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Technology-free microgrid modeling with application to demand side management

Jose Gonzalez de Durana*, Oscar Barambones

University of the Basque Country, EUI Nieves Cano 12, 01006 Vitoria-Gasteiz, Spain

HIGHLIGHTS

- Microgrid comprehensive model, including generators, loads, energy storage elements and electrical network.
- Technology-free modeling approach: all microgrid elements are modeled in a tech-free way.
- System Dynamics, Discrete Event and Agent Based methodologies are used to model.
- Power-flow modeling on System Dynamics.
- A demand side management application instance is also included.

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ABSTRACT

When trying to model a microgrid, with renewable distributed generation, previous models of generators, loads, electrical networks, and further equipment are necessary, in order to build it.

In this paper the authors attempt to put everything in a model in a technology-free way and using a reduced number of data, regardless of the accuracy in representation of loads and generators, only to get a roughly idea about magnitudes, in order to achieve a relatively easy way to experiment some demand side management algorithms, to get a rather general modeling approach, independent of technologies used, and useful to be applied on migrogrid instances. Also a demand side management instance is performed as a possible model application.

1. Introduction

From tens of years ago, factors like pollution, global warming, scarcity of fossil fuels, etc., favored the progressive transformation of the old power grid, featured by its centralized power generation, into a new network, where gradually distributed generation and use of new information and communication technologies were gaining prominence. Successively new methods and devices allowing this transformation have been emerging, but because that methods and marketed devices are usually very sophisticated, nowadays the complexity of the grid has become huge, leading to the so called *Smart Grid*, whose modeling is a great challenge. However that can be cut down assuming the power grid as a number of interconnected microgrids (MGs) [1], which makes even more attractive the study and modeling these systems [2,3].

Being MGs the basic building blocks of the Smart Grid, many works have been published on their peculiar aspects, using appropriate approaches to address several problems related to demand side management (DSM) [4,5], optimal energy management [6–8], real time aspects of energy management [9,10], multiple coupled MGs [11], issues on islanded MGs [12,13], several market aspects [14–16], pricing mechanisms [17], etc.

Thinking on complexity [18] and diversification [19] of MGs, it may be tempting to design somehow universal or polyvalent power system models, not conditioned by the used technology, which could be called technology-free models. As far as the authors know, not much information has been published on this subject, although something similar can be seen for instance in [20], albeit applied to another field, that of communication of information. Therefore in this paper they try to cover this *knowledge gap* by giving a way to make models as independent as possible of actual equipment and considering that *technology-free modeling* of power systems can be view as a new body of knowledge.

The idea occurred to the authors after the work described in [21], where *power oriented graphs* (POG) [22,23] were used to model electromechanical elements in hybrid cars. While POGs represent energy

* Corresponding author.
E-mail addresses: josemaria.gonzalezdedurana@ehu.es (J. Gonzalez de Durana), jmgdurana@gmail.com (O. Barambones).

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Nomenclature

t	time
$P,p,p(t),p_0(t)$	power
$V,v,v(t),v_0(t)$	electric voltage
$\eta,\overline{\eta},\widetilde{\eta}$	efficiency
P_{PV}	PV power
T	temperature (K)
N	natural number
p, pi	power flow
x, y	Matlab file vector
fn, fit	Fitting Toolbox function
SD	System Dynamics
event	Anylogic event
p_off, p_on	SD power flow
load_off, load_on	SD constant
x	real value
$r,r_0,r_1,\overline{r},\widetilde{r}$	resistance
$I,i,i(t)$	electric intensity
a,b,c	positive constant
A	panel area
α	temperature coefficient
Z	hub height
p0	load power
a_i,b_i,c_i	coefficient values
f_{load}	Fitted load profile
off, on	Statechart state
p, q	SD power parameter
e_off, e_on	SD energy stock
on_frac	SD dynamic variable

Load switching – Markov chains

$\mathbb{P}$	conditional probability
P	stochastic matrix
$X_0,X_1,...$	discrete random variable
p,q,π,π_0,π_1	probability value

Energy storage modeling

h	tank height
g	gravity acceleration
ρ	water density
Q	battery electric charge
q	water flow
A	tank area

Model building – Anylogic agents

$a_1,a_2,...$	power agent
z,r_i	energy
pg, pi, pl, ps	power flow
p, g, l, l1, l2, l3, l4	dynamic variable
loadProfile	table function
i, pv, wind	Anylogic variable
$p_i,p_{12},p_{13},...$	power flow
C	constant
c, ri	constant
Npv, eta	parameter
house1,…	instance agent
windTurbine	instance agent

ports with two variables, effort and flow (e,f), whose product is power (p) [24], sometimes it is sufficient only to use one variable $p = u\,v$, instead the two ones. Hence power graphs are used in this work that, as we shall see, leads to a substantial simplification, without any loss of accuracy. Together with this, other complementary tech-free developments which appear in the following list and are hereafter described, draw up the main paper contributions:

1. Technology-free approach
   1.1 Power systems as graphs
   1.2 SD Power flow modeling
2. Microgrid modeling
   2.1 Power generation
   2.2 Load modeling
   2.3 Energy storage modeling
   2.4 Interconnection network
3. Microgrid instance model
   3.1 DSM procedure

2. Technology-free approach

An electric power system can be represented as electrical circuit but can also be view as a power network whose elements perform special processes to supply (sources), transfer (transmission lines), store (storage devices), and use (loads) electric power. Usually the posed problem is: given the power flowing through loads and storages, calculate the necessary input flows.

What the authors want to mean with the term technology-free is a set of methods conceived to represent these four elements with no mention to the special devices used, but only using the efficiency η and a time dependent function $p(t)$ of the power flow associated to each. This does not mean that no technology is used in these devices, but that it has been previously analyzed and figured out to obtain these functions. In this way, technology is hidden and the power system appears as a single power graph where all elements are known. Moreover, if the actual values of circuit components are known, then the usual electrical variables (voltages and currents) can be eventually obtained.

It should be said that while the applied methods may not be considered as new, it is their appropriate setup which confers the approach the category of technology-free of modeling. To fulfill this, three combined modeling tools also are employed: *System Dynamics* (SD) to model power flows and stocks, *Discrete Event* (DE) to model discontinuities, events and switching elements, and *Agent Based* (AB), to put all together, using Anylogic as modeling tool [25].

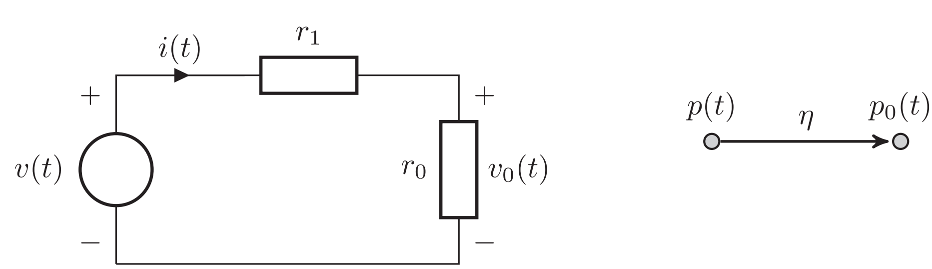

Fig. 1. Simple circuit and “equivalent” power graph.