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An ARX-Petri Nets algorithm for Active Identification of an AC/DC Microgrid Simulation

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***Abstract*—In this article, a new algorithm is developed for the identification of an AC/DC Microgrid (MG) using methods of "Auto-Regressive with eXogenous inputs (ARX)" and Petri Nets (PN). An algorithm is shown in order to obtain a model of Distributed Generation (DG) systems for a MG. This algorithm aims to obtain a bank of models in which each model is obtained through the identification of a different point of operation. This method facilitates the identification of dynamic non-linear systems associated with MG systems. During the development of this research, a bank of models for converter systems are obtained in state space which reflect the nonlinear dynamic properties of the systems and converters that compose an AC/DC MG.**

Keywords— Microgrid; Identification; No-lineal systems; State Space Model; ARX; Petri Net

I. Introduction

The identification of systems with unknown dynamic characteristics that are difficult to capture or are highly non-linear, have opened a highly important field of research entitled, "system identification". Basically, it can be defined as a set of statistical and stochastic methods which allow to tune in optimally, from observed data, a mathematical model suitable to a known dynamic system and apply it to model the dynamic behavior of the unknown system.

Current studies that seek to solve problems related to the resilience of the Electric Power System (EPS) have been directed, without a doubt, to Smart Microgrids. MGs will contribute significantly to solve these problems and begin to play an important role in the new decentralized paradigm of Smart Grid (SG). These surely play a key role in the evolution of SG, becoming ideal prototypes for both: isolated sites and sites interconnected to the national electrification system.

In practice, the modeling of a MG becomes complicated due to the high non-linearity of the devices that comprise it. However, obtaining mathematical models of MGs become a key issue when carrying out system analysis and designing controllers, where most of the methods are based on the knowledge of the system dynamics.

In this paper, a novel algorithm is developed through the use of PN and ARX that allows us to identify a bank of dynamic models in state space, that describe the evolution of the different components of the MG towards the steady state. For this models the system is considered as a "black box".

The paper is organized as follows: Section II "*Electric Microgrid*" presents the main characteristics of the MGs modeling and the MGs architectures. Section III "*Petri Net*" and IV '*Identification problem*' provides a brief description of the PNs and ARX identification used in the investigation. Section V discusses the analysis of the identification problem and the proposed algorithm. Section VI describes the simulation results of the proposed Dynamic Identification algorithm and, finally, future research areas and conclusions can be found in Section VII.

II. Electric Microgrid

In the future, MGs are an attractive solution for the integration of Distributed Generator (DG) units in SG which will bring a reduction in the dependence on fossil fuels and an increase in the efficiency of the distribution systems.

MGs must be robust to keep the voltage and frequency within given tolerances, to protect the Main Grid and the loads connected to the various faults to which they are exposed [1]–[3]. In addition, MGs need to facilitate the administration and re-synchronization on the demand side. These are usually types of small scale SGs that provide a very interesting solution to improve power flow in the distribution grid and reduce power losses in transmission lines [4] – [8].

A. Microgrid architecture

In the literature, three definitions for MGs can be found: microgrids, nano-grids (NG), and pico-grids (PG). Additionally, MGs can operate in parallel to the main electrical grid, both in stand-alone mode (stand-alone power) and in interconnected mode (assuming Main Grid references) [2], [5], [8]–[16].

As described in [17], MGs can be in Serial, Switched, and Parallel configuration. In the MG series configuration, there is a DC bus where all the generation systems and loads are connected through their respective converters. In contrast, the parallel configuration has an AC bus where the generation systems and the loads are directly connected and the DC devices are connected through their own inverters, or through a

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DC bus coupled to the AC bus through an inverter or bidirectional voltage source converter (VSC) [2], [17].

The combination between the AC and DC MG configurations have given rise to the concept of hybrid AC / DC MGs and propose an optimal approach because it combines the main advantages of the AC and DC MGs [5]. Future trends show that features such as scalability, modeling, design, and control structures require further investigation to achieve integration of hybrid MGs into the main power grid [8], [15].

B. Microgrid architecture

The models of MGs are dynamic and can change depending on their configuration, type of topology, and components. Therefore, different modeling methodologies are required that are capable of representing: rapid dynamics, short response time of DG, inherent unbalanced nature of the MG, low energy storage capacity, lack of inertia, high degree of parametric uncertainties, a high number and diversity of micro-sources, electronic power converters, circuits, other devices, and high failure rates [3], [4], [8], [18]–[21].

In the dynamic modeling, the very slow and fast dynamics are often neglected. For instance, the dynamics of generators (conventional sources) are much slower than the dynamics of VSC which can disregard the generator dynamics. Many authors consider the voltage on the generator bus as a constant parameter. Nor do they consider the modeling of the associated dynamics. They also do not consider the modelling of the associated dynamics. In addition, due to the high switching frequency of some elements like converters / inverters, the relevant dynamics are also considered insignificant [2], [22].

