Visión Electrónica Vol. 13 No. 1 (2019) • January-June • p.p. 17-23 • ISSN 1909-9746 • ISSN-E 2248-4728 • Bogotá (Colombia)

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A RESEARCH VISION

Optimization of fuzzy controllers for a radial distribution network

Optimización de controladores fuzzy para una red de distribución

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INFORMACIÓN DEL ARTÍCULO

Historia del artículo:
Enviado: 26/10/2018
Recibido: 13/12/2018
Aceptado: 02/01/2019

Keywords:
Control
Distribution
Energy
Fuzzy
Optimization

Palabras clave:
Control
Distribución
Energía
Difuso
Optimización.

ABSTRACT

Energy distribution systems present alterations in the voltage profile in their nodes when distributed generation elements are installed. As a consequence, tension can be risen in a level beyond the admissible. This paper presents the optimization to three fuzzy controllers located in a distribution network with radial topology. The optimization of each controller is performed using the maximum descent algorithm, which is separately carried out; thus, having a distributed approach. The interaction between generators is considered to perform this process; the results show that the adjustment of the controllers is achieved.

RESUMEN

Los sistemas de distribución de energía presentan alteraciones en el perfil de tensiones de sus nodos cuando se instalan elementos de generación distribuida, haciendo que en algunos nodos se eleve la tensión, la cual puede llegar a estar por encima de lo admisible. En este documento, se propone la optimización de tres controladores difusos para generadores distribuidos localizados en una red de energía. La optimización de cada controlador se lleva a cabo mediante el algoritmo de máximo descenso, que se utiliza por separado, teniendo así un enfoque distribuido. Para realizar este proceso se considera la interacción entre los generadores, cuyos resultados muestran que se logra el ajuste de los controladores.

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Cite this article as: H. E. Espitia-Cuchango; I. Machón-González; H. López-García; D. G. Díaz-González, "Optimization of fuzzy controllers for a radial distribution network", *Visión electrónica, algo más que un estado sólido*, vol. 13, no. 1, january–june 2019, pp. 17-23, DOI: *https://doi.org/10.14483/22484728.14681*

1. Introduction

Among the different renewable resources, wind energy has had a fast development that represents a significant contribution in electric energy systems [1], [2]. In terms of economy and technology advances in wind energy generation, the use of this energy has broadened its usage in developed countries [3], showing a rapid growth as a source of endless clean energy worldwide [4].

Nevertheless, as it happens to other renewable sources like the solar, the wind energy tends to be unstable as the wind speed is affected by natural and meteorological conditions [5]. Regarding this, it is relevant to bear in mind that the unsteady power of wind parks can influence the proper functioning of interconnected networks [6]. Reference [7] displays an example of how the output power can have increments and abrupt falls during the day.

Aiming the avoidance of destructive impacts on the stability on electric networks, it is mandatory to have the capacity to manage the intermittent nature of wind energy together with the large fluctuations generated by the stochastic behavior of the meteorological conditions [5]. Thus, some measures may be required to soften the output power in a reliable system of energy [8].

On the other hand, voltage is an important control parameter in electric energy systems and the Distribution Network Operators (DNO) has the responsibility to regulate the voltage supplied to the user within the legal boundaries. The connections of the Distributed Generation (DG) to the network affect the voltage profiles and influence in voltage control in the distribution systems [9].

The Automatic Voltage Regulator (AVR) in rural areas help to both reduce the waste of energy and to improve the quality of electrical services balancing the voltage drops through the lines of distribution [10]. Frequently, weak networks have problems when a low charge and high generation are present, which may lead to the activation of protections that interrupt the supply of energy.

This paper presents the optimization to three fuzzy controllers located in a distribution network with radial topology. The optimization takes place through the algorithm of maximum descent that uses gradient calculations. For controller optimization, it is necessary to bear in mind the fact that despite having a distributed localization of generators, it is necessary to include the interactions among them when calculations are performed in the distribution network.

The optimization is performed with a distributed approach; this means that the controllers are separately adjusted. Even though a centralized approach allows the optimization of the controllers at the same time, a higher flexibility to add or suppress generators is obtained when performed in a distributed approach; moreover, for the centralized approach, it would be necessary to update the algorithm configuration for new parameters. Meanwhile, in a distributed approach each controller is optimized with the same algorithm configuration. Even though the distributed approach to controller optimization slows down the process because such process is sequentially performed, the results show that with this scheme the optimization is achieved.

