997), which was used for several years. In the 4×H model, the number of flashes collected by the distribution line was estimated by a width of twice the line height on both sides of the line.

The exposure of the distribution line to lightning depends on how much the structures protrude above the surrounding terrain. Structures located along the top of mountains, ridges, or hills will be more likely targets for lightning strikes than those shielded by natural features.

Induced-voltage flashovers: Lightning may account for many power interruptions in distribution lines. Lightning may cause flashovers from

- Direct strokes
- Induced voltages from nearby strokes

Direct lightning to power distribution lines causes insulation flashover in the great majority of cases. For example, a stroke of as weak as 10 kA would produce an overvoltage of around 2000 kV, far in excess of the insulation levels of overhead distribution lines operating up to 69 kV. However, experience and observations show that many of the lightning-related outages of low-insulation lines are due to lightning that hits the ground in proximity of the line. Most voltages induced on a distribution line by flashes that terminate near a line are less than 300 kV. Flashes may be collected by taller objects, so height and distance from the distribution line of shielding objects such as trees and buildings will influence the lightning performance of the line.

According to Rusck, the maximum voltage which is induced in a power line at the point closest to the strike may be estimated by:

$$V_{max} = 38.8\frac{I_o h_a}{y} \tag{4}$$

Where

I_o is the lightning-peak current;

h_a is the average height of the line over the ground level;

y is the closest distance between line and the lightning stroke.

Equation 4 is used for an infinitely long, single conductor above a perfectly conducting ground. A grounded neutral wire or overhead shield wire will reduce the voltage across the insulation by a factor which depends on grounding and proximity of the grounded conductor to the phase conductors. This factor is typically between 0.6 and 0.9.

Distribution-line insulation level: Most overhead construction utilizes more than one type of insulating materials for lightning protection.

The more common insulating components used in overhead distribution-line construction are porcelain, air, wood, polymer and fiberglass. Each element has its own insulation strength. When the insulating materials are used in series, the resulting insulation level is not the exact summation of those levels associated with the individual components, but is something less.

The following factors affect the lightning-flashover levels of distribution lines and make it difficult to estimate the total insulation level:

- Atmospheric conditions including air density, humidity, rainfall and atmospheric contamination.
- Polarity and the voltage rate of rise.
- Physical factors such as insulator shape, shape of metal hardware and insulator configuration (mounted vertically, horizontally, or at an angle).

If wood is in the discharge path of the lightning stroke, the stroke's effect on the insulation strength may be quite variable, dependent primarily upon the moisture on the surface of the wood. The insulation strength depends to a lesser degree on the physical dimensions of the wood. The total insulating capacity of any combination of materials is expressed using the Basic Impulse Insulation Level (BIL).

ADMISSIONS CONSIDERED FOR PROGRAM DESIGN

In order to facilitate the calculations, without importing serious error, the following admissions were considered during program development:

- The single-phase equivalent of the line was used.
- Every distribution electric energy network tower was considered, for calculating reasons, as a circuit node.
- Lines were considered not to be protected by shield wire, because the medium voltage lines in Greece do not bear shield wire.
- No further disturbances were considered to be present, such as single pole, bipolar and three polar short-circuits and interruptions that can lead to potentially grave situations for calculations simplification.
- The impulse wave damping caused by the skin and corona effects was considered negligible, because deviation is minimal and the obtained results are on the safe site.
- The impulse wave damping caused by the interaction with adjacent installations was considered negligible.
- The overvoltage was considered to be less than the maximum value (125 kV) that the regulations for the 20 kV lines predict and any breakdown on the line was not considered.

- The impulse overvoltage form was considered to be 1,2 μs/50 μs, as the regulations predict.
- The current concept was applied only on medium voltage lines, because distributed producers in Greece are connected to such lines
- The operation voltage was not considered at the calculations.
- Any installed surge arresters are not considered at the calculations.
- Both high to medium voltage and medium to low voltage transformers were considered as open circuits for the impulse overvoltage.

