INCLUDING A WIND ENERGY CONVERSION SYSTEM MODEL IN ELECTROMAGNETIC TRANSIENTS PROGRAM

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Abstract

Due to the increasing penetration of wind energy, it is necessary to possess design tools that are able to simulate the impact of these installations in distribution grids. Electromagnetic transients programs are suited to deal with these problems, but a detailed wind energy converter model which is able of carrying the transient behaviour of these systems is also required. In this paper, an interface between two available software packages, EMTP and INDUSAT, containing the digital implementation of these features, is presented. This tool will enable the assessment of the influence that both voltage flickering and power oscillations may have in the performance of distribution networks in face of dispersed wind production. A simple case-study is discussed and the main conclusions are commented.

Keywords: Power systems dynamics, wind energy, wind turbine models, EMTP.

Introduction

The full use of the endogenous energy resources is particularly crucial in regions which are ill-favoured in terms of energy resources. The case of the islands is often referred to as being typical of regions where the full use of endogenous resources is a must in order to ensure both the supply of energy and quality of life.

One of the forms of endogenous energy that is generally abundant in the islands is wind energy, thus justifying the importance of this form of energy to these regions. The foreseen increase in the levels of wind energy penetration will rise some technical issues which must be dealt with in order to guarantee that the quality of the utility power is not affected. Actually, wind energy being a reliable source of energy on a "year to year" basis, is an intermittent source of energy on a "day to day" basis, meaning that it is a non-dispatchable form of energy. Moreover, the power generated by the Wind Energy Conversion Systems (WECS) generally fluctuates in amplitude over a wide frequency range which may have a non-negligible impact in the quality of the utility power, specially in cases where wind power is a significant component of the utility generation mix. If one further takes into account that WECS are generally connected to the distribution system and not to the transmission system, one may foresee the necessity of performing an assessment of the level of wind penetration in local terms, even in cases where, globally, the wind energy penetration is modest when compared to the utility power mix.

In order to address these technical issues it is necessary to possess design tools that are able to correctly simulate the impact of the wind energy penetration in the utility distribution grids. Electromagnetic transients programs are powerful tools for evaluating disturbances that usually occurs in power systems, and, therefore, are suited to deal with these problems. On the other hand, a detailed WECS model which is able of describing the transient behaviour of these kind of systems in its interaction with the existing a.c. network is also required.

In this paper, an interface between two available software packages, EMTP and INDUSAT, containing the digital implementation of these features, is presented.

ElectroMagnetic Transients Program (EMTP)

ElectroMagnetic Transients Program, EMTP, is a well-known computer program whose aim is the simulation of power systems transients. It is composed by a library of models of components (lines, transformers, generators, etc.) that once linked enable the creation of any kind of network.

Recently, a new tool, known by the designation of MODELS [1] [2], has been added to the ATP version of EMTP (EMTP/ATP), allowing, among other features, the introduction of control systems models and enabling external functions written in any programming language to be connected to EMTP. Therefore, users may connect their own models of some components and test them with any kind of network, ensuring that the source code remains unchanged.

INDUSAT Program

INDUSAT is a software package designed to serve as a simulation tool of the transient behaviour of WECS connected to an infinite bus [3]. It contains the digital implementation of the models developed for each component of the system, namely, wind turbine, induction generator, reactive power compensation system, transformers, interconnection feeder and possible local loads connected to the feeder.

Figure 1 shows the different elements modelled under INDUSAT.

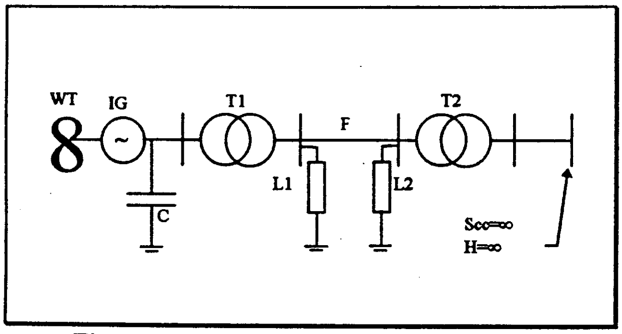

Figure 1: Elements modelled by INDUSAT.

Models have been developed to describe the behaviour of these different subsystems that constitute the system studied. Also, a wind model able to generate correlated wind time series was developed [4]. Currently this model addresses only the wind turbine side-by-side configuration but is being improved in order to take account for wakes effects.