The paper is organized as follows: it starts by giving a brief introduction to energy distribution systems and fuzzy control proposed. Section 2 contains the energy distribution network framework showing the distribution system considered. Section 3 describes the gradient-descent method used for controller optimization, and the fuzzy controller is shown in Section 4. The optimization methodology used is presented in Section 5. Finally, in Section 6, the optimization process results are shown, and the conclusions are given in Section 7.

2. Distribution network systems

Electrical distribution networks are a critical part of the whole infrastructure because these allow homes and companies to access electric power. Offering a continuous and stable service is a key function for the operators of the Distribution Network Operators (DNOs).

The incorporation of a Distributed Generation (DG) in electric networks produces relevant effects in the traditional operation of this system; the existing distribution networks are designed to behave as passive, where the transport of electricity has low levels of supervision, control and monitoring; therefore, DG introduces new challenges for the DNOs for more active networks [11].

2.1. Load flow calculation

In electric engineering, the study of flow power is an important tool that implies numeric analysis applied to an energy system [12]; load flow calculations permit to determine flow power and voltage in an energy system according to generators, condensers and transformers [13]. The Backward/Forward Sweep (BFS) is the most widely used technique for establishing flow power in networks of radial topology.

2.2.Model of the distribution network

The radial network model considered can be seen in figure 1, this model consists of 33 nodes [14], [15]. The generators are in nodes 18, 25, and 33. Impedance values for the distribution system lines are same used in [14] and [15]. Node 1 is the reference node.

3. The gradient-descent method

This algorithm calculates the gradient of the objective function for a current position in the search space. Firstly, the gradient for the objective function f is:

$$\vec{G} = \vec{\nabla} f(\vec{x}) \tag{1}$$

The $\vec{G}$ vector aim in direction where the descent of the objective function is the steepest [16]. If the step size is small enough towards -$\vec{G}$ direction, then the value of the objective function in this new point will be smaller. The next point is calculated using the equation (2).

$$\vec{X}_{x+1} = \vec{X}_x - \alpha\vec{G} \tag{2}$$

Where $\alpha \in R^{+}$ corresponds to the rate of descent. It is possible to use a sequence of α_n values which decreases when n increases as this guarantees convergence. The greater the learning rate, the farer the algorithm moves in one single step, this with the risk of stepping above a minimum [16].

When a computational calculation of derivatives is required, numerical approximations can be taken using (3).

$$\frac{\partial f(\vec{x})}{\partial x_i} = \frac{f(\vec{x}+\Delta\vec{x}_i)-f(\vec{x}-\Delta\vec{x}_i)}{2|\Delta\vec{x}_i|} \tag{3}$$

4. Fuzzy controller

Figure 2 displays the scheme of the fuzzy control system. Controller general architecture is obtained modifying a linear controller (in discreet time) using fuzzy sets to incorporate non-linear relations in its structure.

Figure 1. Radial network model, [14], [15].

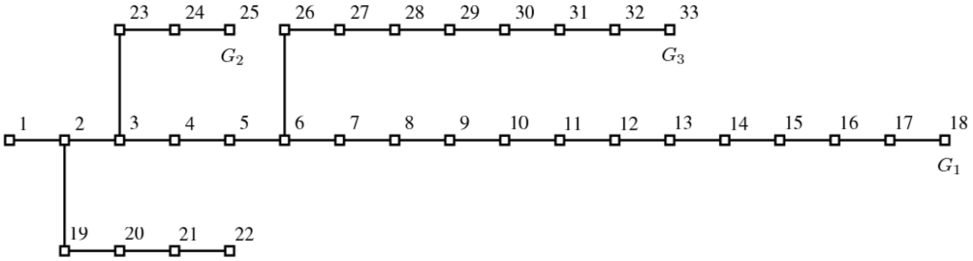
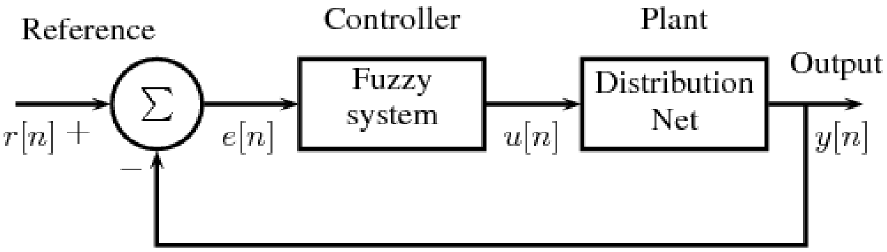


Figure 2. Control system general scheme.