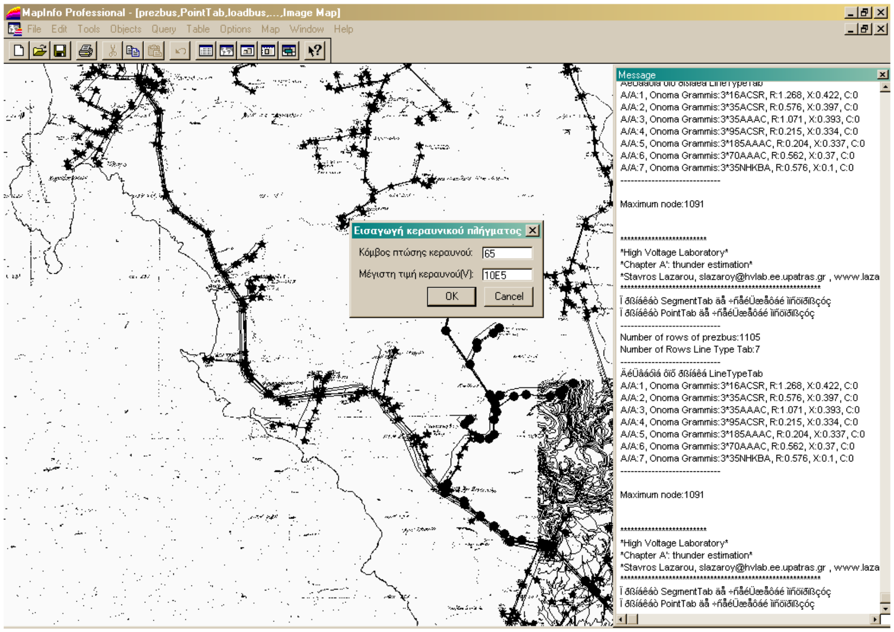
The single-phase equivalent of the line was used and the inductive overvoltages that may occur at the remaining phases of the line were not taken into consideration; this decision was taken in order to decrease the requirements in the calculating load and to conform to current practice. The choice of towers as circuit nodes serves in the direct connection of distributed production at the desirable point of the network with relatively good precision. The operation voltage is considerably smaller than the disturbance impulse overvoltage and consequently no serious error is introduced to the calculations. The transformers for high frequency signals, such as the disturbances under examination can be considered as open circuits without fault.

HOW THE PROGRAM WAS DEVELOPED

The initial application of High Voltage network recording was materialized in MapInfo environment using the programming language MapBasic, an adapted language for geographic information system applications planning. High Voltage laboratory had already recorded the territorial data with complete technical characteristics of the medium voltage electric network equipment, as previously reported in chapter 2. In order to carry out all the necessary calculations, a concrete process of program concretization was followed. Initially the following graphic user interfaces for data importation were manufactured:

- The node number that the overvoltage appears and its amplitude in Volts (Fig. 3 a).
- An option is given to calculate again the length of the lines as draw in the geographic information system and to re-estimate their technical characteristics (Fig. 3 b).
- Import of measurement node (Fig. 4 a).

Then the program draws all the essential equipment data and makes all the essential calculations. The final stage includes the creation of the ATP-EMTP entry file, which uses concrete format. In this file information about the simulation, like date, place and program author, is entered. Then the types of the lines with their technical



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Maximum node:1091


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Fig. 3a: Graphic user interface to import the node that the impulse overvoltage appeared and the impulse overvoltage amplitude in volts in the area of prefecture of laconia, Greece

