Proceedings of the Ninth IASTED European Conference
Power and Energy Systems (EuroPES 2009)
September 7 - 9, 2009 Palma de Mallorca, Spain

COMPLETE AGENT BASED SIMULATION OF MINI-GRIDS

J.M. González de Durana*, O. Barambones*, Enrique Kremers†, and Pablo Viejo†
* Dpto. Ingeniería de Sistemas y Automática, EUI de Vitoria,
Universidad del País Vasco, Spain.
† European Institute for Energy Research - EIFER
EDF and the University of Karlsruhe, Karlsruhe, Germany.
Tel: +34 945013228; Fax: +34 945013270; E-mail: jtpgogaj@ehu.es

ABSTRACT

With eyes focused on simulation we review some of the main topics of Hybrid Renewable Energy Systems (HRES). Then we describe an Agent Based model of a simple example of one of such systems, a micro-grid, oriented to designing a decentralized Supervisor Control. The model has been implemented using AnyLogic.

KEY WORDS

Hybrid Renewable Energy Systems (HRES), Distributed Energy Resources (DER), Agent Based Modeling & Simulation (ABMS), Hybrid Systems (HS), AnyLogic.

1 Introduction

The vast majority of the non-electrified population are living in remote and rural areas of the developing countries where micro-grids have proved to have a very high potential to participate actively in the electrification of remote and rural areas. Such grids may be fed by electricity from different renewable and conventional decentralized sources.

There are a lot of interesting Hybrid Renewable Energy Systems (HRES) micro-grid applications like as mobile equipment, autonomous equipment, small village electricity power supply, water pumping and irrigation systems, communications power suply, mobile health emergency clinics, etc.

1.1 Microgrids

A micro-grid is formed by interconnection of small voltage generators, storage and controllable load distribution systems. Micro-grids can be connected to the main power network or be operated autonomously, similar to power systems of physical islands.

1.2 Microgrid control

For controlling a micro-grid seme strategies can be used:

- Supervisor Control
- Local Decentralizad Control
- Centralized/decentralized Load Dispatching

Usually these strategeis can be combimed in applications which results in a number of combinations of possible to control types.

1.3 Configuration

In [3] the authors investigate an specific architecture of autonomous hybrid power system, based upon the utilization of a DC bus, a DC/AC inverter, and an individual DC/DC converter for each power source. A main advantage of the discussed system's architecture exists in providing a decoupling of the state values of the conversion systems from those of the grid through the use of the DC/DC converters". Figure 1 shows a sample of micro-grid configuration using this architecture.

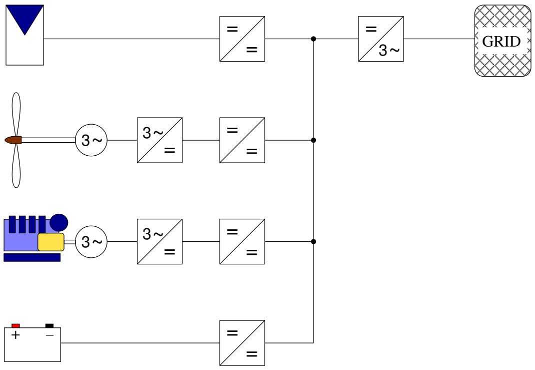

Figure 1. Microgrid configuration

By addition of DC/DC converters, the state values of the energy conversion sources become completely decoupled from each other and from the state values of the grid. That means that the variations of the renewable resources like the velocity of the wind and the intensity of the solar radiation will not influence the state values of the electrical grid. These values are only controlled by the inverter. On the other hand, changes in the loads, which influence the state values of the grid will not affect the generation side.

2 Simulation

Depending on simulation time or modeling horizon, three types of simulation are often distinguished: long term, medium term and short term. Modeling horizons are in some way related to the model abstraction degree: high abstraction level, middle abstraction level or low abstraction level.

2.1 Block based and object based simulation

Block based and Object Oriented simulation languages are the two traditional categories we have to model HRES systems. In our opinion, object oriented languages are best posed to cope with complexity that HRES systems exhibit.

One additional advantage of Object Oriented languages deals with the possibility of create Agent Based (AB) models. AB ranges from small, minimalist models to large-scale decision support systems. Minimalist models are based on a set of idealized assumptions, designed to capture only the most salient features of a system.

3 AnyLogic model

AnyLogic is a simulation program developed by XjTek [6] using a subset of UML for Real Time (UML-RT) as a modeling language, and extended it to incorporate continuous behavior.