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This model consists of non-linear relations for each delay in both input and output feedbacks. First, a linear controller is considered (in discreet time) for obtaining the design of the fuzzy controller where the transfer function is:

$$C(z)=\frac{U(z)}{E(z)}=\frac{b_0+b_1z^{-1}+b_2z^{-2}}{1+a_1z^{-1}+a_2z^{-2}} \qquad (4)$$

The equation in differences for this controller is:

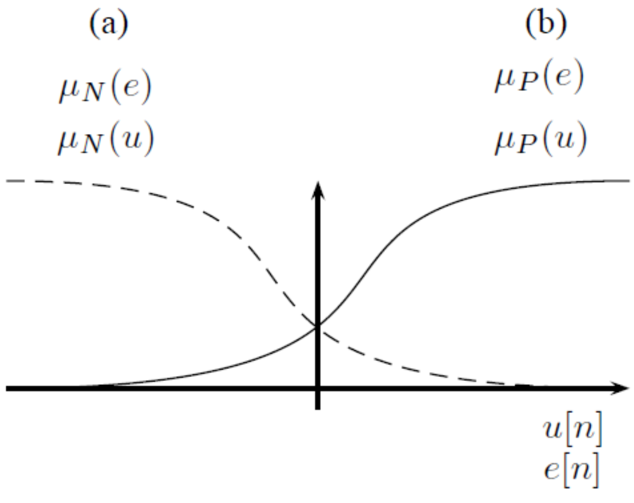
$$u[n]=b_0e[n]+b_1e[n-1]+b_2e[n-2]-a_1u[n-1]-a_2u[n-2] \qquad (5)$$

In equation (5) the coefficients a_i, b_j are constant, while in the fuzzy controller those constant values are replaced by non-linear relations given by fuzzy membership functions, where:

$$u[n]=f_c(e[n],e[n-1],e[n-2],u[n-1],u[n-2]) \qquad (6)$$

The fuzzy control system employs the fuzzy sets shown in figure 3. Part (a) shows a sigmoidal fuzzy set to modeling the negative values of the discourse universe; meanwhile, part (b) represents the positive values for the error $e[n]$ and the control action $u[n]$.

Figure 3. Membership functions employed.



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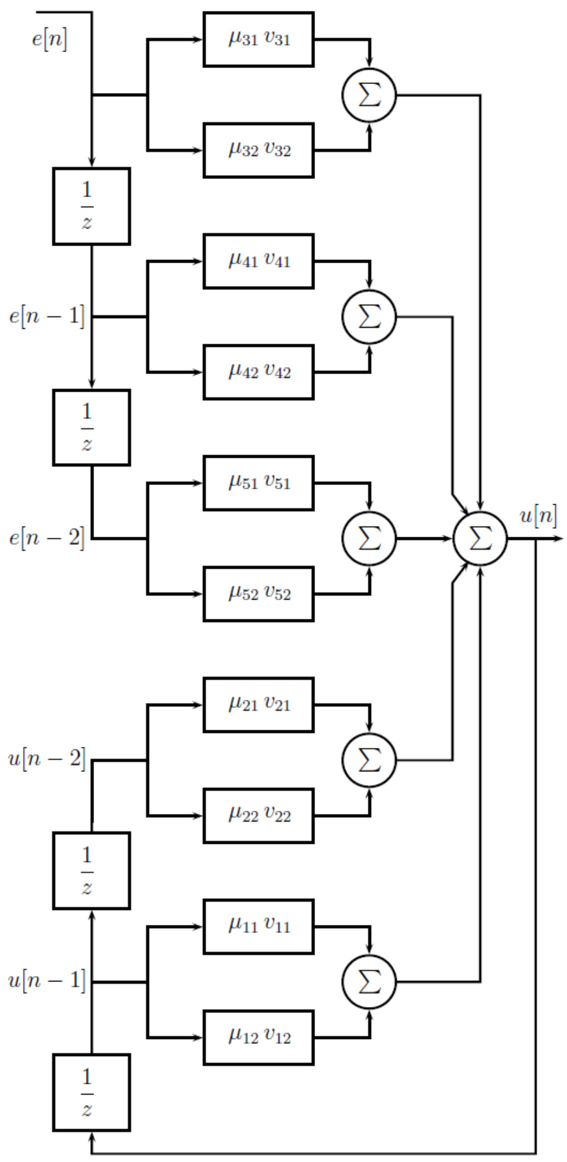
Considering the fuzzy sets of figure 3, together with the general structure of the controller given by equation 6, the proposed fuzzy controller is shown in figure 4.