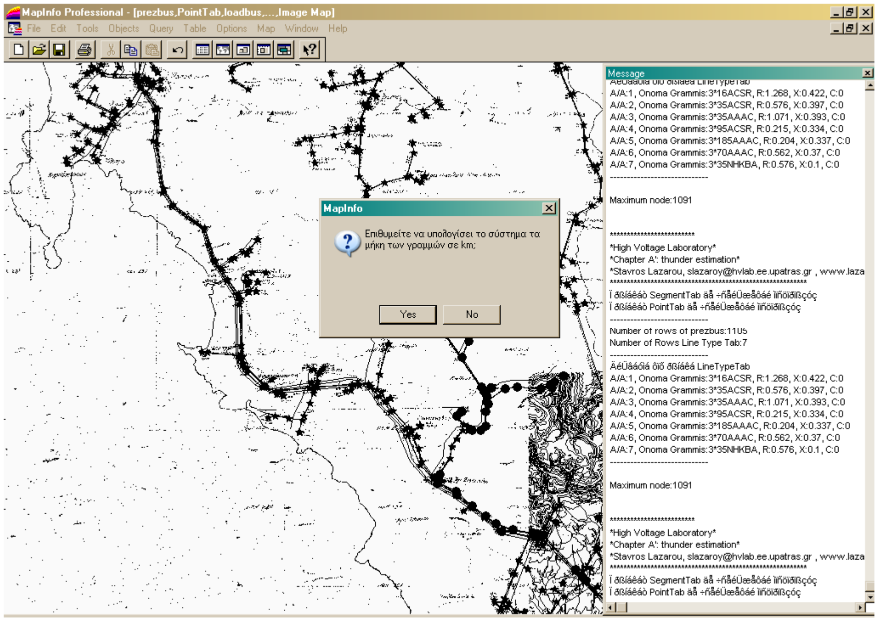

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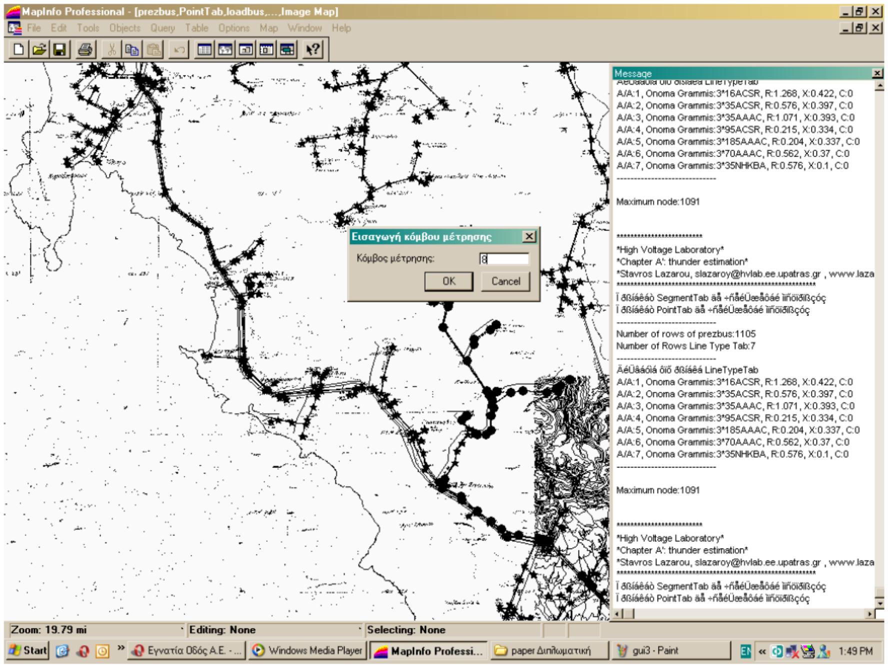
Fig. 3b: Graphic user interface that informs the user that the program is going to calculate the length and the technical characteristics of the studied line



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Number of Rows Line Type Tab:7
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ÄéÜâáóìá ôïõ ðßíáêá LineTypeTab
A/A:1, Onoma Grammis:3*16ACSR, R:1.268, X:0.422, C:0
A/A:2, Onoma Grammis:3*35ACSR, R:0.576, X:0.397, C:0
A/A:3, Onoma Grammis:3*35AAAC, R:1.071, X:0.393, C:0
A/A:4, Onoma Grammis:3*95ACSR, R:0.215, X:0.334, C:0
A/A:5, Onoma Grammis:3*185AAAC, R:0.204, X:0.337, C:0
A/A:6, Onoma Grammis:3*70AAAC, R:0.562, X:0.37, C:0
A/A:7, Onoma Grammis:3*35NHKBA, R:0.576, X:0.1, C:0
-----------------------------