Three simulation paradigms are included in AnyLogic:

- System Dynamics (SD)
- Discrete Event (DE)
- Agent Based (AB)

This methods can be combined in a model, for example it is possible to include SD and DE methods into an Agent model, so each agent can be an hybrid system. In this way we can obtain models with a very high refinement level.

The Dynamic System (DS) paradigm, the main method used in block based programs like Matlab-Simulink, is considered to be as a part of SD paradigm in AnyLogic since version 6 appeared.

AnyLogic is specially well positioned to model Hybrid Systems.

3.1 Micro-grid simulation

We have developed a computational hybrid, agent based, system modeling and simulation method, as a valuable tool for analysis, design and validation of micro-grids. Trying to simplify the exposition and the result analysis, and also for didactic reasons, the method is applied to a rather simple one.

The model has been built in AnyLogic and we used some formulae given in [2] for building some components. It is composed of 7 Active Object clases: Battery, Bus, Diesel, Load, Multiplug, Pv and Wind besides the Main class.

3.2 Wind system simulation

Power output of wind turbine generator at a specific site depends on wind speed at hub height and speed characteristics of the turbine. Wind speed at hub height can be calculated by using power-law equation [2]:

$$V_\mathrm{z} = V_\mathrm{i} \left(\frac{Z}{Z_\mathrm{i}} \right)^x$$

where V_z and V_i are the wind speed at hub and reference height Z and Z_i, and x is power-law exponent.

Power output Pw $(\mathrm{kW/m^2})$ from wind turbine generator can be calculated as follows [2]:

$$\begin{array}{ll} P_\mathrm{w} = 0, & V < V_\mathrm{ci} \\ P_\mathrm{w} = a\,V^3 - bP_\mathrm{r}, & V_\mathrm{ci} < V < V_\mathrm{r} \\ P_\mathrm{w} = P_\mathrm{r}, & V_\mathrm{r} < V < V_\mathrm{co} \\ P_\mathrm{w} = 0, & V > V_\mathrm{co} \end{array}$$

where $a = P_r/(V_r^3 - V_{ci}^3)$, $b = V_{ci}^3/(V_r^3 - V_{ci}^3)$, P_r is the rated power, V_{ci}, V_{co} and V_r are the cut-in, cut-out and rated speed of the wind turbine.

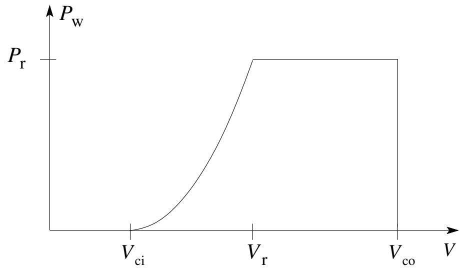

Figure 2. Power output

Actual power available from wind turbine is given by [2]:

$$P = P_w A_w \eta,$$

where A_w is the total swept area, Z is efficiency of wind turbine generator and corresponding converters.

In [5] a time series model has been developed to simulate the real wind speed. Historical wind speeds can be obtained for some specific site, based on which, future hourly data are predicted using the time series model. The simulated wind speed w_s is obtained from the mean wind speed μ_t and its standard deviation σ_t at time t,

$$w_{st} = \mu_t\, \sigma_t\, y_t$$

and the original data series set y_t can be used to create a wind speed time series referred to as an ARMA (Auto-Regressive and Moving Average Model) stochastic process as

$$\begin{aligned} y_t = &\phi_1\, y_{t-1} + \phi_2\, y_{t-2} + \cdots + \phi_n\, y_{t-n} \\ &+ \alpha_t - \theta_1\, \alpha_{t-1} - \theta_2\, \alpha_{t-2} - \cdots - \theta_m\, \alpha_{t-m} \end{aligned}$$

where $\phi_i,\ i = 1, 2, \ldots, n$ and $\theta_j,\ j = 1, 2, ..., m$, are the auto-regressive and moving average parameters of the model respectively, $\{\alpha_t\}$ is a normal white noise process with zero mean and variance of σ_a^2.

The above equation allows new values of y_t to be calculated from current random white noise α_t and previous values of y_{t-i}. The hourly wind speeds incorporating the wind speed time series can be generated using this equation.