Figure 4. Scheme of the fuzzy control system.



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The output of the controller can be calculated as:

$$u[n]=\sum_{i=1}^{5}\sum_{j=1}^{2}V_{ij}\,\mu_{ij}(X_i) \qquad (7)$$

Where $x_i\in\{u[n-1],u[n-2],e[n],e[n-1],e[n-2],\}$, meanwhile, the membership function $\mu_{ij}(x_i)$ corresponds to:

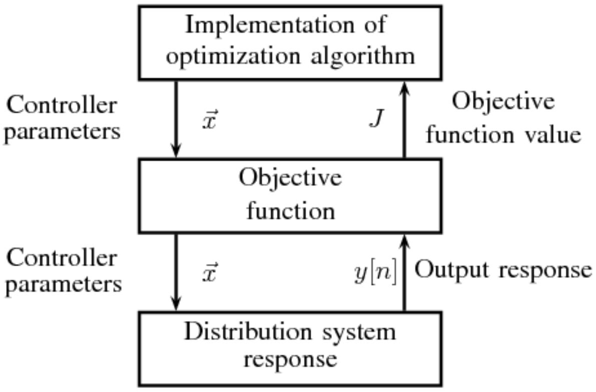
$$\mu_{ij}(x_i)=\frac{1}{1+e^{-\sigma_{ij}(x_i-\gamma_{ij})}} \qquad (8)$$

Thus, the set of parameters of the controller to be optimized are: v_{ij} , σ_{ij} and γ_{ij} .

5. Process for the optimization of fuzzy controllers

From a general view, the optimization process consists of determining the optimum parameter values for the three controllers; this can be achieved considering all the parameters at the same time for a centralized-type approach (optimization process); however, there will be necessary to configure a new algorithm if controllers are added or removed. On the other hand, a distributed approach facilitates the inclusion or elimination of generators when the controller optimization is separately performed. It is necessary to bear in mind that controllers interact in the distribution system to separately obtain the optimization; whereby, it is proposed to develop the optimization of one controller keeping the same parameters for the rest of the controllers as constant values and thus successively until achieving the optimization of all controllers. This process is executed until achieving the desired value in the objective function for all the controllers. Particularly, the method gradient-descent is utilized for the optimization of one controller. Figure 5 shows the scheme for this process; first is implemented the simulation of the system together with parameters to be optimized, then with that simulation comes the implementation of the objective function by which the gradient calculations are made; finally, parameter adjustments in the control system take place.

Figure 5. Process employed for the optimization.



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In this process the objective function considered is:

$$J = \frac{1}{2}\sum_{n=1}^{N_T}[r_y - y[n]]^2 \tag{9}$$

Where N_T is the number of data of simulation, y the control system response, and r_y is the reference or desired output.

6. Results

This section presents the results when undertaking the controller optimization considering their interaction in the distribution system. In this process, from each iteration the values of the optimized controllers are taken, and the new optimization of each controller also takes place. The improvement of the response of the controllers is seen, that is, each generator (with its controller) allows the regulation of both the voltage in the node and the nodes of the other generators.

Table 1 displays the values of the objective function in each training process. It is evident that the value of the objective function decreases as iterations advance until reaching values in the order of 10^{-7} in the fourth iteration, which demonstrates that the optimization of the controllers is achieved.

Table 1. Objective function values in each iteration.

Outputs	Iteration 1	Iteration 2	Iteration 3	Iteration 4
Node 18	0.0039071	0.00017262	1.4844×10^{-5}	8.0478×10^{-7}
Node 25	0.00063201	2.4037×10^{-5}	1.8901×10^{-6}	1.0724×10^{-7}
Node 33	0.0014641	0.00016074	6.8184×10^{-6}	6.0586×10^{-7}

Source: own.

