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## A NEW EXPERT SYSTEM BASED CONTROL TOOL FOR POWER SYSTEMS WITH LARGE INTEGRATION OF PVs & WIND POWER PLANTS.

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### ABSTRACT

In the present paper an advanced control system for the optimal operation and management of medium size power systems with large penetration from renewable power sources is presented. This control system is aimed to assist the power system operators in their managing task, by proposing them optimal actions for the economic and secure management of the power system. The control system is composed of various modules performing functions like short-term forecasting of the load and of the renewable sources, economic dispatch of the power units and on-line dynamic security assessment. The pilot control system is being installed and evaluated in the Greek island of Lemnos.

### INTRODUCTION

A considerable number of PV and wind power plants are installed or planned to be installed for electricity production in islands of the European Union and in developing countries, where favourable conditions of renewable sources often exist.

In these cases the objective is to maximise the use of renewable energies in order to increase the resulting benefits like fuel savings. However, solar and wind penetration are limited by the repercussions of the solar and wind power variability on the existing power station, which usually includes diesel units.

In order to achieve a larger penetration of renewable sources, without deterioration of the quality of service offered to customers, the development of new control tools is necessary, that will assist the power system operators.

In the present paper the essential elements of an advanced control system for the optimal operation and management of medium size power systems with a large penetration from renewable power sources are presented.

This control system is developed within a JOULE-II project funded by the European Union and the Greek utility PPC and is going to be implemented in the Greek Island of Lemnos.

The developed control system is aimed to assist the operator of a medium size autonomous power system by proposing optimal dispatching scenarios for the various power units, as well as various actions needed to avoid dangerous situations which might result from a poor prediction of load or weather or unforeseen disturbances.

The control system minimises the production costs through an on-line optimal scheduling of the power units which takes into account the technical constraints of the diesel-units as well as short-term forecasts of the load and the renewable resources.

The power system security is maximised through an on-line security assessment module, which supervises the scheduling of the power units and enables the power system states to be capable of withstanding any sudden change in the load or in the production of the renewable sources, without exceeding acceptable limits for frequency excursions and voltage deviations in the grid.

Special attention is given to the monitoring of the security margin defined by the frequency deviation during emergency situations, such as sudden power variations from the renewable units.

An advanced software, having real-time performance and a sophisticated man machine interface, has been developed. The various modules, that perform the control system functions, have been integrated in the software and validated with real data obtained by the existing SCADA system in Lemnos.

The prototype control system will be installed in the island of Lemnos before the end of 1994, where its performance will be evaluated and guidelines for further use in other islands will be prepared.

### DESCRIPTION OF THE CONTROL SYSTEM

The developed control system is designed to produce optimal scenarios, both from the economic and security point of view, for the power system operation. For this purpose, various functions have been developed and integrated in the control system structure, which is shown in Fig. 1, and they are performed periodically as described below :

- i) Initially, a data-base is continuously updated by a data acquisition system (SCADA). The data concern wind speed and solar radiation, power output for the conventional and renewable units, load consumption levels, temperature, etc. The data-base checks for errors, filters erroneous data and translates the incoming information to be accessed by the control software. The data-base incorporates also the necessary comprehensive information about the entire system - e.g. the various machine parameters.
- ii) Using these data and other fixed parameters, the expected load and renewable units power are forecasted for a period equal to the planning period.

