DECISION – SUPPORT INFORMATION SYSTEM FOR EVALUATING THE PENETRATION OF DISPERSED RENEWABLE ENERGY SOURCES GENERATION IN TRANSMISSION AND DISTRIBUTION NETWORKS

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1. INTRODUCTION

The development of Renewable Energy Sources in Greece has been among the major energy policy lines for the last 10 years. This development is seen as an important contribution to the improvement of the environmental indicators in Greece and, in particular, to the abatement of CO₂ emissions. Legal measures and financial incentives are the tools for supporting RES projects. This status led to a solid background that attracted a great number of RES investors, particularly in wind and small hydro energy.

Under these developments, all the parameters concerning the implementation of wind energy and small hydro projects should be evaluated, in order to access the “technically and economically exploitable wind and small hydro energy potential” in wide geographic areas. These actions lead to the identification of the existing barriers for the development of RES investments, such as unavailable wind and small hydro potential information, inadequate financial schemes or inadequate infrastructure networks, such as the high voltage network. According to the previous, the technical issues that had elaborated were:

- the combination of the theoretical (computer calculated, based on the measurements at specific points) wind and small hydro potential with geographical and legislative parameters, which affect the possibility of installing RES projects in a given area (terrain barriers, land use, protected areas etc.)
- the evaluation of alternative RES policies and the definition of the appropriate subsidy levels or fiscal policies, in order to ensure attractive conditions for wind energy investors (level of investment or energy produced subsidies, tax exemptions, etc.)
- the identification of priorities concerning the specific support actions to be implemented in specific regions presenting strong advantages, e.g. high potential or disadvantages, e.g. inadequate high voltage network infrastructure.

The implementation of the tasks considered required the development of an information system for processing a large volume of data, which have a strong geographical character. The information system presented is driven by a geographical information system (GIS) platform, giving the ability to analyze the viability of RES investments in wide geographical areas.
2. METHODOLOGY

2.1 System operation

The methodology implemented in the decision support system takes into account a large amount of data and parameters affecting the technical and economic viability of RES investments. These data are classified at meteorological data, geographical data, electricity network data, RES technologies, technical and economic data relevant to the RES technologies and RES policies information.

The approach follows a five step procedure giving the user the ability to focus on specific areas and analyze in detail specific problems associated with RES exploitation. A full chain of steps is used for the assessment of the wind energy potential or the evaluation of a candidate RES investment project and a thorough analysis is performed, including macro – siting (for wind projects), energy performance, grid integration aspects (techno – economic feasibility of the connection interface) and economics.

The structure follows six main steps, as depicted in Figure 1, which is an application for wind projects evaluation:

1. Potential Estimation: This option offers a quick estimation of the prevailing potential in an easily visualised way, retrieving data from the data base.
2. Available Potential Estimation: In this option the user estimates the RES potential which is available for applications, by applying queries. These queries are based on geographical data and rules of thumb such as land use and elevation, distance from infrastructure networks (roads, high voltage power lines, etc.).
3. Estimation of the Technically Exploitable Potential: In this step, the user defines the technology (wind turbine type, hydro turbine type, etc.) to be used and the associated technical data. The system calculates the expected energy output on a monthly and yearly basis.
4. Estimation of the connection cost of the network: In this step the connection cost of the RES project with the electrical grid is calculated. Electricity network analysis models are incorporated in this step.
5. Estimation of the Economically Exploitable Potential: In this step the system processes the results of all the previous steps and calculates the costs per kWh. Investment costs, Operation and Maintenance costs as well as the costs of the connection to the electricity grid (both connection cost and bulk network reinforcement cost, if any) are taken into account. Electricity Networks analysis models are incorporated in this step.
6. Estimation of RES Investments Profitability: This option offers to the user the ability to examine the economic viability of RES projects. The system takes into account existing regulations.

![Figure 1: Six step methodology and system operation. Step by step procedure giving the ability to focus on specific areas and resolve problems associated with wind energy exploitation.](image-url)

(legislation, dispatching rules, subsidies, energy prices, etc.) and the current financial environment and calculates indicators, depicting the investments profitability (i.e. IRR, pay-back period etc.).

