A Voltage Fuzzy Controller For A Permanent Magnets Wind Generator

Controlador Difuso De Tensión Para Un Generador Eólico De Imanes Permanentes

Cazes Ortega R.[1]

Fandiño Pelayo J.[2]

Abstract

This article shows the design of a voltage fuzzy controller to carry out the battery charge control in order to assure the improvement of the three-phasing system tension for a permanent magnet wind generator (PMWG). The use of clean energies has become more common in our current environment, due to the low contamination that these systems present, as observed in the wind generation systems. The controller design and simulation processes were carried out by means of the instrument called Fuzzy Toolbox of Matlab, which is a fuzzy logic controller for a permanent magnets wind generator. The behavior of the controller towards different disturbance signals can be observed through the simulation.

Keywords: Clean energy, fuzzy logic, PM wind generator, wind energy.

Resumen

En este artículo se muestra el diseño de un controlador difuso de tensión para realizar el control de carga de baterías con el fin de asegurar la mejora de la tensión del sistema trifásico para un generador eólico de imanes permanentes (GEMP). El uso de energías limpias se ha vuelto más común en nuestro entorno actual, debido a la baja contaminación que presentan estos sistemas, como se observa en los sistemas de generación eólica. Los procesos de diseño y simulación del controlador se realizaron mediante el instrumento denominado Fuzzy Toolbox de Matlab, el cual es un controlador de lógica difusa para un generador eólico de imanes permanentes. A través de la simulación se puede observar el comportamiento del controlador frente a diferentes señales perturbadoras.

Palabras clave: Energía limpia, lógica difusa, aerogenerador PM, energía eólica.

1. Introduction

[1] Magister. Universidad de Pamplona, Pamplona, Norte de Santander, Colombia. cazesrocio@gmail.com
[2] Magister. Unidades Tecnológicas de Santander, Bucaramanga, Santander, Colombia. jfandino@correo.uts.edu.co

Nowadays, the use of clean energy is becoming more commonplace in our environment, as well as the automatic control systems that allow these pieces of equipment to improve their performance. The analysis of these systems has led to more detailed research studies about each of their processes, carried out to produce electric energy. One of these processes is the wind energy, which is a renewable and inexhaustible resource that produces electric energy from the wind power by means of a generator.

By the middle of the last century, the air navigation principles were applied to these techniques, which basically consist of moving some blades by means of the wing lift that the wind speed produces. Since the 70s, a new generation of wind machines is said to have emerged. The first new technological system was one of capture or rotor, composed of a series of vanes that turn around an axis as an effect of the wind power, turning kinetic energy into mechanical. The rotors' axes can be of two types: vertical and horizontal. The Savonius is a vertical rotor, composed of two semi cylinders set at certain distance from each other, in such a manner that the air can circulate between them, but it is generally of low power. (Chen, Y. Pillay P. Khan A. (2004). The Darrieus wind generator is composed of two or three vanes in parabolic shape joined together to a vertical axis by their ends. Although the Giromill and the Darrieus are similar, the vanes of the Giromill automatically modify its inclination according to the wind dimension. As a result, a better performance is produced, since it starts off by itself (Pérez García, et al, 2019). The modern horizontal axis rotors are generally composed of two or three vanes that have a higher aerodynamic performance. However, they need a relative high wind speed to start off, an order of five meters per second. This allows the rotor to spin at certain revolutions that generate electric energy (Deenma, 2009).

2. Wind energy

The wind energy has been exploited during hundreds of years, from the ancient Netherlands to the American farms. The wind mills have been used to pumping water or grinding. Currently, the modern wind generators, the wind turbines, can use the wind energy to produce electricity.