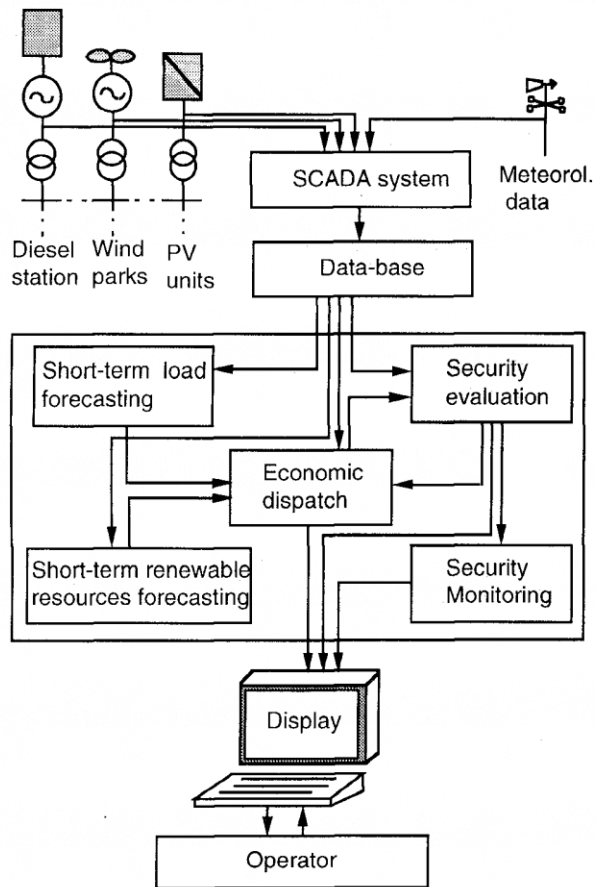


Fig. 1. The control system architecture.

- iii) Taking into account the forecasted load and renewable units expected power, a "Logistic" program schedules the operation of the system for the next time period (e.g. two hours, taking decisions every 10 minutes) so that maximum fuel saving is achieved, without deterioration of the quality of service to the consumers of the power system.
- iv) The quality of service concerns mainly loss of load events due to a possible deficit between generation and demand, as well as dynamic instabilities and important frequency deviations due to sudden wind speed or solar radiation fluctuations. Both are related to the diesel spinning reserve provided during the scheduling of the operation of the system.

Two different modules perform the security assessment of the power system. The first one checks if the proposed by the logistic module operation scenarios might lead to dynamically unsafe situations. If yes, these scenarios are rejected and the output of the logistic module is revised. The second module provides a real-time quantitative evaluation of the system security for its current operating state, expressed by its frequency deviations if a preselected power disturbance from the renewable sources occurs.

The above functions have been incorporated either as independent modules or in the form of rules within an expert system (ES) shell. The modular structure of the developed system permits the testing of various different methods that perform the same function, e.g. various forecasting or operational planning methods.

An advanced man-machine interface has been designed so that the control system is ergonomic and friendly to the user. The operators can easily communicate with the control system in order to obtain data on the power system behaviour in graphical form.

Special attention has been given to the presentation of the proposed schedules, the predicted load and wind power profiles, the various actions that are proposed in critical situations, recording of historical information and finally on monitoring the power system security.

A multi-tasking operating system - Windows NT - and an Expert System (ES) shell - NEXPERT - provide the real-time performance required by the project. The ES shell is used to incorporate the various security rules. The type of computer chosen for the implementation is a PC 486. In the following sections a more detailed description of the various functions is given.

#### ECONOMIC DISPATCH-"LOGISTIC"- MODULE

The economic dispatch or "logistic" module has the following two roles:

- i) to simulate the operation of the power station on time scales of one minute or greater, to simulate the effect of various alternative control strategies and so assess their effectiveness.  
(Dynamic stability over time scales of a few seconds is considered outside the role of the model).
- ii) to form the basis of the real-time control system.

To fulfil the first role, the performances of logistic models developed by RAL and NTUA/PPC have been compared for a range of operating conditions [1].

To fulfil the second role - to form the basis of a real time control system - it is required to produce a load dispatch algorithm and to take decisions on whether to stop/start diesel or renewable units. The NTUA load dispatch algorithm has been extracted from the corresponding logistic model and incorporated into the advisory controller for the power station.

The two Logistic Models (LM) developed by NTUA/PPC and RAL are based on time series analysis and utilise a time step in the order of one-minute to include the load and renewable sources fluctuations, as well as their influence on the system performance and a higher time step, in the order of ten minutes, to determine the necessary decisions. The main components of each one of the two LMs are:

*The Autonomous Diesel Station model.* It simulates a number of diesel units working in parallel. Emphasis is given in the detailed representation of the start and stop procedures. The individual technical characteristics of each unit, e.g. characteristic fuel consumption curve, are taken into account.