2.2 System Structure

All the functions of the system require the development of well structured databases comprising of the necessary information for the operation. This information could be categorized into:

1. Potential information describing the geographical distribution of the RES potential. This information includes time series describing the variation of associated quantities, such as wind velocity, river stream flow, etc.
2. Digital elevation model, describing the essential earth surface parameters, such as earth’s elevation, slope, aspect, etc.
3. Other geographic information describing the existing infrastructure and the environmental constrains, such as roads network, areas under protection, land use, visibility from towns or villages etc.
4. Electricity network information describing the geographic distribution, topology and attributes of the high (and medium) voltage network.
5. Renewable energy technologies (e.g. windmills, hydro turbines, etc.) and technical and economical data.

Taking into consideration all the functioning and data processing requirements, the system has been developed using a client – server architecture including three separate system components:

1. The database where all the geographical, descriptive and numerical information is being organized into a common area located on the server.
2. The computational models, aiming at calculating all the necessary indicators and parameters, located either on the server or on the client.
3. The user interface that provides the user with all the necessary tools for the assessment of RES potential located on the client.

2.3 Computational models

The implementation of the above options requires computational models for the:

- Calculation of the energy production. The energy produced by the wind farm (or the small hydro project or the biomass plant) is calculated per monthly or year basis. For the wind farms, a probabilistic approach is being implemented to take into consideration the stochastic nature of the wind. For the small hydro projects, the optimum type of hydro turbine is selected.
- Network analysis to estimate the network reinforcements needed and define the optimum connection scheme. Load flow analysis and static security assessment tools are utilized for this purpose.
- Economic analysis to calculate the cost of energy per kWh, taking into account the investment and the operational and maintenance costs for RES projects.
- Parametric economic analysis of investments to estimate the profitability.

3. THE ELECTRICAL NETWORK MANAGEMENT MODULE

3.1 Module operation

Integration of dispersed non-utility generation into utility grids must be examined from the network point of view, as the interconnection scheme affects both the investment cost and the power quality characteristics at consumers’ buses. It is a common practice in transmission and distribution systems operation to guarantee the smooth operation at both normal and emergency conditions (N-1). The transmission – distribution system must be adequate to securely transfer the power demanded at any substation while the voltage levels must be sustained within specific limits. The penetration of wind parks usually equipped with asynchronous generators imposes some additional problems concerning voltage levels and reactive power control. These generators are
reactive power consumers not contributing to voltage control due to the absence of an excitation system. This problem may be of great importance since the existing networks in windy sites are usually weak.

In summary, this module aims at:

1. Defining the most efficient connection scheme with the electricity grid. The user can apply different schemes and verify the smooth system operation under various conditions. For any candidate scenario, steady-state network analysis is performed in order to:
   - examine the adequacy of system transfer capability by detecting any overloading of transmission lines,
   - verify voltage profiles at system substations,
   - determine any network reinforcement needed, in transmission lines, capacitor banks, etc.
2. Calculate the grid connection cost in order to include this cost to the total installation cost, for proceeding to the economic analysis of the candidate RES project.

For performing the above checks at the electrical network in order to estimate the penetration level for a specific area with given candidate projects, a load flow analysis tool is the core of this module.

3.2 Module Structure

The module which handles the electrical network analysis, starting from the digitization and management of electrical networks, has been developed from the High Voltage Laboratory, University of Patras in collaboration with the CRES. The module, named e-Zeus, consists of four major subsystems—submodules (for simplicity reasons are called modules), which are:

- **Editor Module** – EM
- **Map Generation and Query Module** – MGQM
- **Scenario Manager Module** – SMM
- **Electrical Studies Module** – ESM

The electrical network management module digitizes the electrical network combining electrical topology information, geo-information for the distribution of the electrical network and other geographical information of the area of interest. These data are stored in a geo database and constitute the basic input for the two major applications of the module, the technical and economical study for electrical penetration of RES projects.