We use the ARMA model given in [2] (for specific site indicated in the paper):

$$\begin{aligned} y_t = &1.17 y_{t-1} + 0.10 y_{t-2} - 0.35 y_{t-3} + 0.03 y_{t-4} \\ &+ \alpha_t - 0.50\alpha_{t-1} - 0.29\alpha_{t-2} + 0.13\alpha_{t-3} \end{aligned}$$

where α_t is a white noise with zero mean and standard deviation $\sigma = 5247602$.

3.3 Photo Voltaic (PV) system simulation

The solar radiation on an inclined plane is given by [2]:

$$I_T = I_b R_b + I_d R_d + (I_b + I_d) R_r,$$

where I_b and I_d are direct normal and diffuse solar radiations, R_d and R_r are the tilt factors for the diffuse and reflected part of the solar radiations. T_T depends on position of sun in the sky, which varies from month to month.

Hourly power output from PV system with an area A_{pv} (m^2) on an average day of jth month, when total solar radiation of IT (kW h/m^2) is incident on PV surface, is given by [6]

$$P_{sj} = I_{T_j} \eta A_{PV},$$

where system efficiency η is given by

$$\eta = \eta_m \eta_{pc} P_f$$

and the module efficiency η_m is given by

$$\eta_m = \eta_r [1 - \beta (T_c - T_r)],$$

where Z_r is the module reference efficiency, Z_{pc} is the power conditioning efficiency, P_f is the packing factor, β is the array efficiency temperature coefficient, T_r is the reference temperature for the cell efficiency and T_c is the monthly average cell temperature, calculated as

$$T_c = T_a + \frac{\alpha\tau}{U_L} I_T,$$

where T_a is the instantaneous ambient temperature, $U_L/\alpha\tau = I_{T,\mathrm{NOCT}}/(\mathrm{NOCT} - T_{a,\mathrm{NOCT}})$, and NOCT is normal operating cell temperature, $T_{a,\mathrm{NOCT}} = 20^{\mathrm{o}}\mathrm{C}$ and $I_{\mathrm{T,NOCT}} = 800\ \mathrm{W/m^2}$, for a wind speed of 1 m/s.

3.4 Diesel engine

If load requirements are not met by either renewable energy system or by batteries then load requirements are met by operating diesel generator in HRES. Overall efficiency of diesel generator is:

$$\eta_{\mathrm{overall}} = \eta_{\mathrm{brakethermal}} \cdot \eta_{\mathrm{generator}},$$

where $\eta_{\mathrm{brakethermal}}$ is brake thermal efficiency of diesel engine.

3.5 Battery system

Batteries are sized to meet the load demand during non-availability period of renewable energy source, normally about 2 or 3 days. Required battery capacity in ampere hour is given by

$$B_{\mathrm{rc}} = \frac{E_{\mathrm{c}(Ah)Ds}}{(DOD)_{\max} \eta_t},$$

where $E_{\mathrm{c(Ah)}}$ is the load in ampere hour, D_{s} is the battery autonomy or storage days, DOD_{max} is the maximum battery depth of discharge, η_t is the temperature correction factor.

Difference between power generated and load, decides whether battery is in charging or discharging state. The charge quantity of battery bank at the time t can be calculated by

$$E_{\mathrm{B}}(t) = E_{\mathrm{B}}(t-1)(1-\sigma) + (E_{\mathrm{GA}}(t) - E_{\mathrm{L}}(t)/\eta_{\mathrm{inv}})\eta_{\mathrm{battery}}$$

where $E_{\mathrm{B}}(t)$ and $E_{\mathrm{B}}(t-1)$ are the charge quantities of battery bank at the time t and $t-1$, σ is the hourly self-discharge rate, $E_{\mathrm{GA}}(t)$ is the total energy generated by renewable energy source after energy loss in controller, $E_{\mathrm{L}}(t)$ is load demand at the time t, η_{inv} and $\eta_{battery}$ are the efficiency of inverter and charge efficiency of battery bank.

Charge quantity of battery bank is subject to the following constraints:

$$E_{\mathrm{B_min}} \leq E_{\mathrm{B}}(t) \leq E_{\mathrm{B_{max}}},$$

where $E_{\mathrm{B_{max}}}$ and $E_{\mathrm{B_{min}}}$ are the maximum and minimum charge quantity of battery bank.

3.6 DC bus simulation in System Dynamics

As already we have said, we will focus our simulation in the specific architecture for autonomous hybrid power system (HPS) investigated in [3]. The first element we are trying to model is the DC bus (figure 1). Basically all we need is to write up the equations for the circuit in figure 4, where we assume the Thevenin equivalent circuit for one of each n electrical power sources, and that load is composed by m switched and possible varying resistances.

