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Building Simulation Modeling Environments

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Abstract: - Concise and descriptive modeling and simulation procedures plays a central role in the design of electrical systems, especially those that are highly complex. This paper introduces a schematic approach to modeling and simulation in order to create environments that can support important features such as simulation model validation. It is important to establish various general procedures and quality attributes because there are numerous tools for a variety of modeling methods and simulation techniques and it is useful to study the relationships between the realm of model building and simulation execution in conjunction with the system design, and development.

Key-Words: - Modeling, Simulation, Stand Alone Power Systems, Simulink.

1 Introduction

The advantages that result from the use of Simulation Modeling Environments can be summarized in the following way:

1) Possibility to represent in a synthetic, rigorous, well structured, well organized and extremely powerful manner the whole of the empirical knowledge and of the theoretical speculations that concern a studied phenomenon;
2) Possibility to deduce, in a rigorous way, the logical consequences of the hypotheses introduced in the model;
3) Possibility to foresee the results of experiments not yet performed;
4) Possibility to estimate, through the comparison between the forecasts of the model and the corresponding experimental results, the truthfulness or the falsehood of the formulated hypotheses;
5) Possibility to predict the consequences of changes in the studied system and the corresponding advantages and disadvantages;
6) In general, the study of the properties, of the characteristics and of the behaviour of a system through a mathematical model and a simulation tool is quicker, easier and less expensive than the study directly carried out on the physical system, especially for systems of a certain complexity, like those specific for electrical engineering.

The first four points listed above particularly concern the use of the models in basic research and in those phases of scientific activity in which the objective is to understand mechanisms or phenomenon that are not yet clear. Points 5) and 6) concern typical uses of applied or technological research. There needs to already be deep knowledge of the phenomenon of interest and sufficiently validated mathematical models. The possibility to take full advantage of the potentialities of a mathematical model depends, obviously, on the availability of adequate mathematical and calculation tools for the solution of the system of equations that constitute the model. We call simulation the use of such tools to draw from the model forecasts concerning the behavior of the system under determined conditions (input agents and boundary conditions). Simulation then allows the verification of the hypotheses and can make the study of the behavior of the system easier, quicker and cheaper than an experimental study. This last advantage is appreciable especially when we work with systems on which, for a whatever reason, is difficult or unsuitable to do in laboratory or on field experiments. Regarding the construction of the models, we can certainly say that there do not exist methods or techniques of general validity. Rather than a consolidated technique, the construction of a model is still "an art", even if, as in all the arts, it has its own tools..

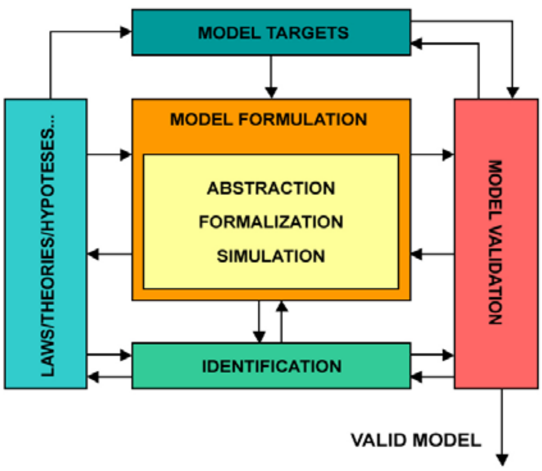

Fig.1 : Scheme for the development of a mathematical model.

As shown in Figure 1 the development of a mathematical model can be represented as a cyclical process. The process begins with the *identification* and the *definition* of the problem that we want to solve with a simulating approach. Once we have defined the *targets* and the aims of the use of the model, we can then start its *formulation*.
This can involve various phases:

a) a process of *abstraction* that aims to identify the interesting aspects of the phenomenon according to the goals of the modeling approach and the aspects that can be neglected;
b) a phase of *formalization* of the aspects through the use of chosen conceptual and methodological tools;
c) the *simulation* of the model; in this phase it is generally necessary to estimate some unknown parameters (*identification*);
d) In every phase, for the construction of the model, the experience and the ability of the modeler and the use of laws, theories, experimental evidence and other pertinent hypotheses are, of course, important.