3.2.1 Editor Module

The Editor Module (Figure 2) is used to digitize the electrical network using as a reference the hardcopy map of the network. Depending on the needs, the maps of the electrical network provided by the Greek utility are scanned and constitute the background for the digitization.

The module has specific tools to insert each element of the network’s equipment. There are custom tools to insert a new node, line or cable, transformer or capacitor. For each element, there are special data forms that the user fills in order to describe the elements of the network.

The insert node form is shown in Figure 3. Custom data forms are available for each type of element, respectively. The digitizing process starts by digitizing some nodes and then the interconnection lines or cables. To digitize a node, the user selects the insert line/cable procedure of the module and clicks on the working area with the mouse, above the node he wants to digitize. The insert node properties form appears (Fig. 3), and the required data must be entered. The technical data as long as the spatial data, i.e. the geographic coordinates of the node, are stored in the node layer of the system as a new line of the layer’s table.

The same procedure is followed to insert a transformer or capacitor. In order to insert an interconnection line or cable, two points must be defined. These points, the starting point and the end of the line/cable must be two digitized nodes of the electrical network.

When all the elements of the network have been digitized, the database contains all the required information needed in order to totally describe the electrical network, referring to spatial, topology and electrical information. The digitizing module has also processes to edit or delete digitized elements.
3.2.2 Map Generation Module

Geographic Information Systems (GIS) are informational systems which help to manipulate, analyze and present data relative to spatial information (geo-information). The motive to base the system on a GIS platform was the strong geographical character of the data which were necessary as inputs for the system. These data, such as the theoretical wind or small hydro potential, the morphology of the terrain, the land uses, the visibility problems from inhabited areas, the routes of high voltage power lines, etc have plain geo-related information.

GIS combine the stored information in layers. Each layer includes specific information for the given area, e.g. one layer is used for roads, one for rivers, etc. The layers used for the study are in addiction to the problem which is being solved. The more layers combined the better accuracy to the digitized view of the given area.

GIS are ideal systems to produce any kind of maps. According to each time special needs, the Electrical Network Layer Group combined with other geographic layers as soon as with other type of layers (e.g. RES potential) could be presented electronically and printed. The model could also produce thematic maps. The thematic map presents the elements of the high voltage network according to the value of a selected variable. Finally, there is the option to add labels to the elements of the network, e.g. power flows near to the electrical equipment.

3.2.3 Scenario Manager Module

The system is equipped with a scenario manager, in order to study several scenarios about the connection of RES projects with the network. The scenarios, in general, could vary at the topology, or have the same topology but different loads or generations at the nodes (e.g. new wind farm), etc. The scenario manager stores characteristic variables, like total loads, productions, minimum node voltage, power losses, connection costs etc. A summary table is produced by the module which contains all the scenarios with the characteristic variables of each scenario. The scenarios are available for preview through the scenario manager report process as and for further modification.

3.2.4 Electrical Studies Module

The Electrical Studies Module (ESM) includes two sub modules. The first one creates automatically text files in a PSSE format, according to the electrical network database. This file is used as an input file for the PSSE load flow program or other load flow program that handles the same format. After the establishment of the load flow solution, the user could export the results from the PSSE in a text file with the same format. The ESM could read that file and import in the database the results, i.e. the
modulus and the angle of the voltage at each node. The ESM then calculates the power flows and current flows at each interconnection line or cable and stores the results in the database. At this point there is a control for overloading at lines or transformers. When the user saves the scenario, summary characteristic variables related to the load flow results are stored in the scenario manager database, so the user could have a supervisory view about the load flow results for all the scenarios he made. The second sub module creates the ybus matrix and other required matrixes of the electrical network, in case that the user has a load flow code which handles these matrixes. In a pilot implementation of a load flow code which was embedded in this sub module, a satisfactorily solution was established. All the results return automatically back to the database. The advantage of an embedded load flow code or library is the avoidance of external transactions with applications and data files. Furthermore, an interface of the electric network management module e-Zeus with the EMTP-ATP is developed so electric transient phenomena could be analyzed as well by using this tool.