*The Renewable Power Plants model.* The model



simulates arbitrary number of wind parks and PV plants. It considers that all wind turbines within a park and PV units within a plant operate under the same wind or solar conditions respectively.

*The Load Management and Control System.* This system monitors all the operational parameters of the diesel generators and the renewable units, as well as environmental data. It incorporates the rules for optimal operation of the power system and performs the decision making for the starting and stopping of the diesel units and the renewable units.

The LM calculates, for each diesel unit, the energy production, the hours of operation, the fuel consumption and the number of starts-stops. It calculates also the energy produced by the renewable units and the renewable energy spilt due to the load management commands. Finally, the model records the loss of loads events as well as the relevant lost energy.

A series of validation studies have been carried out for both the NTUA and the RAL models for the case-study of Lemnos. Both models have been used to simulate the power system operation and their output has been compared with measurements of the actual operation of the power system of Lemnos [1].

#### Issues on the control algorithm

The economic dispatch is realised by the NTUA LM, which is based on two different time steps; one-minute (basic) and ten-minute (decision-forecasting) steps.

*One-minute time step.* The logistic model performs the following operations on an one-minute basis :

- It collects all operational data of the power system.
- It calculates the diesel station load and checks the operation limits of the diesel units.
  - if the lower acceptable operation limit of the diesel units is violated some wind turbines are stopped
  - if a diesel unit is overloaded, a part of the load is rejected by a load management command.

*Ten-minute time step.* The following actions are performed on a ten-minute basis :

- Communication with the forecasting modules in order to obtain the load and renewable power sources profiles for a period of two or three hours ahead with a time step of ten-minutes.
- Decision making on which diesel generator is going to be started or stopped by taking into account the following factors :
  - a priority list of the available diesel units (running or not),
  - the forecasted load and renewable power sources profiles for the planning period under consideration as well as factors expressing the uncertainty of the forecasts,
  - the required spinning reserve of the diesel units as a function of the load and the wind and solar margins,
  - the cost optimisation of the diesel station operation for the planning period,

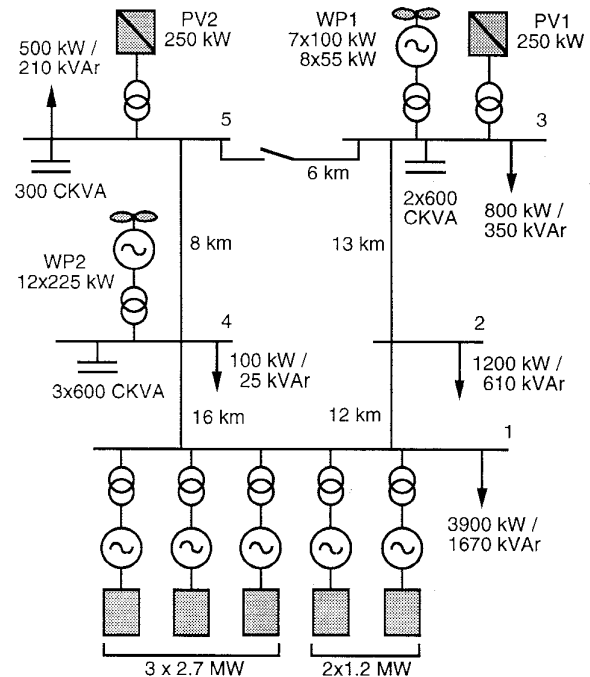


Fig. 2. One-line diagram of the power system model of the island of Lemnos.

- the security assessment of the system in order to determine if the dispatching scenario examined is dynamically safe for the power system.

#### FORECASTING MODULES

The objective of the two forecasting modules is to provide an estimation for the load and the renewable power sources profiles for the next planning period (e.g. 2 hours) with a time step equal to the time step used by the logistic module to take decisions (e.g. 10 min).

The principal method used for load forecasting is the Winter method, which is based on exponential smoothing and takes into account seasonal variations.

Concerning wind speed and solar radiation forecasting, the "persistent" method has been used, which assumes that the power from the renewable units during the scheduling period will remain at a constant value equal to an average of past values. It was found that for the case of Lemnos the optimal persistent predictors are obtained by using the average of two or three past values (20 to 30 min) according to the forecast time step ahead.