A wind turbine model was built after the blade aerodynamic characteristics and taking into account the effects of variable rotational speed, thus enabling a torque/speed characteristics to be obtained [5]. An improvement of this model is currently under test and was not used in this paper. The new wind rotor model has a flexible approach enabling the blades to have both flap and lead-lag freedom concentrated on the hub.

The induction generator characteristics of low cost, robustness and virtually maintenance-free operation clearly indicate it as the preferred mechanical-electrical converter for dispersed generation systems. Particular care was taken when considering the model of the induction generator. A squirrel cage type of machine was considered, as this is the type of induction machine generally used in WECS. Recently, it has been recognised that the prediction of both synchronous and induction machines steady-state and transient performance requires proper account of saturation effects. Moreover, in the squirrel cage induction machine, saturation plays a major role in situations where the machine is isolated from the a.c. system.

The theoretical basis for the consideration of saturation in the generalised equations of electrical machines was first established by *Von der Embse* who suggested a generalisation of the quadratic decomposition of the magnetic coenergy, used when saturation is not taken in account. In order to take proper account for saturation effects, a model based on *Von der Embse*'s circuit theory was developed [6].

The reactive power compensation system was represented by a bank of fixed capacitors sized in accordance with the Portuguese legislation in what concerns the impositions related to the power factor of the installation [7].

The local loads were modelled as constant active and reactive power for the computation of initial conditions and as a constant impedance in the transient studies. Both the transformers, the feeder and the a.c. system were modelled also as a constant impedance.

MODELS Interface

In order to be able to model a network with embedded dispersed generation an interface between EMTP and INDUSAT has been developed [8], using a simulation tool available in EMTP called MODELS.

In MODELS, a distinction is made between a model *description* and a model *use*. In the description of a model one has to describe the algorithm that the model represents and the interaction (Input, Output, etc.) with the environment in which it is embedded. In the use of a model one has to specify the directives with which the model is to be used.

An example of model description and use is shown in Figure 2.

```
MODEL voltage_regulator
   DATA
      INPUT
      -- Input variables for this model
      OUTPUT
      -- Output variables from this model (ex Vf0)
   EXEC
   -- model description
   ENDEXEC
ENDMODEL
USE Voltage_regulator AS AVR
-- model use
   DATA
      INPUT
      -- Input variables assignment when the model
         is used
      OUTPUT
      -- Output variables assignment when the
         model is used (Ex: vf := vf0)
ENDUSE
```

Figure 2: Model description and use of an Automatic Voltage Regulator using MODELS language.

Figure 3 shows the communication flux between INDUSAT and EMTP using MODELS as the interface.

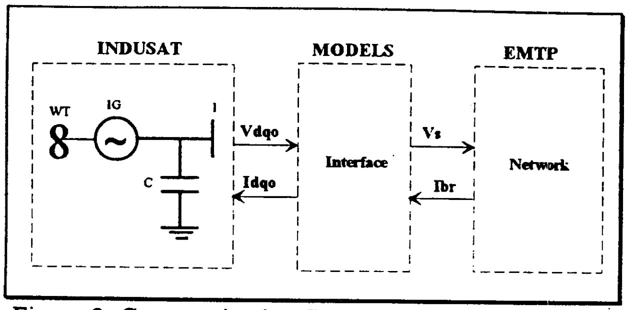

Figure 3: Communication flux between INDUSAT and EMTP using MODELS.

In order to build up the interface some practical problems had to be overcome.

The first problem to be solved concerns the fact that INDUSAT deals with *dqo per unit* variables, while EMTP works with phase quantities. To allow the desired communication, Park transformation was used to transform the phase branch currents, *Ibr*, given by EMTP (*Ia*, *Ib*, *Ic* in *Ampere*) to *dqo* currents, *Idqo*, understood by INDUSAT (*Id*, *Iq*, *Io* in *per unit* values) as shown in figure 3. Furthermore, after the calculation of the new terminal voltage, *Vs*, (*Vd*, *Vq*, *Vo* in *per unit* values) by INDUSAT, which is based on the branch currents (given by EMTP) and on the wind speed (from the WECS model), the inverse Park transformation is required in order to return the phase quantities back to EMTP. Both Park transformation and its inverse were implemented by creating a specific model for each transformation using MODELS language.