On the other hand, authors seek to model each source of GD by reducing the order of the model to a linear time invariant first order system (LTI) with a time constant and gain factor thereby neglecting the dynamics of the grid. Other researchers represent MG by a DC source with a VSC connected to the main network, an RL filter, a transformer and a circuit breaker which obtains a dynamic model in low order for the equivalent system that can be easily used for the purpose of control analysis [2], [22].

There are also other approaches with DG based on inverters, such as [23]. In that work the complete dynamic model of the entire grid was considered in place of the inverter, dividing the MG system into three subsystems: inverter, distribution grids, and loads. In the inverter model, the dynamics of the controller was incorporated; the output filter and the coupling inductor; and for the state equations of the grid and load, both were represented it in one of the reference frames of the inverter, assuming that it is the common reference. Then, using the transformation technique, the other inverters transform them into this common framework and model each subsystem in combined state-space in the mentioned common frame of reference. In [24], the authors also developed a LTI model in state space and perform an analysis of the eigenvalues to study the dynamic behavior of the MG while changing the electrical parameters and the control gains.

III. Petri Net

PNs allow the study and description of information processing systems characterized by being concurrent, distributed, non-deterministic and / or stochastic [25]–[28]. A PN is a rigorous and powerful mathematical and graphic representation, commonly used in discrete, distributed, and continuous systems [25], [28]–[30].

The PNs are a directed graph that contain two types of main nodes: the places (P) represented by circles and the transitions (T) represented by rectangular bars, together with one or several initial states that is called the brand initial (μ_o) represented by black dots located within each location [25], [28], [31]. The PN of **Figure 1** for example is made up of 3 places, three transitions and 7 arcs of weight one [25], [30].

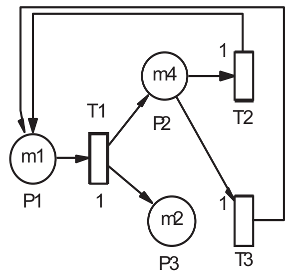

Fig. 1. Petri Net [25].

The nodes are interconnected with directed arcs which connect the transitions with places and vice versa, in addition to modifying the different states of the system according to the assigned weights. The weight of an arc determines the number of marks that the place consumes or that is deposited in another place, if the enabled transitions are triggered. Arcs directed without a number are understood to consume or deposit a mark [20], [25], [26], [28], [31].

IV. Identification problem

The system identification problem deals with the estimation of a dynamic system model from observed data of inputs $u(t)$ and outputs $y(t)$, considering the system as a black box operating in a stochastic environment [32], [33].

For the identification of systems, the most studied methods are based on the step response such as: the Oldenbourg - Sartorius method; Anderson's method; step response for oscillatory systems; Strejc method for systems of order n; models with transport delay; among others [32], [33].

A. Auto-Regressive with eXogenous inputs

The ARX represents a dynamic process modified by one or more input entries considering the uncertainties. This model describes the observed output of the system, process or plant, $y(t)$, as a regression sum of the observations of the inputs, $u(t)$, and output, $y(t)$, and the model error, $e(t)$ [32], [33].

Considering input and output data:

$$\{(u\ (t), y\ (t))\}_{t=1}^{N}. \tag{1}$$

The ARX model is expressed according to the following equation:

$$\begin{aligned} y(t) + a_1 y(t-1) + \cdots + a_{na} y(t-na) = b_1 u(t-nk) + \ldots \\ + b_2 u(t-nk-1) + \cdots + b_{nb} u(t-nk-nb+1) + e\ (t) \end{aligned} \tag{2}$$

The dynamic system output from data and disturbances is:

$$y(t) = -a_1 y(t-1) - \cdots - a_{na} y(t-na) + b_1 u(t-nk) + .. \quad (3)$$
$$+ b_2 u(t-nk-1) + \cdots + b_{nb} u(t-nk-nb+1) + e(t)$$

The output at time t is modeled as a lineal regression of inputs and outputs at previous times, so

$$\theta = [a_1 \ldots a_{na} \; b_1 \ldots b_{nb}]^T \quad (4)$$

$$\varphi(t) = [-y(t-1) \ldots -y(t-n) \; u(t-1) \ldots u(t-m)]^T \quad (5)$$

$$y(t) = \varphi^T(t)\,\theta \quad (6)$$

The output predictor is modeled as:

$$\hat{y}(t \mid \theta) = \varphi^T(t)\theta \quad (7)$$

Using the least squares method, a system of equations is generated where the coefficients of the discrete transfer function, a_i and b_j (i=1,2,…n, j=1,2,…,m), are the unknowns. The model error, $e(t)$, is assumed to be white noise.