Maximum node:1091


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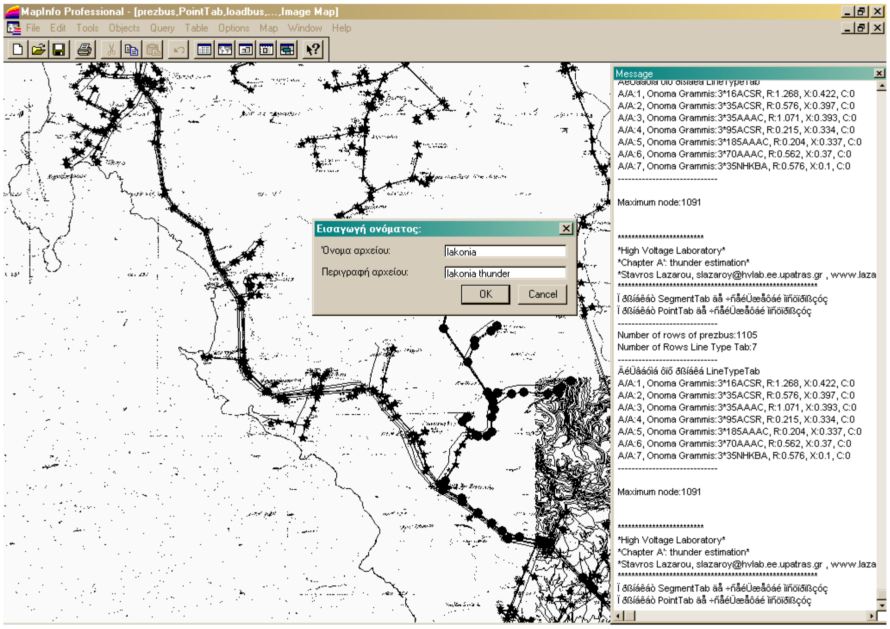
*High Voltage Laboratory*
*Chapter A': thunder estimation*
*Stavros Lazarou, slazaroy@hvlab.ee.upatras.gr , www.laza
*********************************************************
Ï ðßíáêáò SegmentTab äå ÷ñåéÜæåôáé ìïñöïðïßçóç
Ï ðßíáêáò PointTab äå ÷ñåéÜæåôáé ìïñöïðïßçóç
```

Fig. 4a: GUI for measurement node importing

characteristics are entered; it is noteworthy that this program can calculate up to 10^6 nodes. In the end of this file the measuring nodes and the characteristics of the overvoltage are entered. For the completion of the simulation this file is imported in the ATP-EMTP for process.

The program provides the possibility of two different options of operation. The usual operation calculates the expected overvoltage in the node of the line that is connected to the distributed production following a hypothetical lightening incident of known amplitude in



Όνομα αρχείου: lakonia
Περιγραφή αρχείου: lakonia thunder

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A/A:2, Onoma Grammis:3*35ACSR, R:0.576, X:0.397, C:0
A/A:3, Onoma Grammis:3*35AAAC, R:1.071, X:0.393, C:0
A/A:4, Onoma Grammis:3*95ACSR, R:0.215, X:0.334, C:0
A/A:5, Onoma Grammis:3*185AAAC, R:0.204, X:0.337, C:0
A/A:6, Onoma Grammis:3*70AAAC, R:0.562, X:0.37, C:0
A/A:7, Onoma Grammis:3*35NHKBA, R:0.576, X:0.1, C:0
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Maximum node:1091


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************************************************************
Ï ðßíáêáò SegmentTab äå ÷ñåéÜæåôáé ìïñöïðïßçóç
Ï ðßíáêáò PointTab äå ÷ñåéÜæåôáé ìïñöïðïßçóç
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Number of rows of prezbus:1105
Number of Rows Line Type Tab:7
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ÄéÜâáóìá ôïõ ðßíáêá LineTypeTab
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A/A:2, Onoma Grammis:3*35ACSR, R:0.576, X:0.397, C:0
A/A:3, Onoma Grammis:3*35AAAC, R:1.071, X:0.393, C:0
A/A:4, Onoma Grammis:3*95ACSR, R:0.215, X:0.334, C:0
A/A:5, Onoma Grammis:3*185AAAC, R:0.204, X:0.337, C:0
A/A:6, Onoma Grammis:3*70AAAC, R:0.562, X:0.37, C:0
A/A:7, Onoma Grammis:3*35NHKBA, R:0.576, X:0.1, C:0
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Maximum node:1091


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************************************************************
Ï ðßíáêáò SegmentTab äå ÷ñåéÜæåôáé ìïñöïðïßçóç
Ï ðßíáêáò PointTab äå ÷ñåéÜæåôáé ìïñöïðïßçóç
```