Another important difficulty that had to be overcome concerns the initialisation process of the network. EMTP performs the a.c. steady-state initialisation of the electrical circuit using a linearised circuit driven by one or more sinusoidal sources. All non-linear components are ignored for the initial steady-state solution. This became a real limitation since the target of the work was to include an external non-linear program in EMTP.

The approach followed was to build up a linear equivalent of the induction generator only for initialisation purposes (i.e. during the first time step) and then, disconnect it from the rest of the circuit by switch operation as shown in figure 4.

By using this technique the initial operating point is correctly evaluated, this being a crucial requirement for the success of a simulation process involving the integration of differential equations.

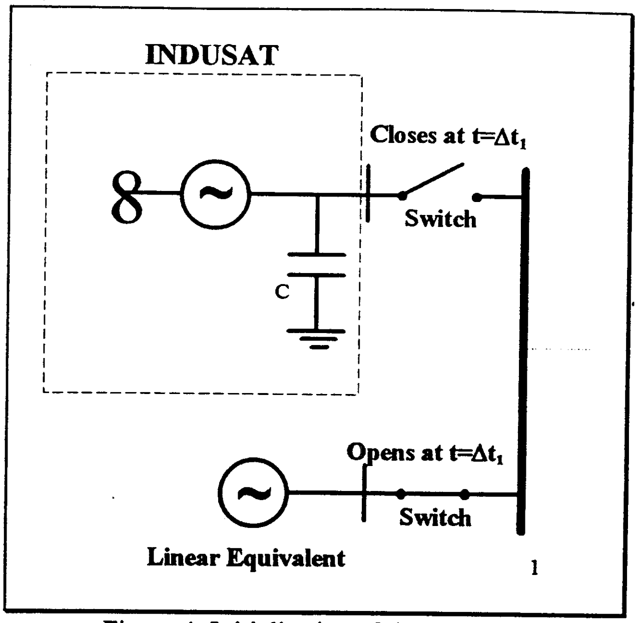

Figure 4: Initialisation of the network.

Yet another example of practical problems that had to be dealt with was the delay of one time-step inherent to the communication between control actions modelled "outside" EMTP and EMTP itself. This could be a source of numerical instabilities for certain systems in which the duration of events are of the order of the time-step.

Recently, it has been added to EMTP a non-linear component, known as *Type94* component, that provides a synchronisation between the electrical solution of the network modelled by EMTP and the operation of external programmes [9]. This new component was used in order to avoid the delay of one time-step.

Validation and Applications

In order to show the usefulness of possessing a tool able to assess the impact of wind energy generation on the utility distribution network, namely in the case of islands, a simple case-study was selected.

Figure 5 presents the system studied.

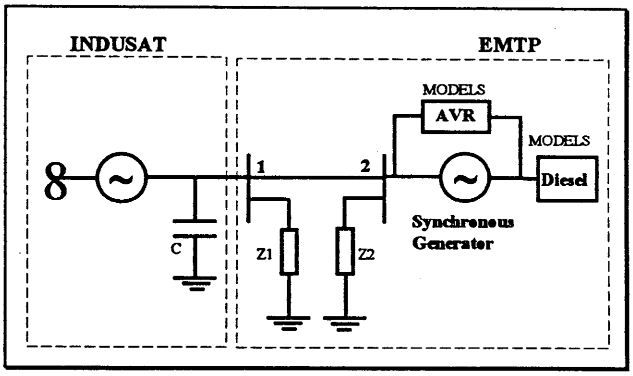

Figure 5: System studied.

In figure 5 is shown a small network that represents, in a very simplistic way, a typical topology used in islands with dispersed generation and where Diesel engines are used to provide voltage profile and frequency of the system. Both voltage and speed regulators of the synchronous generator are also represented.

The model assumed for the Automatic Voltage Regulator (AVR) is based on *IEEE mod2* excitation systems [10]. It was implemented using MODELS language taking advantage of the possibility it offers of modelling control devices by means of transfer functions. In what concerns the Diesel engine that drives the synchronous generator it was represented as a simple delay. A refinement of this model, taking into account internal characteristics of the engine [11], is possible but this is only justified when the aim of the study is the specific dynamic performance of the engine, which is not the case.

As far as the speed regulator is concerned, the IEEE general model for speed governing systems [12] has been used. It was implemented, using MODELS, in a simplified way in order to obtain a first order model describing the governor's delay.