V. Problem Formulation

Consider a hybrid AC/DC MG, both in its connected mode to the grid and in its isolated mode, that is composed of: a distributed energy resource (DER) and a set of smart systems designed for the conversion of energy (DC/DC, DC/AC, AC/AC, bidirectional or not), control, monitoring and protection. The intention of this study is to get a state space model of the whole MG using the observed information for control purposes, whereby the very fast dynamics of highly nonlinear systems such as inverters and rectifiers is not the main objective for the design and tuning of the controllers.

Figure 2 illustrates the proposed approach that allows to obtain the set of linearized models for the hybrid AC/DC MG. The PN state machine introduces the preset disturbances of the input variables m-index (*m*) and angle (*ang*) to the VSCs, coordinates the identification strategy and the assignment of the mathematical model obtained for each system of the MG in the form of a bank of ordered models. The identification is made based on the data observed: *m* (*t*), *ang* (*t*), *v* (*t*) and *i* (*t*).

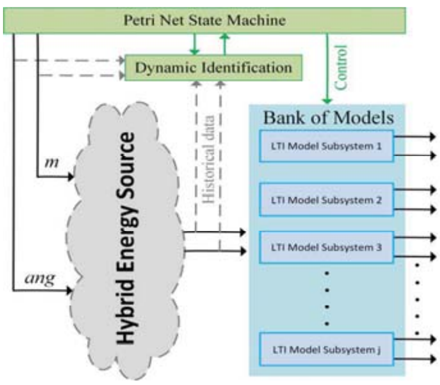

Fig. 2. Bank of LTI model.

The **Table I** shown below contains the description of the variables used in the methodology of the **Figure 3**.

TABLE I. Variables of the PN algorithm

Symbology	Variable
$onDer_1$; $onDer_n$	Start status of the methodology for the GD_n.
$total_1$; $total_n$	Test signals buffer for the angle.
LG_{d1}; LG_{dn}	Macro-state of start of test signal injection.
Md_{11}; Md_{12} Md_{13}; Md_{21} Md_{22}; Md_{23}	Data of the input variable *j* measure of the plant.
arx_1; arx_n	Macro state of start of the Identification algorithm for GD_n.
$next_1$; $next_n$	Start status of the process in the GD_{n+1}.

The algorithm based on a PN (see **Algorithm 1**) models a state machine that allows to introduce a series of step type test signals, coordinate the identification algorithm with the observed data between the different systems and organizes the bank of linearized models for different points of operation in the various systems that make up the MG. **Figure 3** shows the test signals created by the strategy. The Petri net state machine implemented for this purpose can be seen in **Figure 4**.

Algorithm 1: PN model methodology for system test.

1. Set up the distribution of initial Tokens for the PN model, M_O.
2. Determine the characteristic vector, Ui for the transition state as a fault state.
3. Construct the incidence matrix, C (P,T) of the PN
4. Determine the dynamic transition process model through vector M_1.
5. Using the vector M_1 redistribute the token after the first shot start.

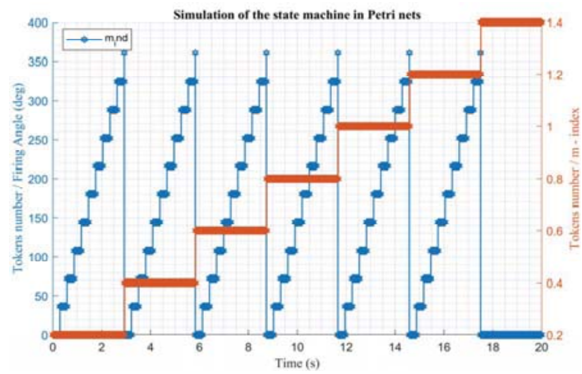

Fig. 3. Test signal and setpoint for bi-directional AC/DC converters, inverters or rectifiers.

The use of the step type test signals generated by the state machine in the PN allows obtaining the variables that feed the identification algorithm and has as its main advantage its simplicity, unveiling the non-linearity of the system. On the other hand, due to the non-linearity of the MG and its components, this type of test signals has as a disadvantage, given that that they use a rather large variation between the operating points of the system and prevent the exact identification between them. The algorithm based on PN is complemented by another identification algorithm using ARX which is able to freely determine the order of the model based on the observed variables of inputs and outputs.