Fig. 4b: GUI for file description and file name importing

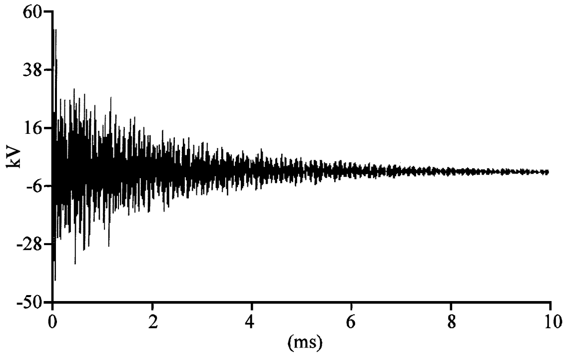

Fig. 5a: Effect of the impulse overvoltage at node 220. The lighting incident occurred at the network node 229

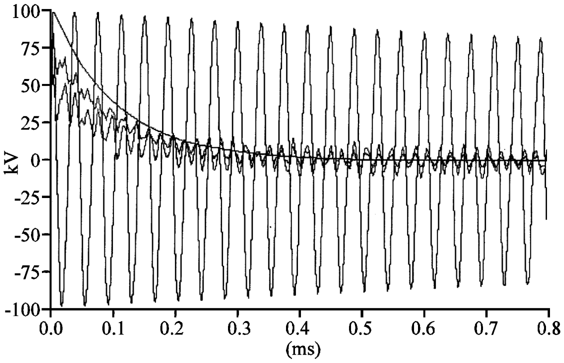

Fig. 5b: Effect of impulse overvoltage caused from lighting at network node 229(red color), to the neighboring network nodes 227(violet color), 228 (green color), 230(blue color)

the line, possibly in an area of high mountains or in regions with intense lightening activity (Fig. 5 a). According to the alternative operation, the program can also calculate the effect of an impulse disturbance, which occurred in a specific node, at up to 10 near neighboring nodes (Fig. 5b).

Program reliability was checked by using two different ways:

- With the analytic resolution and confirmation of a small circuit.
- By checking the required time for the fault to reach a node at a known distance.

THE INTERFACE

The program was manufactured in order to calculate the impulse wave in given network with two different ways. The process of calculation begins with the electric network selection. Then using the algorithm that was already described in the previous paragraph, the renewable energy source in the desirable area is spatially placed and connected into the electric network. The node of circuit that is in lightning danger is selected and the amplitude of the overvoltage is considered. Finally the node that has been connected to the renewable source of energy is selected. Eventually the program calculates the precise impulse voltage in the node of installation connection.

The alternative program operation is recommended when the production unit is located in a region of high lightning danger. For example it is desirable to install the renewable energy source plant in the top of a mountain; intense danger of impulse overvoltage appearance at the installation exists and consequently a sophisticated decision for node connection in the network is of outmost importance. In this case a hypothetical overvoltage is considered at an adjacent to the installation node and the program calculates the precise waveform for the near nodes.