In a first stage this case-study will be used to test the operation of the developed interface. Therefore, comparison of the results obtained with EMTP against the results obtained with INDUSAT working in stand-alone mode will be firstly performed. Induction generator slip, terminal voltage (busbar 1 voltage in figure 5) and WECS power output to the feeder are shown in figures 6, 7 and 8, respectively.

In order to allow this validation procedure the network shown in figure 5 has been slightly modified, since INDUSAT addresses only the connection to an infinite bus. The synchronous generator driven by the Diesel engine has been removed and replaced by an ideal source of constant voltage and frequency (EMTP *Type14* component).

The wind input was an available wind time series (mean wind speed = 6,86 m/sec.) derived from the wind model currently under development. Selected WECS is composed by a 24kVA, 400V induction generator, squirrel cage type, driven by an horizontal axis wind turbine. WECS detailed data can be found in previous works on wind energy domain [4], [5].

Results obtained with the WECS model and with EMTP show a good agreement. Initial numerical instabilities due to the above mentioned initialisation problems in EMTP were minimised as a consequence of the initialisation procedure implemented. The small differences found can be mainly explained by the fact that INDUSAT and EMTP actually solve the differential equations using different integration methods.

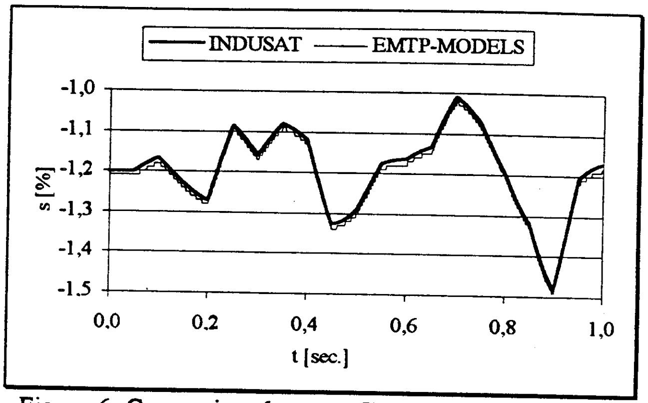

Figure 6: Comparison between INDUSAT and EMTP results (induction generator slip).

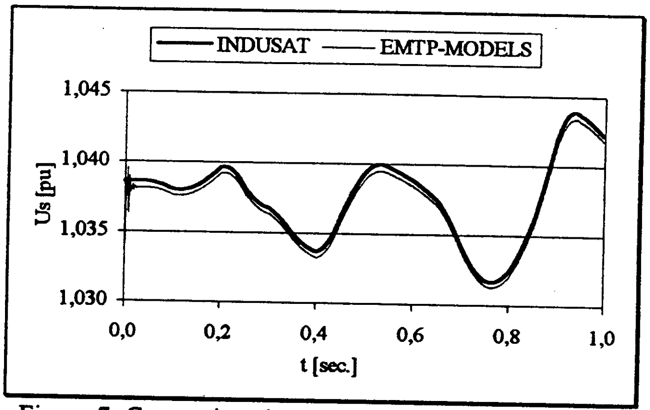

Figure 7: Comparison between INDUSAT and EMTP results (terminal voltage).

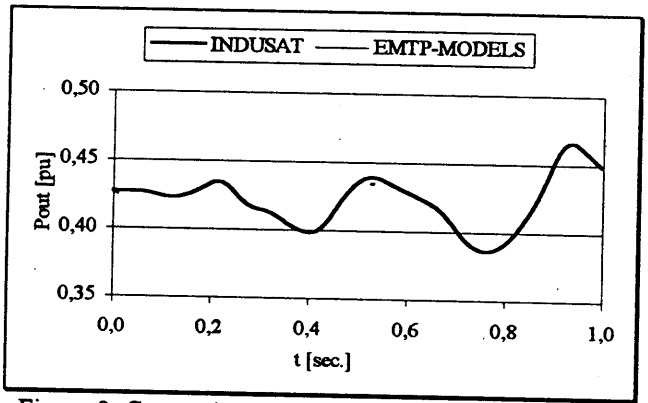

Figure 8: Comparison between INDUSAT and EMTP results (WECS power output).

The tests performed allow the conclusion that a WECS model has been successfully included in EMTP, thus enabling the evaluation of the impact of dispersed wind energy generation in the distribution network.