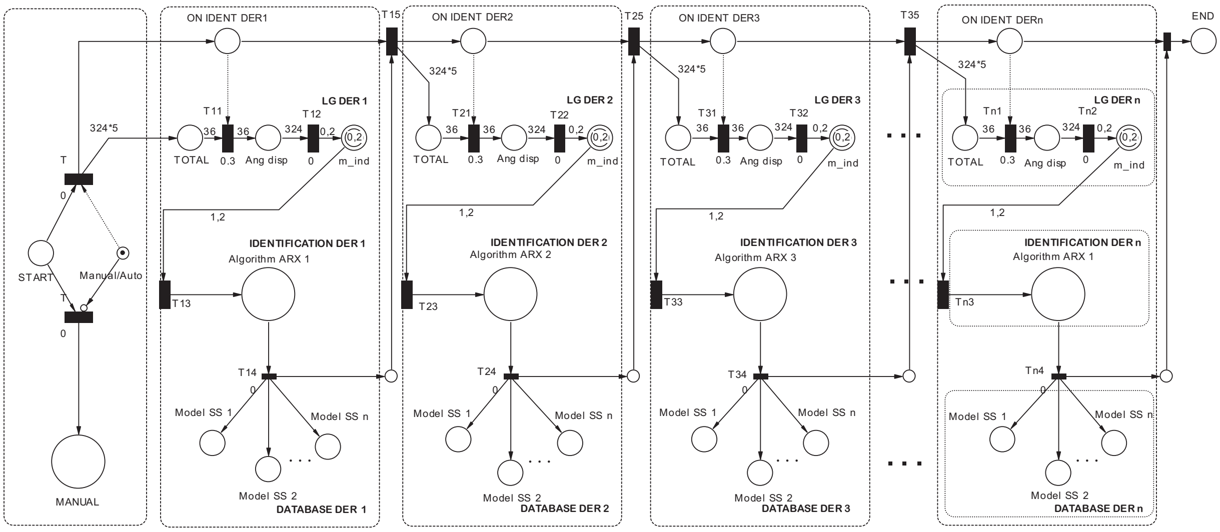

Fig. 4. State machine using PNs.

Once the empirical model in state space is obtained, the continuous time response of the dynamic system to arbitrary inputs is simulated to determine the estimation error.

VI. Case Study

The results presented in this section are based on a "*benchmark*" test model corresponding to an AC/DC MG connected to the Main Grid. The benchnark is modeled and simulated and using Matlab / Simulink.

Figure 5 shows a single-line diagram of the MG case study. This AC /DC MG includes: one Diesel Generator (DiG), two Photovoltaic Panels (PV), two Battery Energy Storage Systems (BESS), Linear Loads (LL), and Nonlinear Loads (NL).

The results shown in this article are related to the BESS shown in green color in **Figure 5.** It consists of 3 nickel-metal-hydride (Ni–MH) battery units of 650 VDC nominal voltage, with a rated capacity of 1,5 (Ah) which are connected to an interfaced inverter in a cascaded topology that steps up from 650 VDC to 900 VAC.

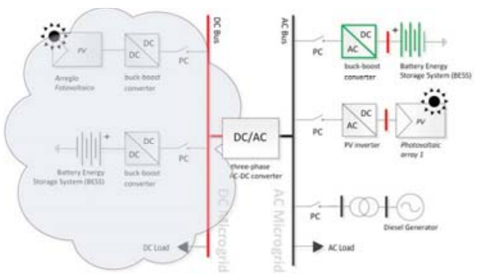

Fig. 5. Single-line diagram of AC/DC MG.

A. *Identification and analysis on the AC for the operating point*

In this section, the results of the model in inverter mode are shown. The outputs of the model are the voltage and the current in phases a, b, and c; the inputs of the model are the test signals for *m* y *ang* which are imposed by the designed PN (**Figure 4**).

Consequently, the operating point corresponding to DERn Gn is selected.

For this case of study the identified model represents the dynamics of the BESS (DERn Gn) between the Battery System in DC and the MG in AC. In **Figures 6** and **7** a dynamic behavior of the variables of voltage is seen with test signals generated as shown in **Figure 4.** Observed data are selected on point of operation DER_n G_n (see **Table II**) and then used in the identification.

TABLE II. Test signal adjusted to establish operating point on the AC MG bus

Operation Point	**Step signas**		**Initial output conditions, V (pu), I (A)**					
	m	*ang*	*Va*	*Vb*	*Vc*	*ia*	*ib*	*ic*
DER_n G_n	1.2	0º	0.794	0.831	0.803	688.6	687.8	688.2