The wind turbines are mounted on a tower to capture the most energy possible. At 100 feet (30 meters) or more over the ground, they exploit the fastest and least turbulent wind power. The wind power is captured by the turbine blades, similar to propellers. Usually, two or three blades are assembled on an axis to form a rotor. A blade works as a plane wing; when the wind blows, a low-pressure air bag is formed in the side in favor of the blade wind. The low-pressure air bag pulls from the blade towards it and makes the rotor turn. This is called raising. The raising power is in fact much stronger than the wind power towards the blade frontal side, and this is called pulling. The combination of raising and pulling forces makes the rotor turn like a propeller and the turning axis produces electricity by making a generator turn (J. Kelly , 2017), (Manwell, J. F. McGowan J. Rogers G. A. L. 2002).

This type of energy is produced by the wind by means of air turbine generators, which are able to generate electricity from the wind flows. The wind energy is one of the oldest energy sources humanity has used, since the sailing vessels were used to the latter wind mills, which aimed to turn the wind power into mechanical energy. Every air turbine generator has a sail in the superior part that facilitates the process of conducting the air and easily spin on the tower to automatically move. The blades also spin on their axis to offer it the highest resistance. The wind power, in other words, the kinetic energy, contained in the wind flow movement makes the blades spin. They are designed to capture the most energy possible and they can be more than 60 meters long each.

They are made of lighter and more resistant materials in order to facilitate its movement. For that reason, they can produce energy with very ligth winds, from 11 Km/h approximately. In contrast, with very strong winds such as 90 Km/h, the blades place themselves in the position to brake the wind generator for safety reasons. The blades couple with the generator through the bushing, which in turn, is coupled with the slow axis. This slow axis is named in that manner because it spins at the same blades speed, between 7 and 12 spinnings per minute. To produce electricity, it is necessary to increase the slow axis spinning speed; that is the fuction of the multiplier that increases such speed more than a hundred times and transfers it to the fast axis. Such axis that spins at more than 1,500 times per minute, is connected to a generator. The generator exploits the fast axis kinetic energy to transform it in electricity, which is a form of energy that is easy to transport and use. The electricity produced by the generator as a direct current power is conducted through the inside of the tower as far as its foundation. There, a converter transforms it into alternating current, the one we normally use. Additionally, a transformer raises the voltage to transport it inside the wind farm (Conrado Moreno , 2008).

3. Permanent Magnet Synchronous Generators

A permanent magnet synchronous generator is where the excitation winding has been modified, usually in the rotor, with a system composed of permanent magnents that provides a constant excitation field. Its abbreviation is PMG and it significantly differs from being a usual synchronous generator in which the output voltage is controlled by means of the generator exciter. Unlike the usual generator, the PMG excitation is constant, since the generator output voltage has no regulation option. The PMG are used when it does not matter if the voltage descreases at certain level or whenever electronics is applies when leaving the generator. The electronics application can turn a range of variable voltages into DC voltage of constant value (OBEKI, 2014).

An electric generator is normally composed of two parts; a stator and a rotor. There exist several types of electric generators, of direct current, of alternating current, of vehicles, of human energy, among others.

The spinning and stationary parts of an electric machine are called rotor and stator respectively. Either the rotor or the stator of the electric machines works as an energy producer component and it is called armature. The electromagnets or permanent magnets mounted on the stator or rotor are used to provide the magnetic field of an electric machine. The generator in which the permanent magnet is used instead of the coil to provide an excitation field is called permanent magnet synchronous generator or simply synchronous generator (Martinez Quintero, Diaz Rodriguez, & Pardo Garcia, 2012).

Generally, the synchronous generator consists of two parts, rotor and stator. The rotor consists of field poles and the stator is composed of the armature conductors. The rotation of field poles in presence of armature conductors induces an alternating voltage that turns into electrical energy (Bermeo, y otros, 2015). Different techniques have been used to control these synchronous generators, one of them is used by identifying their system components in relation to their control design. The system identification is considered a fundamental part of the controller (Restrepo Chaustre, Becerra Vargas, & Pardo Garcia, 2015). This is known as an adaptable controller and it is basically used to control systems whose dynamic characteristics vary in time. One of the ways to control speed is through sliding modes.