The efficiency of artificial neural networks has been also examined in wind power forecasting. According to the results obtained using data sets from the island of Lemnos, an improvement in the order of 15% over persistent method can be achieved in the forecasting accuracy [2].

The effectiveness of different wind speed, solar radiation and load forecasting techniques can be proven off-line by the use of the logistic model. By this way, it can

be shown their likely value in reducing operational costs before final implementation on-line.

### ON-LINE DYNAMIC SECURITY ASSESSMENT MODULE

In the case of autonomous power systems with a large penetration from renewable power sources, large frequency excursions and dynamically unstable situations may occur, due to fast variations of the renewable production, like in the case of very high winds that may result the loss of wind generator production.

Such disturbances, occurring in a time scale of a few seconds, are not foreseen in the logistic modelling and the derivation of the operating plans of the system. A Dynamic Security Assessment (DSA) module is therefore of primary importance, in order to guard the system against pre-selected severe wind or solar radiation disturbance.

The DSA is provided in two ways, each one serving a different objective:

First, during the planning of the power system operation by the economic dispatch module, the dynamic security of each one of the proposed scenarios is evaluated by the DSA module and the scenarios that might result in large frequency excursions or loss of synchronism in case of severe renewable power disturbances are rejected.

Second, a real-time quantitative evaluation of the system security for its current operating state is provided, expressed by its frequency deviations if a preselected wind power disturbance occurs.

In order to obtain from the DSA module fast, credible and easily interpreted results, Artificial Intelligence techniques were used for the elaboration of efficient security classifiers. More specifically:

- i) The Decision Trees (DT) method is used for the security assessment of the proposed by the dispatching module operating plans. Using suitable DTs, the proposed operating state is classified as safe or unsafe with respect to preselected disturbances. If it is found unsafe, the dispatching algorithm is instructed to revise its output.

The DTs have been implemented in the form of rules within an ES-shell. By this approach easy modifications in the case of changes in the power system configuration e.g. installation of new wind parks are possible [3].

- ii) Artificial Neural Networks were implemented for the real-time evaluation of the system security, providing an emulation of the expected transient frequency excursion if one of the preselected disturbances took place. In this way, the operators of the system are notified for its security and preventive control actions can be taken, if it is considered necessary [3].

The expected transient frequency excursions that the system can experience were selected, from a practical and operational point of view, as a dynamic security indice, because in several networks, wind park disconnection and/or load shedding are triggered by frequency, according to the relay settings.

### EVALUATION OF THE CONTROL SYSTEM

The evaluation of the control system performance includes two stages. The first stage includes the testing of the various modules as well as of the entire software by using data files obtained by the SCADA system of Lemnos.

The second evaluation phase will be performed on-site after the control system installation and the training of the operators. During this phase, which is planned to start by the end of 1994 and is going to last three months, the final tuning of the control system will take place.

The control system performances and its use by the operators will be evaluated on-site. The response of the control system during emergency situations will be of particular interest.

It is anticipated that in certain situations the operators may be inclined to countermand certain decisions of the controller. Such occasions will be recorded and simulations will be carried out using the logistic model in order to demonstrate the consequences of such an action.

### CONCLUSIONS

In the present paper an advanced control system for medium sized grids that performs the management of the power units (diesels, wind turbines, PV plants, etc.) has been presented. This control system maximises the benefits coming from the renewable energy sources (in terms of fuel and capacity credits), while maintaining a high level of security to the grid.

Various models that perform functions like optimal scheduling, forecasting, security assessment, etc. have been integrated in a modular way within the developed software. The control system provides a communication interface with a data base fed by a SCADA system and an advanced man-machine interface for an efficient communication with the power system operators.

The developed control system has been tested with measurements from the Greek island of Lemnos. The installation phase is about to start in the island of Lemnos within 1994, where its operation will be evaluated on-site.

The modular development of the control system permits further adaptations for diffusion in other islands than Lemnos; for this purpose guidelines are being prepared presenting the necessary adaptations.

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