During the construction of the model new hypotheses can be proposed or new experimental data can be used; this can be useful to clarify remarkable aspects of the goals of the modeling and, in the final analysis, for the solution of the system we are dealing with. Similarly, every phase of the draft of the model must be addressed with a critical and extremely rigorous spirit, submitting the model to a continuous verification process (*validation*). The validation has to guarantee the internal congruence (the model must not contain contradictions), the congruence with the theories and the commonly accepted facts (or the possibility to justify presumed incongruities), the correspondence to the objectives of the study. Moreover, the validity of the validated model has to be extendible to the description and/or to the interpretation of other phenomenon besides that of primary interest. The validation can sometimes involve the comparison between the performances of the model and those of reference models or other competitive models. We have identified the following general phases applicable to every system we want to analyze:

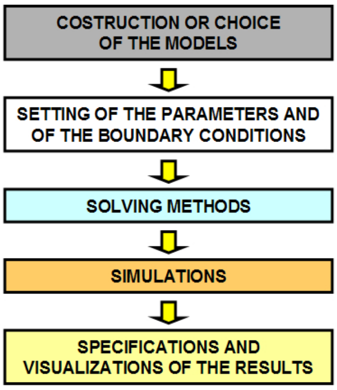

Fig.2 : General phases for the analyses of a general system.

Construction or choice of the model : A model is an elaborate theoretical scheme to represent the fundamental elements of one or more phenomenon (natural or not) and gives a simplified representation of a system at some particular point in time or space intended to promote understanding of the real system. The process of creation of a model is deeply innate in man, since the representation of the external world (which happens through mental models) it is at the base of learning. A process of synthesis is necessary first: to create a model means therefore to accept some compromises in which certain details of the real system will necessarily be excluded. This is not always a limit, but can be a point of strength of the model in the extent to which it helps us to understand something that we did not know about the real system. Every model has its own complexity and finality, but some characteristic elements can be generalized as follows:

-*Control variables:* these are the real subjects of the simulation and can monitor and pilot specific situations of the system. Thanks to the use of different interfaces, it has to be possible to represent (as equations or graphics), the different relationships between the control variables and the other elements of the system.
-*Simulation time:* it is necessary to choose the correct time evolution and to understand the intrinsic speed of the analyzed phenomenon in order to give us the possibility to choose the right time step (times, days, months, years), the period of time in which to carry out the simulation, the step and the speed of simulation.
-*Data and validation:* to verify the truthfulness of a model it is necessary to test its operation inserting some real elements: the data. The model has to be projected to bring advantages both in the insertion of the data and in their validation. Thanks to the use of special functions the data can be directly inserted into the elements of the system they refer to; as it regards the output information , the possibility to show them in charts and graphs allows us to have an immediate confrontation with the real data at any step.
-*Parameters:* a parameter is one of the variables of the model that cannot be measured previously; its variation can influence the other variables and the nature of the model itself. Parameters can be modified in every moment without altering the structure of the model; the procedure of setting the parameters in order to reach a final situation close to the desired one can be iterative: in this way at every step new parameters can be established and the results of the simulation are analyzed to decide the variation of parameters at the following step.
-*Linear and non linear models:* A model is linear when the dynamics of the control variables are regulated by linear laws. A non linear model has more complex relationships and many different factors and elements can intervene to modify the dynamics of the control variables.

Setting the parameters and the boundary conditions: Once we have selected and structured the model we can insert the parameters and the initial data and then it will be possible to start the simulation. The results obtained can be subject to errors and can be far from what we hoped to achieve. Therefore, the parameters must be modified to get new results. This procedure has to be repeated until the results reach pre-established values. In this phase it is possible to insert boundary conditions and other relationships between the parameters using Boolean algebra or graphic relationships.