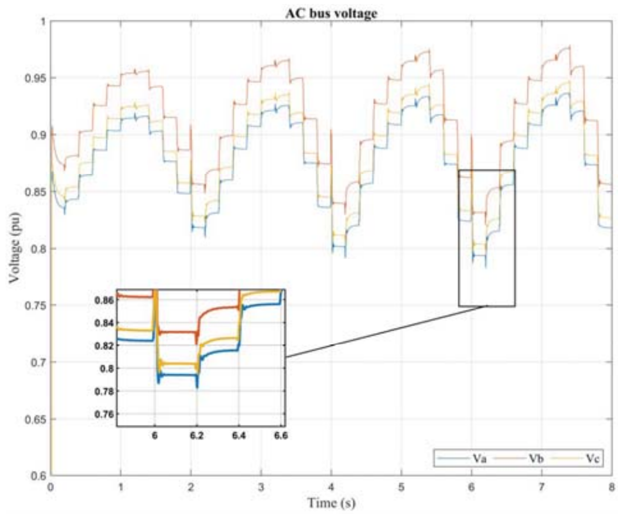

Fig. 6. Observed voltage data on the AC MG bus.

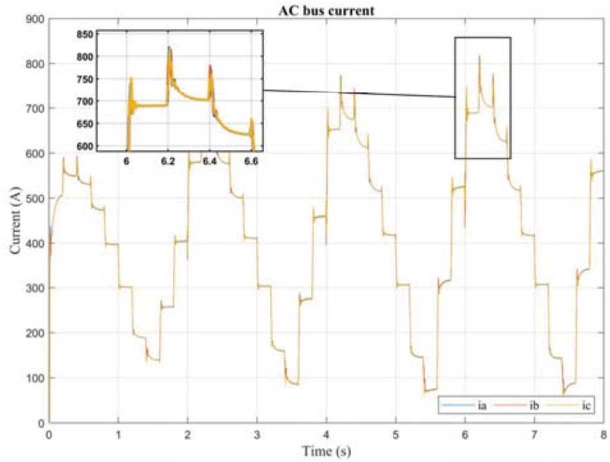

Fig. 7. Observed current data on the AC MG bus.

VII. Analysis of Results of the AC Microgrid Bus

Once the strategy in PN assigns the mark to the macro-state of identification of the BESS, the implemented identification algorithm is automatically executed based on the ARX method which will perform the analysis and adjustment of the data obtained with the step type test signal between two work levels.

A. Identification and analysis on the AC for the operating point

Afterwards, the method performs the identification using the data obtained around the corresponding operation point DER_n G_n and a MIMO system is obtained with two inputs (m y ang) and six outputs (V_a, V_b, B_c, i_a, i_b, y i_c) for the dynamic model of the BESS:

$$U_{ei}(t) = [m\,(t)\; ang\,(t)\,]; \tag{8}$$

$$Y_{si}(t) = [V_{abc}\,(t)\;\; i_{abc}(t)\,]; \tag{9}$$

Figure 8 shows the high degree of similarity between the results obtained by simulating the mathematical state space model (identified by the ARX structure) and the data from the simulation of the BESS for the operation point DER_n G_n.

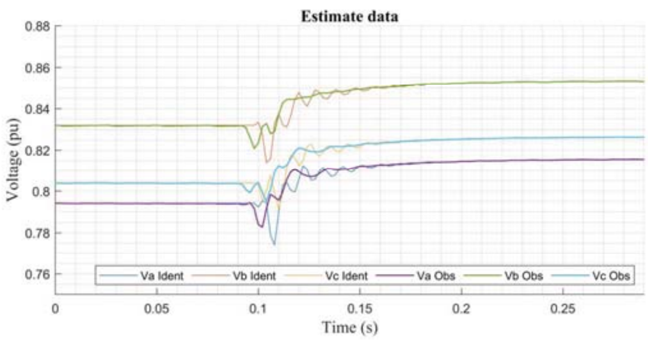

Fig. 8. Dynamic voltage response of DER_n G_n and estimates data.

Figure 9 shows the high degree of similarity between the results of the mathematical model in the linear state space which is obtained under digital simulation with the validation data from the simulated experimental study of BESS for the operating point DER_n G_n.

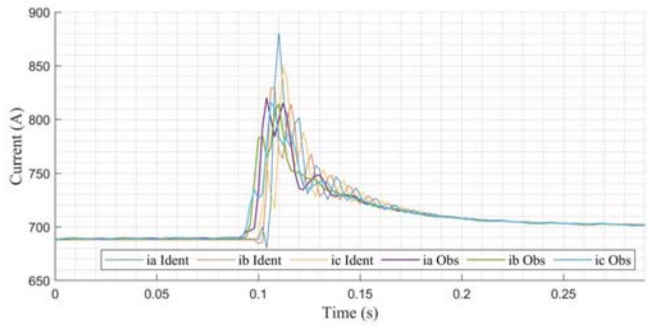

Fig. 9. Dynamic current response of DER_n G_n and validation data.