The equivalent resistance to the m load resistances connected in parallel is

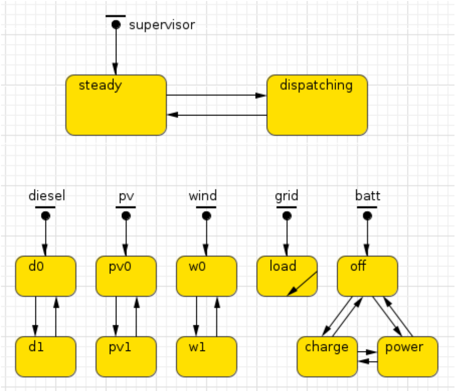

Figure 3. Supervisor control

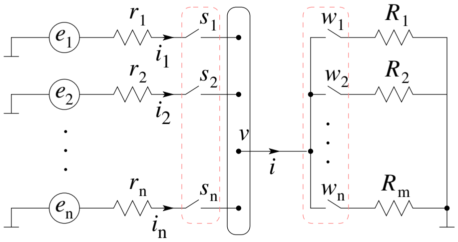

Figure 4. Basic connection circuit

$$R = \frac{1}{\dfrac{w_1}{R_1} + \dfrac{w_2}{R_2} + \cdots + \dfrac{w_m}{R_m}}$$

where $w_i = 0$ if the switch is open and $w_i = 1$ if the switch is closed, for $i = 1, \ldots, m$. Then we have $v = R\,i$ and we can calculate the intensity flowing through generator line,

$$i_1 = \frac{e_1 - v}{r_1},\ i_2 = \frac{e_2 - v}{r_2}, \ldots,\ i_n = \frac{e_n - v}{r_n}$$

if each switch is closed, or $i_i = 0$ $(i = 1, \ldots, n)$, if the switch is open. So

$$i = i_1 + i_2 + \ldots + i_n$$

If one realize that there is a feedback from output voltage v until each voltage source e_1, e_2, $\ldots$, e_n, it is not difficult to draw to the Forrester diagram that appears in figure 5. The load resistance R can be changed by the user during simulation by controlling the slider. This is the basic model to build all the other objects

3.7 Supervisor Control

As in [4], for designing supervisor control we assume the main generation role is in charge of the wind subsystem while the solar subsystem would play a complementary role. However here we propose a rather different method to implement the control: we use a centralized scheme for supervisor control and assume that load dispatching will be done in a decentralized manner (see figure 3).

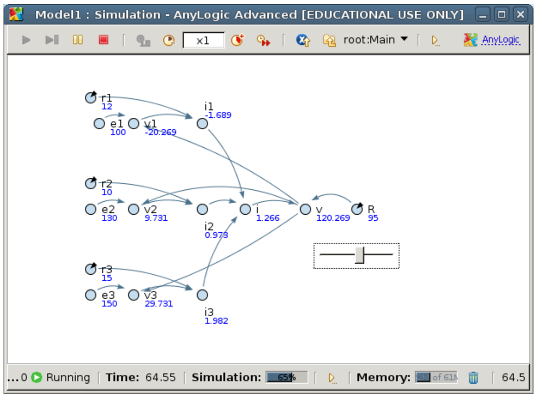

Figure 5. Basic Sistem Dynamics model

Supervisor control performs a centralized operation. It is modeled with a statechart with two states: steady and dispatching. Transition from steady to dispatching is fired when it receives a message indicating that a change in load dispatchig must be done. Then the system changes to dispatchig state, performs the oportune change and returns to the steady state.

3.8 Running sumulation

Once all the objects had been created it is possible to connect them and run simulation. Any number objects can be connected to DC_bus. The displayed figure represents the AnyLogic simulation window of a simple example with 5 generator elements and three loads. Source intensities $i_{s_1}, i_{s_2}, i_{s_3}$ and load intensities $i_{l_1}, i_{l_2}, i_{l_3}$ are also represented.

One can see that supply is guaranteed even if load demand of power or metheorological conditions change. It is possible to study the microgrid behavior in all conditios which could be very interesting in order to sizing microgrid elements and designig its structure.

A Clock object (associated to Java calendar class) has been borrowed from AnyLogic Enterprise library to show data and time, from minutes and hours to months or even years.

The model also uses two AnyLogic TableFunction objects in order to store local meteorological historical data about wind velocity and sun radiation. See figure 6.