Solving methods: The various elements constituting the model are represented by functions and equations. Simulation occurs through the calculation of these relationships at every single step and generally the computer has to solve differential equations - (ODEs). Sometimes it can be very complex or even impossible to solve these equations with the procedures of classical analysis and this is why it is important to use the right solving method in order to find the particular integral of a differential equation. There are many methods for solving differential equations; one of the most widespread is, for example, Eulero's method. This method, like every numerical method, provides approximate results, it is simple to understand and it is easily programmable; however its convergence is very slow and often it is necessary to make many calculations to get an acceptable approximation of the searched value. However, the calculation speed of modern computers allows the use of the method with practically instant resolution times.

Simulation: In the simulation, the model can be manipulated in order to make changes and processes visible and clear that would not be perceivable observing the real system, because this would require too much time, money or risk. With a simulation the different possible alternatives can be explored, verifying our own hypotheses and intuitions. Finally, by comparing the behavior of the model and the real data, it is possible to obtain a clear understanding of the phenomenon we are simulating. The process of creation and simulation of the model generally take place simultaneously, in the sense that the model gives the structure for the simulation, and the results of the simulation are analyzed and used for calibrating the parameters of the model in order to create a better one (according to the goals). Through specific functions it is then possible to establish the time and the speed of simulation, and the time steps needed to reach the wanted final situation. The results of the simulations can be represented as graphics or charts and with different scales. The Simulink-Matlab tool, for example, allows us to choose how to visualize the output elements making the analysis and interpretation of the graphs synthetic and comprehensible. The main characteristic of such a tool is that it can be used for the implementation of the models using a simple graphic environment in order to analyze and fully simulate dynamic systems through the assemblage of elementary blocks on a working virtual space.

Specifications and visualization of the results: The choice of the specifications of simulation and the visualization of the results are very important: it is therefore necessary to choose the output variables that we want to represent and to set the temporal simulation step (years, months, days,…) and the methods of resolution of the differential equations. Variables can be visualized in many different ways changing theirs ranges and making it then possible to visualize many variable behaviors in the same graphic.

2 An application example

To illustrate an application of the arguments expounded in the preceding paragraphs we choose to simulate the functioning of a Stand Alone Power System based on solar-hydrogen energy technology. Over the past decade there has been an increasing interest in the analysis of these kinds of systems and there is a clear need for detailed models to be used for their dynamic simulation. Another increasingly important requirement is that it should be possible to couple detailed technical models and economic models that account for both investment and operational components' costs. A general scheme of the studied system is shown in Fig. 3.

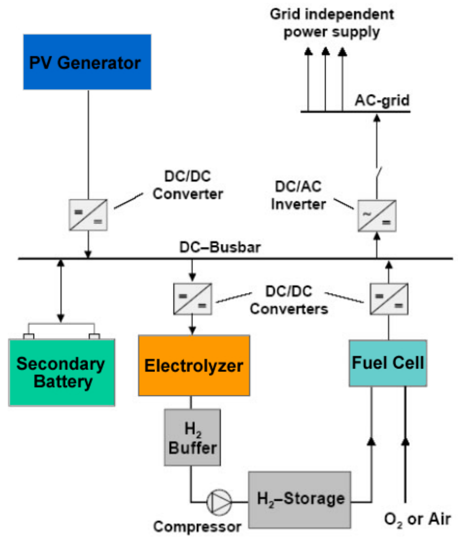

Fig.3 : Scheme of a Stand Alone Power System.