The working principle of the synchronous generator is the electromagnetic induction. If there exists a relative movement between the flow and the conductors, then an electromotive force is induced in the conductors (Oscar Javier Suarez Sierra, Aldo Pardo Garcia, Diego Jose Barrera Oliveros, 2019). The synchronous generators are designed to meet the customers' needs. The automated design and standardized solutions are required to simplify the generators' modification for different customers and applications as well as to accelerate the inquiry process. One the limitations that can sometimes emerge is the low voltage. For that reason, several research studies focus on improving this issue through voltage control processes. One solution is to implement an excitation force with a winding that uses the power in flux density harmonics in air space to be supplied to the automatic voltage regulator. In that manner, a standard solution is created for the winding and the voltage regulator system. The analytical dimensioning of winding solutions is analyzed and the most optimum one for the synchronous low voltage generators is chosen. The analytic dimensioning of the winding solution chosen is implemented as a software. The excitation requirements are established according to different standards and classification. In that manner, the automatic voltage regulator supplied with a winding is determined and a solution for the voltage regulator system is implemented. When the problem is addressed from the generator point of view and focusing on the power converter input stage, which is composed of a passive three-phasing rectifier, a boost type DC-DC converter, and a connection inverter. To minimize the THD_I factor in the output currents of the wind generator and increase its power factor, the convertor DC-DC works in discontinuous conduction, by using a principle applied to three-phasing rectifiers with front-end power factor correction for a feeding system with an electric network connection of fixed amplitude and frequency (Carranza Castillo, 2012).

The non-linearity in the phasing movement transformer and the interphasing reactors limit the THD_I improvement. In general, all the three-phasing rectifiers of twelve momentums that only use the phasing movement technique have 15.22% in the THD_I input currents. In a synchronous generator, the voltage wave shape generated is synchronized with the rotor speed. The synchronous generator, under the supposed reactive constant synchronization can be represented by an equivalent circuit consisting of an ideal coil in which an electromotive force is proportional to the electric field excitation (Fengxiang, W. Qingming, H. Jianlong, B. Jian, P. 2005).

If a synchronous generator is considered at constant speed and constant excitation in an open circuit in the V terminal, it is the same as the open circuit in the electromotive force. (Vasudevan, Rao, & Rao , 2010).

4. Controller Design and Simulation

To carry out this work, the data taken from a permanent magnet synchronous generator were kept in mind for the system identification.

Table 1: Input Data

177.68	178	178.32	178.44	178.83	178.95
179.08	179.15	179.21	179.28	179.34	179.28
179.21	179.15	179.08	178.95	178.83	178.44
178.32	178	177.68			

Table 2: Output Data

22.78	22.84	22.89	22.91	23	23.03
23.06	23.09	23.28	23.30	23.36	23.30
23.28	23.09	23.06	23.03	23	22.91
22.89	22.84	22.78			

According to these data, the function IDENT of Matlab was used to obtain the transparency function:

$$H(s) = \frac{1.159}{s^2+7.251s+8.982} \quad (1)$$

Most of the control systems are specified in terms of quantities in the time domain. “Systems that can store energy do not instantaneously respond and show transitory responses every time they are subject to disturbance.” (Ogatha & Kuo, 2015). For that reason, the control system performance is defined in terms of the transitory responses for a unitary entry. Normally, in the control systems there are oscillations that are sometimes sub dampered or dampered before reaching their stable state. In this way, several parts of the transitory response can be specified as shown in the references (Carranza Castillo, 2012).

4.1 Fuzzy controller

For the fuzzy controller design, the Toolbox Fuzzy Logic of Matlab was employed (D. B. Blanco, et al., 2023). It allows us to analyze, design, and simulate systems based on fuzzy logic. For the plant analysis by means of the fuzzy logic, the fuzzy inference was considered, explicitly, the Mamdani inference, based on its four steps (González Morcillo, 2011).