3.3 Application of the electrical network management module

The electrical network management module has been applied to digitization of two electrical distribution networks in Greece, Lakonia, where intensive wind potential exists and Epirus, where many small hydro plants may be constructed. In Lakonia 1078 nodes, 1103 branches and 231 transformers have been digitized, while in Epirus 4432 nodes and 870 transformers respectively. Various scenarios for wind farm connections with the distribution network in Lakonia have been developed. For the load flow studies calculations were used both the PSSE and the internal load flow code, with similar results. Figure 4 illustrates the digitized high voltage network (20 kV) of Lakonia along with geographic layers, the contour lines, rivers, roads and towns’ layer. Also, labels of the towns’ layer are enabled. The system, having the modules described, has been proved as a very useful tool for the representation and management of high voltage networks. Moreover, the system could be expanded in various applications, relative to electrical network management, by developing additional modules, which will have as a basic input the electrical network database.

4. INDICATIVE RESULTS FOR WIND PROJECTS

The most promising areas for wind energy installations in Greece are the Aegean islands, the west part of the island of Crete, Thrace and the eastern coast of continental Greece including the Evia island and Lakonia and Troizinia in Peloponese. In a large number of sites in these areas the mean annual wind speeds are very favorable for exploitation (7-11 m/s). Some indicative results for the most windy area of Southern Evia are presented here. Evia is an oblong island adjacent to the eastern part of the country and interconnected to the main high voltage grid. About 180 MW of total wind capacity has been already installed and operating in Southern Evia. Furthermore, permits have been granted in the island for new installations of wind farms which are about 270 MW. New applications for an additional 1000 MW of wind generation are pending, due to transmission network limitations. Studies have been carried out to accommodate this increased demand. The optimum expansion plan foresees connection of future wind farms to the 150kV grid of the Metropolitan area of Athens, through two submarine cables, and reinforcement of the 150kV connecting grid, between Evia and continental Greece. The total cost for this scenario is estimated to about 60 million €, to absorb 530 MW of wind power. This corresponds to 0.11 million € per MW. If we take into account the additional cost for connection of each wind farm to 150kV, a cost of about 0.15 million € per MW is estimated. The parameters and constrains that have been used to run the model for the island of Evia are the following:

- Annual mean wind speed classes: 7, 8, 9, 10 m/s
- Land Slope: < 15°
- Land Aspect: NW to NE
- Flow Accumulation = 0
- Land Use-Areas Excluded: Archeological Sites, Urban Areas, Natura
- Distance from inhabited areas: > 1km
- Distance from airports: > 5 km
- Distance from heliports: > 1km
To calculate the financial parameters, 8% discount rate, 30% subsidization on installation and 30% loan, 5.5% loan interest, 35% tax ratio, 0.063€/kWh selling price and 10 years of project lifetime have been considered.

5. CONCLUSIONS

An integrated decision support information system has been presented for the evaluation of the penetration of dispersed renewable energy sources (RES) generation in the high voltage transmission and distribution network. The tool has been applied for the assessment of the contribution of wind and small hydro potential in the Greek electric energy system. Furthermore, the information system described in this paper could be used for the study of every case of dispersed generation. Especially, the electric network management module (e-Zeus) can be widely used in the high voltage network (transmission and distribution) design, analysis and operation. The module incorporates further to the presentation of the high voltage lines, transformers, switching elements, etc on a GIS and provides interfaces with load flow and transient analysis programs.

<table>
<thead>
<tr>
<th>Computed values*</th>
<th>Wind speed classes (m/sec)</th>
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<tr>
<td></td>
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<tr>
<td>Available Area (km²)</td>
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<td>Annual mean wind speed (m/sec)</td>
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<td>Annually expected energy production (GWh/year)</td>
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<td>Total installed capacity (MW)</td>
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<td>Utilization Factor (%)</td>
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<td>Total installation cost (million €)</td>
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<td>Discounted payback period (years)</td>
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<td>Internal Rate of Return-IRR (%)</td>
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</tbody>
</table>

*The areas selected, satisfy environmental constrains according to the Greek Legislation
6. REFERENCES