USING THE PROGRAM IN THE PREFECTURE OF LACONIA, GREECE

For demonstration reasons we selected to apply the two different operations of this program in the electric distribution network of Laconia prefecture, Greece, which is property of Power Public Company (PPC) (Fig. 1a). The Laconia area was selected due to its rich aeolian potential (http://www.cres.gr) and the relatively weak electric network. Except from the prefecture of Laconia, it is currently possible to use this program in the prefectures of Arta, Lesvos, Achaia in Greece and the provinces of Limassol and Orounta in Cyprus. The laboratory of High Voltage has also undertaken the arduous task to cover all areas in Greece and Southern Cyprus.

As previously mentioned, a distribution network node of Laconia that it is likely to present impulse lightning overvoltage was considered initially. The network node with serial number 229 was considered of high lightning risk, because it is located at the highest point of mountain Chionovouni. This mountain is located at the centre of the map in Fig. 1a. Impulse overvoltage with amplitude 100 kV and form 1.2 μs/50 μs was considered, which is representative for lightning incidents (Fig. 3 and 4). Then a renewable energy sources production station was hypothetically installed at the network node with serial number 220 that is found eastwards. The simulation results are presented in Fig. 5 a. From the above waveform continuous and absorbed reflections caused by the structure of the network were observed. It is anticipated that the highest voltage amplitude the node 220 will receive is about 55 kV.

Moreover taking advantage of the program's capability to calculate the precise voltage waveform at the near nodes of disturbance appearance, the Fig. 5 b for nodes 227,228 and 230 is generated. From this figure it can be deduced that the node 230 (in blue color) strained more than the node 229 where the disturbance occurred. This interesting finding underlines the importance of the proposed application. It is worth mentioning that even for a simple line of certain kilometers, simulation time unfortunately exceeds 20 min with the use of the usual personal computers.

CONCLUSION AND FUTURE WORK

The importance of this application is summarized in the following points:

- For the first time an interface between two completely different programs was developed.
- The program can accurately calculate the final voltage wave.
- It can estimate in a short period of time the largest impulse voltage that can be observed in the installation
- Ultimately it assists optimum lightning design of RES installations.

Certain improvements of the program are scheduled for the future:

- The option of surge arresters incorporation in the line
- Automatic determination of optimal installation place of distributed generation
- Adaptation to Transmission Network.
- Upgrade for more than 10^6 network nodes.
- The option of introducing additional faults, such as short-circuits and interruptions.

Notably the High Voltage Laboratory has already begun researching the possibility of using Wavelet and Fractal analysis for network studies using data that are drawn from this research.

ACKNOWLEDGEMENT

This research was in part supported by the European Union and the Greek Government. PENED 2003, code number 03ED158.

REFERENCES

Agoris, D., K. Tigas, V. Kilias, J. Kabouris, T. Koronides, J. Vlachos, M. Psalidas and E. Pyrgioti, 2004. Decision-Support Information System for Evaluating the Penetration of Dispersed Renewable Energy Sources Generation in Transmission and Distribution Networks', 40th CIGRE Session, Paris, France, pp: 6-104.

ATP-EMTP Rule Book.

http://www.cres.gr, accessed May, 2006.

http://www.desmie.gr, accessed May, 2006.

http://www.eeug.org, accessed May, 2006.

http://www.mapinfo.com/, accessed May, 2006.

IEC 60, IEC 71-1, IEC Standards.

IEEE Std 1410-1997, 'IEEE Guide for improving the Lightning Performance of Electric Power Overhead Distribution Lines.

Psalidas, M., D. Agoris, V. Kilias, K. Tigas, P. Stratis and G. Vlachos, 2005. Decision Support System for Estimating the Technically and Economically Exploitable Renewable Energy Sources Potential in Wide Areas for Connection to High Voltage Networks. Int. J. Comput. Applications Tech., 22: 137-150.

PTI Power Technologies Inc. PSS/E 26, Program Operation Manual, Vol. I.