The evolution in the optimization process is displayed in figures 6, 7, and 8 for nodes 18, 25, and 33. This figures show the improvements in the system response for the nodes where the generators are connected.

Figure 6. System response for node 18.

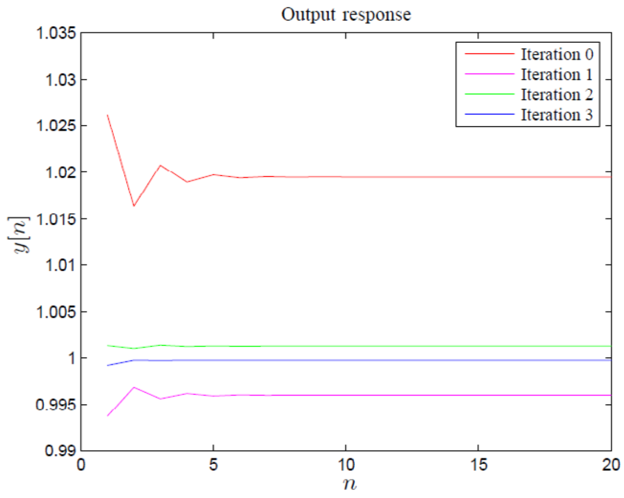

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Figure 7. System response for node 25.

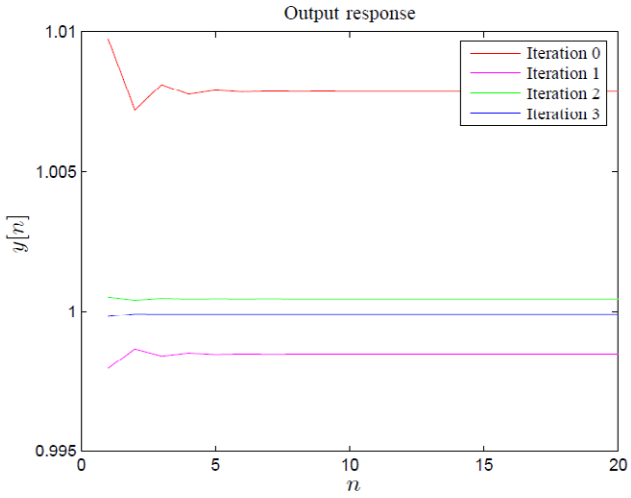

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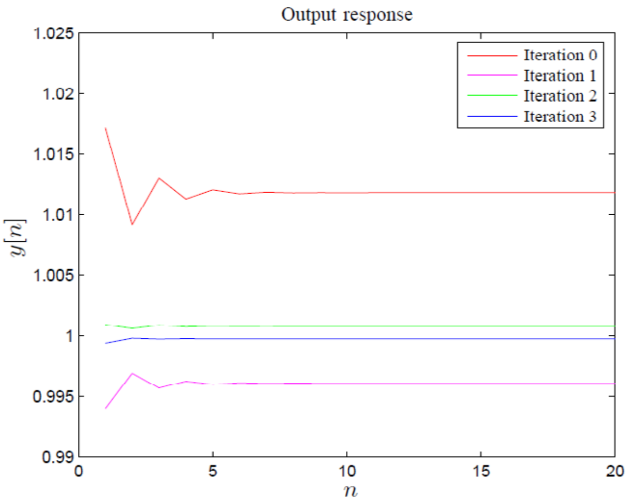
Figure 8. System response for node 33.



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7. Conclusions

In this paper, a separate optimization of controller parameters located in the distribution system was achieved. The implemented approach consists of a decentralized optimization.

Even though the controllers are arranged in a distributed form, they present interactions given by the distribution network, which influences the optimization process; therefore, an iterative and sequential optimization of the controllers is proposed.

With this approach each controller is separately optimized thus facilitating both the connection and disconnection of the generators without requiring a global adjustment in the configuration of the optimization algorithm.

In a work paper will be possible to employ a supervised neuro-fuzzy system to perform the control of power flow.

Acknowledgements

A special recognition to Universidad de Oviedo and the Universidad Distrital Francisco José de Caldas.

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