4 Conclusion

An agent based model for micro-grids has been implemented using AnyLogic. The model is mainly intended to design and try micro-grids and it can be used as a tool for

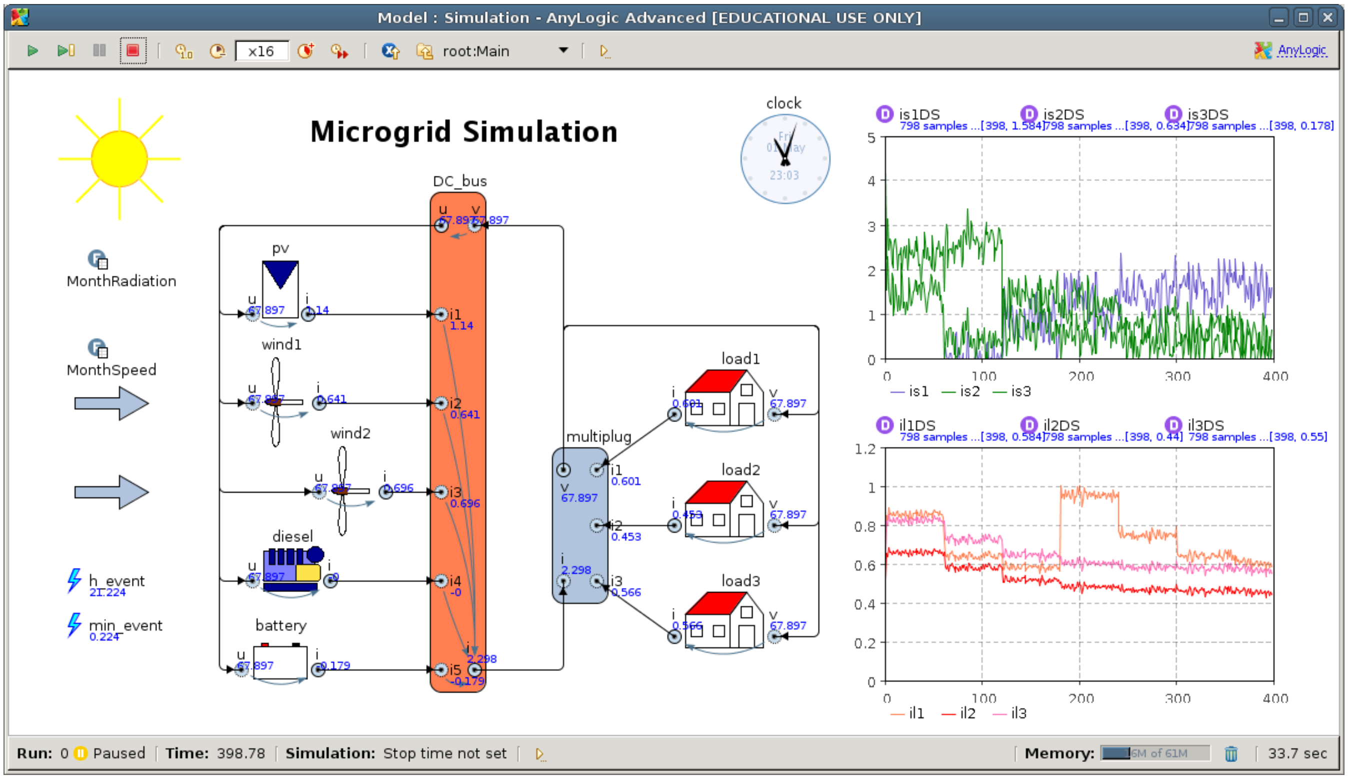

Figure 6. Running simulation

design, development and demonstration of control strategies specially Centralized Supervisor Control and Decentralized Load-Dispatch Control, design and demonstration of micro-grid operation strategies, design and trying of micro-grid communication buses, micro-grid optimal design, and economic benefits demonstration. We think our model can be used to analyze a number of topic design of micro-grids like as design, development and demonstration of control and operation strategies, design and trying of micro-grid communication buses, optimal micro-grid design and economic benefits demonstration.

Acknowledgements

The authors would like to express their appretiation to Sergey Suslov Victor Gleim, Pavel Lebedev, Sergey Suslov, Stanislav Fedotov, Andrei Borshchev, Alexei Filippov, etc. from XJ Technologies Company, for their valuable explanations about AnyLogic topics and their unpayable help answering all the questions they asked.

They are also are very grateful to the Basque Government by the support of this work through the project S-PE07UN04 and to the UPV/EHU by its support through project GUI07/08.

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