The main components of the system include a PV-generator, DC/DC-converters, a DC/AC inverter, an electrolyzer, a compressor, an hydrogen storage, a PEM fuel cell, and a secondary battery. For every component we have used relatively detailed mathematical models present in literature; these models take into account the main dynamics and the transitory phenomenon of the system. In this way a complete simulation model of the system has been produced in the Matlab-Simulink environment. Each physical component is modeled as a separate component

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subroutine and Simulink block for a modular system simulation program.
To describe the various phases of the modeling and simulation process, it can be interesting to show the procedure for the implementation of one of the components, for example the PV generator. Let's follow all the various phases described in the previous paragraph to build a valid simulation modeling environment.

Construction or choice of the model:
The mathematical model of the photovoltaic generator is based on the one-diode equivalent circuit shown in Fig.4.

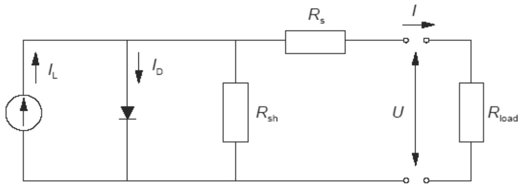

Fig.4 : The equivalent circuit for the one-diode PV generator model

The relationship between the current I and the voltage U of the equivalent circuit can be found by equating the light current I_L, diode current I_D, and shunt current I_{sh} to the operation current I. That is :

$$I = I_L - I_D - I_{sh} = I_L - I_0\left\{\exp\left(\frac{U+IR_s}{a}\right)-1\right\} - \frac{U+IR_s}{R_{sh}} \qquad (1)$$

Where:
I_L:light current,A
I_0:diode reverse saturation current,A
R_s,R_{sh}:series resistance and shunt resistance, Ω
A: curve fitting parameter
U: operation voltage,V
I: operation current,A

The power P produced by the PV generator is simply given by:

$$P = U \cdot I \qquad (2)$$

Fig.5 shows a typical I-U and P-U characteristic for a PV generator.

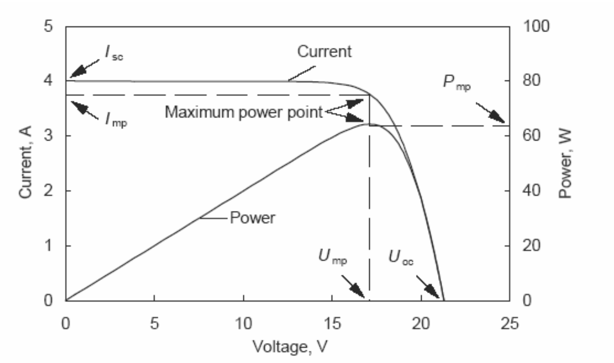

Fig 5 : Typical I-U and P-U characteristics for a PV generator

Setting the parameters and the boundary conditions:
The developed model is based on physical and chemical principles, as well as empirical parameters. The model has been designed to be as general as possible and it takes both design parameters, (such as number of panels in series and/or parallel) and specific component characteristics obtained from manufacturers or from experiments (such us current-voltage curve) into account.

Solving methods:
The model described in the previous point has been implemented in the Matlab-Simulink environment. Simulation of Simulink models involves the numerical integration of sets of ordinary differential equations (ODEs). Simulink provides a number of solvers for the simulation of such equations. Because of the diversity of dynamic system behavior, some solvers may be more efficient than others at solving a particular problem. To obtain accurate and fast results one needs to take care when choosing the solver and setting parameters. You can choose between variable-step and fixed-step solvers. Variable-step solvers can modify their step sizes during the simulation. They provide error control and zero crossing detection. Fixed-step solvers take the same step size during the simulation. They provide no error control and do not locate zero crossings.

Simulation:
For our purpose we used the ode45 solver; this solver is based on an explicit Runge-Kutta formula, the Dormand-Prince pair. It is a one-step solver; which means that, in computing y(tn), it needs only the solution at the immediately preceding time point, y(tn–1). The previous equations have been translated into the Simulink diagram shown in Figure 6.