One of the main aspects of this interaction concerns the behaviour of the voltage regulators in face of a sudden loss of load. In order to assess this problem a situation in which load 2 (figure 5) was disconnected (at t=0,2sec.) has been simulated. Figure 9 shows the synchronous generator voltage (busbar 2 in figure 5) with voltage regulators inhibited.

It should be mentioned that a 500kVA, 400V, synchronous generator driven by a Diesel engine was chosen, the data details of which are about to be published in [8].

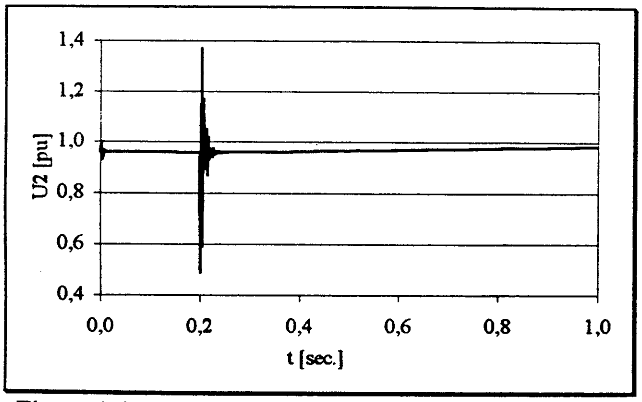

Figure 9: Loss of load, synchronous generator voltage, AVR inhibited.

The voltage increase after the loss of load is apparent from the last figure. Next figure shows the result obtained if AVR acts in order to maintain the voltage profile.

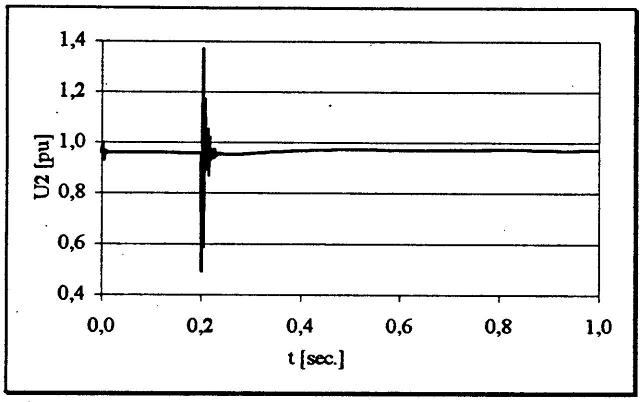

Figure 10: Loss of load, synchronous generator voltage, AVR operation.

In order to show AVR fast operation, figure 11 displays the synchronous generator field voltage in face of the loss of load event.

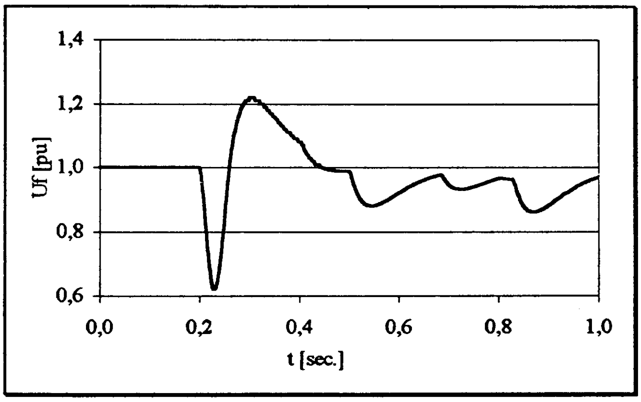

Figure 11: Loss of load, field voltage, AVR operation.

This figure also shows the AVR extreme sensibility to voltage fluctuations induced by the wind speed changes.

Conclusions

In this paper, a procedure to include a WECS model (implemented in INDUSAT computer code) in EMTP by means of a dedicated interface was presented. MODELS language, which allows the communication between EMTP and external programmes to take place, was used as the tool to build up the interface.

A case-study was selected with a twofold objective: to test proper operation of EMTP linked with INDUSAT via MODELS and to illustrate the usefulness of possessing a design tool that enables the assessment of the impact of dispersed wind energy generation in the utility distribution network.

Simulation results were presented showing the validation of the developed interface by comparison of both EMTP and INDUSAT results. Also, the influence of AVR operation in the stabilisation of voltage profiles after a loss of load was presented.

Acknowledgements

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