The estimated parameters of the system DER_n G_n on the operation point are:

$$A = \begin{bmatrix} -12.18073 & 65.73611 & 504.24024 & 0.19344 & -0.26019 & 0.24160 \\ 399.42372 & 77.37053 & -770.62547 & -67950.24 & 0.28998 & -0.39266 \\ 847.85016 & -56.64144 & 65.49071 & -0.17628 & 0.18036 & 0.04967 \\ -1073174.8 & 1906322.9 & -2017167.1 & -13.08947 & 498.361 & -275.915 \\ -1714200.0 & -1635683.2 & 3040047.5 & 170.6506 & -411.013 & 735.684 \\ 1349871.7 & -1828269.5 & -1080251.8 & 786.1223 & -394.705 & 233.866 \\ 340.32607 & -304.58511 & -424.01145 & -0.17352 & 0.20873 & -0.21976 \\ 28.18932 & -932.35786 & 638.92887 & 0.28237 & -0.26891 & 0.09565 \\ -786.67010 & -379.95390 & -137.8842 & 0.12814 & -0.03854 & -0.13802 \\ 5444306.0 & -2099619.9 & -2506197.7 & -136.4709 & 683.109 & -981.286 \\ 2384406.2 & 1355664.5 & -4215942.3 & -912.5237 & 1138.05 & -1168.569 \\ 4225641.9 & -1104110.5 & -2555503.3 & -1254.372 & 1228.18 & -957.711 \end{bmatrix} \cdots$$

$$\cdots \begin{matrix} 1012.1807 & -65.73611 & -504.24024 & 0.19344 & 0.26019 & -0.24160 \\ -399.423 & 922.629 & 770.62447 & 6.7950e-4 & -0.28998 & 0.39266 \\ -847.850 & 56.64144 & 934.50928 & 0.17628 & -0.18035 & 0.04967 \\ 1073174.8 & -1906322.9 & 2017167.1 & 1013.089 & -498.3609 & 275.9151 \\ 1714200.0 & 1635683.2 & -3040047.5 & -170.6506 & 1411.013 & -735.6842 \\ -1349871.6 & 1.8283e6 & 1080251.9 & -786.1223 & 394.7053 & 766.1330 \\ -1340.326 & 304.585 & 424.01145 & 0.17352 & -0.20873 & 0.21976 \\ -28.18932 & -67.64213 & -638.92887 & -0.28237 & 0.26891 & -0.09565 \\ 786.670 & 379.953 & -862.11577 & -0.128142 & 0.03854 & 0.13802 \\ -5444305.9 & 2099619.9 & 2506197.7 & -863.5290 & -683.1088 & 981.2867 \\ -2384406.1 & -1355664.9 & 4215942.3 & 912.5237 & -2138.045 & 1168.569 \\ -4225641.8 & -1104110.5 & 2555503.3 & 1254.371 & -1228.181 & -42.28871 \end{matrix} \tag{10}$$

$$B = \begin{bmatrix} 0.0000 & 0.0227 \\ 0.0000 & -0.0727 \\ 0.0000 & -0.0914 \\ 0.0000 & 184.0787 \\ 0.0000 & 116.0687 \\ 0.0000 & 290.7990 \\ 0.0000 & -0.0327 \\ 0.0000 & 0.0164 \\ 0.0000 & -0.0034 \\ 0.0000 & -148.7338 \\ 0.0000 & -146.1661 \\ 0.0000 & -220.1505 \end{bmatrix} \tag{11}$$

$$C = \begin{bmatrix} 1.01218 & -0.06574 & -0.50424 & -0.000193 \\ -0.39942 & 0.92263 & 0.77062 & 6.795e-7 \\ -0.84785 & 0.05664 & 0.93450 & 0.000176 \\ 1073.174 & -1906.322 & 2017.167 & 1.01308 \\ 1714.200 & 1635.683 & -3040.048 & -0.17065 \\ -1349.871 & 1828.269 & 1080.252 & -0.78612 \end{matrix} \cdots$$

$$\cdots \begin{matrix} 0.00026 & -0.00024 & -1.01218 & 0.06573 \\ -0.00029 & 0.00039 & 0.39942 & -0.92262 \\ -0.00018 & 4.9676e-5 & 0.847850 & -0.05664 \\ -0.49836 & 0.27591 & -1073.175 & 1906.322 \\ 1.41101 & -0.73568 & -1714.200 & -1635.683 \\ 0.39470 & 0.76613 & 1349.871 & -1828.269 \end{matrix} \cdots \tag{12}$$

$$\cdots \begin{matrix} 0.50424 & 0.00019 & -0.00026 & 0.00024 \\ -0.77062 & -6.7950e-7 & 0.00029 & -0.00039 \\ -0.93450 & -0.00017 & 0.00018 & -4.9676e-5 \\ -2017.167 & 1.01308 & 0.49836 & -0.27591 \\ 3040.047 & 0.17065 & -1.41101 & 0.73568 \\ -1080.252 & 0.78612 & -0.39470 & -0.76613 \end{bmatrix}$$

$$D = \begin{bmatrix} 0 & -00000.5 \\ 0 & 00000.42 \\ 0 & -00000.3 \\ 0 & -0.00905 \\ 0 & -0.10766 \\ 0 & 0.10083 \end{bmatrix} \tag{13}$$

Figure 10 show the identification errors (e) of the outputs V_{AC} and i_{DC}.