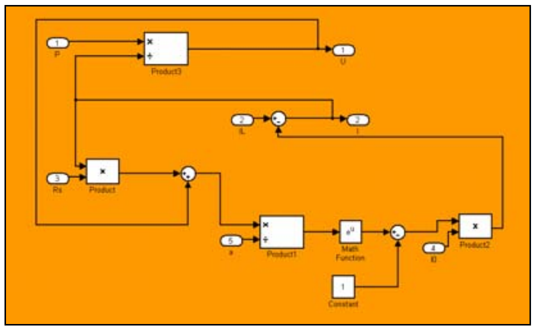

Fig.6 : Simulink PV Model.

Specifications and visualization of the results:
The simulations produced allow us to obtain a graphical visualization of the variables of the component and indications on the behavior of the system under different conditions of operation. This model was then verified. Figures 7-8 show both the current-voltage curve and the power curve obtained from the simulation of a commercial PV module (Solarex MX64). The simulated module shows,

for example, a 64,39 W maximum power point (I=4A) at 25°C and with a 1000 W/m2 solar radiation.

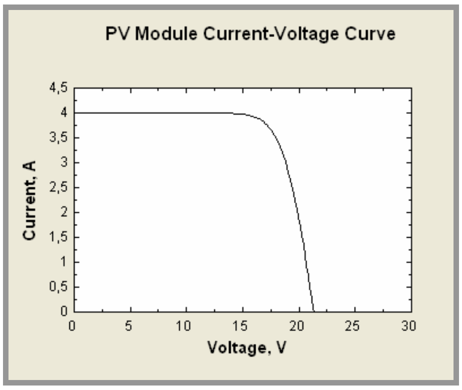

Fig.7: PV Current-voltage curve.

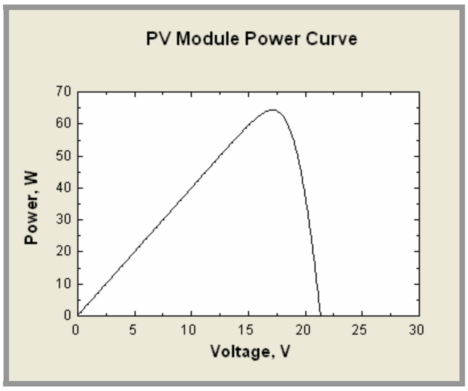

Fig.8: PV Power curve.

The studied case has been used to create the following general procedure applicable to every other plant typology we want to study:

1) Analysis of the state of the art;
2) Problem formulation;
3) Determination of the operative system parameters;
4) Production of models of the components and of the general system;
5) Execution of the simulation calculations;
6) Choice of the optimal configuration and design of the real system.

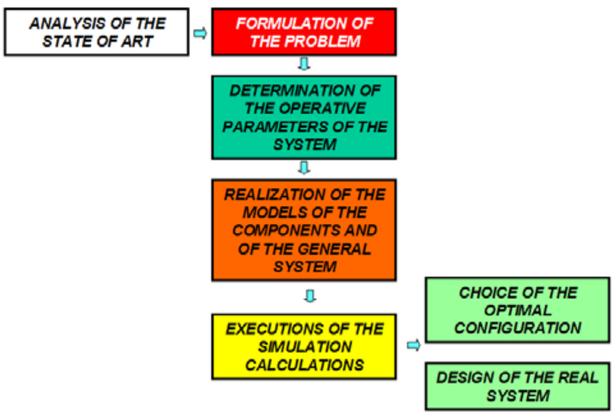

Fig.9: General procedure.

3 Conclusions

Modeling and simulation procedures have been discussed to be the operating platform in the design of electrical systems: the higher the complexity, the greater their importance. The paper discussed a schematic approach to the generic problem of modeling and simulation, paying particular attention to simulation model validation. An approach for the creation of general procedures has been discussed; application to the simulation of a Stand Alone Power System based on solar-hydrogen energy technology. The described operating sequence allows not only accurate considerations on the model's results, but also deep considerations on the model itself.

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