Three linguistic variables were taken into account for the fuzzy controller: Error, Error derivative, and Voltage. From the analysis, the following rules were determined:

Table 3: Fuzzy rules table

Error	Derived from Error	Voltage
B	NCP	MB
MB	NCP	B
C	N	B
C	C	M
C	P	A
A	NCP	MA
MA	N	M
MA	C	A
MA	P	MA

Three linguistic variables were taken into account for the fuzzy controller: Error, Error derivative, and Voltage. From the analysis, the following rules were determined:

*Where in the error, *B stands for low, *MB stands for medium-low, *C stands for center, *A stands for high, and *MA stands for medium high.*

*For the error derivative, *N stands for negative, *C is zero, and *P is positive.*

*For the voltage, *MB stands for very low, B is low, *M is medium, *A is high and *MA is very high.*

*(*For their Spanish initials: bajo, medio baja, centro, alta, and media alta, negativo, cero, positivo, muy bajo, bajo, medio, alto, muy alto).*

In this way, the fuzzy controller is created in Simulink of Matlab:

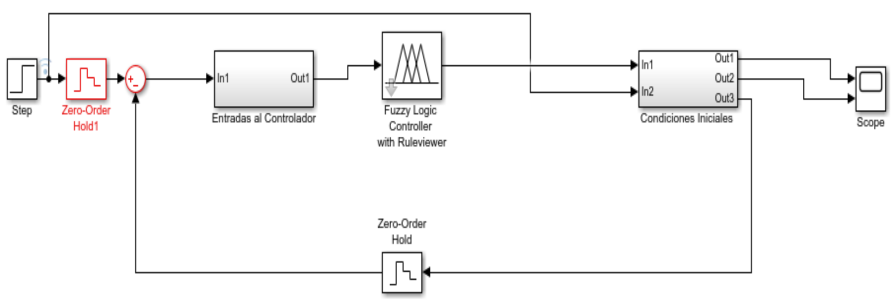

Fig. 1. Fuzzy controller in Matlab

From the design of the controller, the following rectified voltage output responses were obtained from the permanent magnet three-phasing generator:

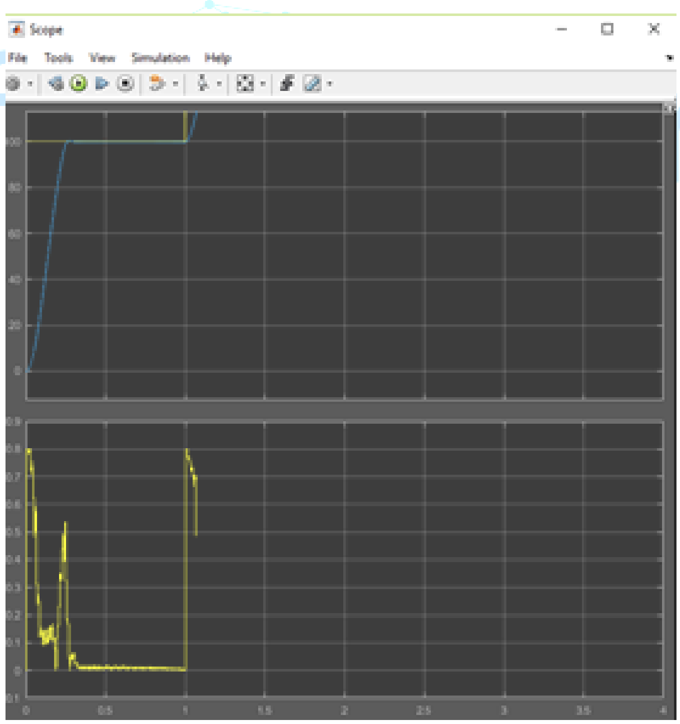

Fig. 2. Fuzzy Voltage stabilization graphics with fuzzy controller

The previous figure shows the cases when there are voltage overtops. When it happens, then the system stabilizes the voltage level again in the rectifier outlet, which is used for the battery charging. This type of systems allow the voltage levels to be stable (J E Araujo et al., 2020). the graphic shows an overtop of 80% and the fuzzy controller gets this system to stabilize as far as achieving 0%. Thus, it is possible to verify that such system can be employed for keeping the battery charging levels stable when used in a PMWG system so as to increase their useful life.