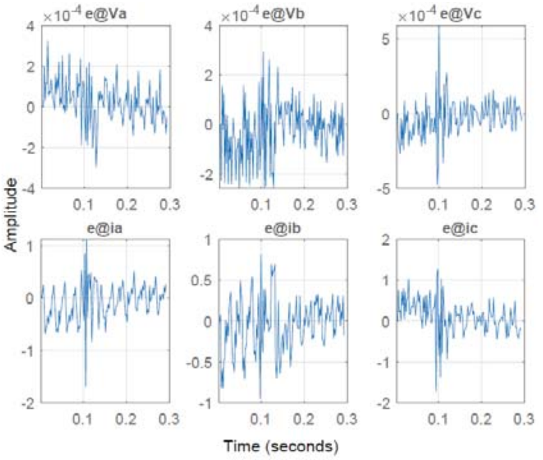

Fig. 10. Identification errors for $DER_n\ G_n$ model.

VIII. CONCLUSIONS

The proposed research shows a new algorithm for the dynamic identification of the systems that compose MGs, such as: VSCs (one-way or bidirectional), BESSs, PVs, DiGs, among others. The models obtained by the developed algorithm are of vital importance which aid in finding the line parameters used in some techniques, e.g., adaptive voltage droop, virtual frame transformation methods, state estimation (Kalman Filter), Fault Detection, Identification and Accommodation Technique and Fault Tolerant Control (FTC) applications.

This method provides state space models for different systems that interact in MGs. In addition to providing mathematical models for both DC MG and AC MGs, it can be used to obtain isolated or connected modes or charging and powering modes of energy storage systems. If necessary, for novel systems with complex dynamics, the PN state machine can be updated with new signals of typical tests in relation to the new objectives and the type of study to be developed

REFERENCES

[1] J. Hare, X. Shi, S. Gupta, and A. Bazzi, "Fault diagnostics in smart micro-grids: A survey," *Renew. Sustain. Energy Rev.*, vol. 60, pp. 1114–1124, 2016.

[2] Bevrani, Hassan, T. Ise, and Others, *Microgrid Dynamics and Modeling*. John Wiley \& Sons, 2017.

[3] D. Carrión and L. Ortiz, "Generación distribuida a partir de bicicletas estáticas y sistemas híbridos," *Ingenius*, vol. 10, pp. 44–48, 2013.

[4] N. W. A. Lidula and A. D. Rajapakse, "Microgrids research: A review of experimental microgrids and test systems," *Renew. Sustain. Energy Rev.*, vol. 15, no. 1, pp. 186–202, 2011.

[5] E. Planas, J. Andreu, J. I. Gárate, I. Martínez De Alegría, and E. Ibarra, "AC and DC technology in microgrids: A review," *Renew. Sustain. Energy Rev.*, vol. 43, pp. 726–749, 2015.

[6] A. Gil-de-muro, J. Andreu, I. Kortabarria, and I. Marínez, "General aspects , hierarchical controls and droop methods in microgrids : A review," *Renew. Sustain. Energy Rev.*, vol. 17, pp. 147–159, 2013.

[7] E. Hossain, E. Kabalci, R. Bayindir, and R. Perez, "Microgrid testbeds around the world: State of art," *Energy Convers. Manag.*, vol. 86, pp. 132–153, 2014.

[8] E. Unamuno and J. A. Barrena, "Hybrid ac/dc microgrids - Part I: Review and classification of topologies," *Renew. Sustain. Energy Rev.*, vol. 52, pp. 1251–1259, 2015.

[9] R. H. Lasseter and P. Paigi, "Microgrid : A Conceptual Solution," in *Annual IEEE Power Electronics Specialists Conference*, 2004, pp. 4285–4290.

[10] A. K. G. K. G. Dimeas Aris; Tsikalakis, *Microgrids: Architectures and Control*. 2014.

[11] T. Samad and A. Annaswamy, "Controls for Smart Grids : Architectures and Applications," *Proc. IEEE*, vol. PP, no. 99, pp. 1–18, 2017.