4.2 Deep-cycle Batteries

Wind system batteries must maintain the energy for long periods of time, so they constantly discharge to lower levels (Rincón Castrillo, E. et al, 2019). The deep-cycle type batteries have thick lead layers that allow batteries to have a longer life. Due to the lead material, these batteries are large and heavy. They are composed of 2 nominal volts cells that connect in a series to reach batteries of 6 to 12 or more volts, depending on the applications (DeltaVolt, 2010). There exit several companies worldwide that make and improve these batteries. For instance, GE Renewable Energy counts on an outstanding turbine platform that incorporates technology into the batteries. The incorporation of such technology into the wind turbines allows a short-term energy storage in the whole turbine system. Besides, it allows the wind farms operators to benefit from the energy storage, not incurring the battery installing heavy costs at farm level (Leal Gonzalez & Hernandez Cely, 2012). By controlling the voltage when it is leaving the generator, it is possible to avoid the high voltage peaks that shorten the batteries life.

This type of control also allows the use of hybrid systems, as:

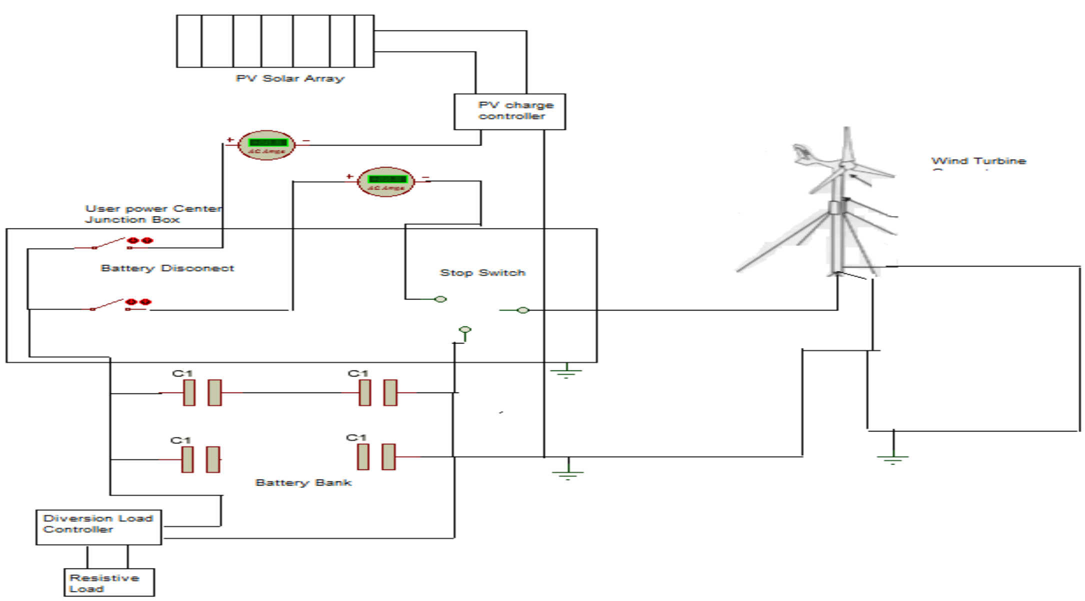

Fig. 3. Hybrid connection between the Permanent Magnet Synchronous Generator and a Solar Panel.

5. Conclusions

From the analysis that was carried out in the system voltage control, it was possible to determine that whenever voltage peaks were generated during the entry, the fuzzy controller regulates the levels so as to make the voltages appropriate for the batteries. These types of systems prolong the batteries useful life, since their voltage overtops are avoided. The deep-cycle batteries are suitable for hybrid connections between generators and solar panels.

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