[12] L. Jia, Y. Zhu, and Y. Wang, "Architecture design for new AC-DC hybrid micro-grid," *2015 IEEE 1st Int. Conf. Direct Curr. Microgrids, ICDCM 2015*, pp. 113–118, 2015.

[13] R. H. Lasseter *et al.*, "CERTS microgrid laboratory test bed," *IEEE Trans. Power Deliv.*, vol. 26, no. 1, pp. 325–332, 2011.

[14] J. M. Guerrero, J. C. Vasquez, J. Matas, L. G. De Vicuña, and M. Castilla, "Hierarchical control of droop-controlled AC and DC microgrids - A general approach toward standardization," *IEEE Trans. Ind. Electron.*, vol. 58, no. 1, pp. 158–172, 2011.

[15] E. Unamuno and J. A. Barrena, "Hybrid ac/dc microgrids - Part II: Review and classification of control strategies," *Renew. Sustain. Energy Rev.*, vol. 52, pp. 1123–1134, 2015.

[16] A. M. Vega, F. Santamaria, and E. Rivas, "Modeling for home electric energy management: A review," *Renew. Sustain. Energy Rev.*, vol. 52, pp. 948–959, 2015.

[17] F. Martin-Martínez, A. Sánchez-Miralles, and M. Rivier, "A literature review of Microgrids: A functional layer based classification," *Renew. Sustain. Energy Rev.*, vol. 62, pp. 1133–1153, 2016.

[18] D. E. Olivares *et al.*, "Trends in microgrid control," *IEEE Trans. Smart Grid*, vol. 5, no. 4, pp. 1905–1919, 2014.

[19] N. Bottrell and T. C. Green, "Modeling microgrids with active loads," *2012 IEEE 13th Work. Control Model. Power Electron. COMPEL 2012*, 2012.

[20] D. Arias Cazco, R. A. Robayo Vasco, and L. Ortiz Matos, "Novel inteligente Step Voltaje Regulator (SVR) for residential electrical connections," *IEEE Lat. Am. Trans.*, vol. 14, no. 4, pp. 1656–1661, 2016.

[21] A. Aguila, D. Carrión, and L. Ortiz, "Analysis of power losses in the asymmetric construction of electric distribution systems," *IEE Lat. Am. Trans.*, vol. 13, no. 7, pp. 2190–2194, 2015.

[22] M. S. Mahmoud, S. A. Hussain, and M. A. Abido, "Modeling and control of microgrid : An overview," *J. Franklin Inst.*, vol. 351, pp. 2822–2859, 2014.

[23] X. Tang, W. Deng, and Z. Qi, "Investigation of the dynamic stability of microgrid," *IEEE Trans. Power Syst.*, vol. 29, no. 2, pp. 698–706, 2014.

[24] A. H. Etemadi and R. Iravani, "Eigenvalue and robustness analysis of a decentralized voltage control scheme for an islanded multi-DER microgrid," *IEEE Power Energy Soc. Gen. Meet.*, pp. 1–8, 2012.

[25] L. O. Matos, J. Wilson, and G. Sanchez, "Reconfiguration Strategy for Fault Tolerance of Power Distribution Systems Using Petri Net," in *Ecuador Technical Chapters Meeting (ETCM), IEEE*, 2016.

[26] T. Murata, "Petri Nets : Properties , Analysis and Applications," vol. 77, no. 4, pp. 541–580, 1989.

[27] A. B. Mboup, F. Guerin, P. A. Ndiaye, and D. Lefebvre, "Petri nets control design for hybrid electrical energy systems," *2009 Am. Control Conf.*, pp. 5012–5017, 2009.

[28] L. Ortiz and A. Aguila, "Modeling and Control of an Automated System in Surgical Microscopy Based on Petri Nets," *IEE Lat. Am. Trans.*, vol. 14, no. 1, pp. 96–101, 2016.

[29] M. M. Mansour, M. A. A. Wahab, and W. M. Soliman, "Petri nets for fault diagnosis of large power generation station," *Ain Shams Eng. J.*, vol. 4, no. 4, pp. 831–842, 2013.

[30] R. Davidrajuh, *APPLIED SCIENCES AND TECHNOLOGY Modeling Discrete-Event Systems with GPenSIM An Introduction*. Stavanger, Norway: Springer, 2018.

[31] A. Control *et al.*, *Control of Discrete-Event Systems*. Springer US, 2013.

[32] J. C. Agüero, J. I. Yuz, and G. C. Goodwin, "Identification of ARX and ARARX Models in the Presence of Input and Output Noises," *Eur. J. Control*, vol. 16, no. 3, pp. 256–257, 2010.

[33] Y. Z. Editor, *Multivariable System Identification for Process Control*, no. October. 2001.