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(Research Article)

Automation of the injection of the aggregate energy by fuzzy logic into low-voltage distribution network

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Abstract

This article describes a basical technique on fuzzy logic to model the amounts of the energy produced in different sites. These energies will be automatically stored and injected into the electrical networks in operation without cutting the networks. When the power grids have sufficient resources, there is no need to inject energy. In this case, they should be stored in suitable equipment to avoid unneeded loss. The instant decision that stores and injects those energies are respectively estimated by using fuzzy inferences that depends on the state of consumption and the charge states for the storage equipment. The Communication between production sites is achieved by using Wide Area Network (WAN). The simulation methodology was made to prove our approximation. The Electricity consumption data were used for this study for the city of Antananarivo, in the 2020. The power consumed over 24 hours was made to simulate the state of charge on the storage equipment and also simulate the energy requirement. These information will be used for the inputs of the fuzzy system. They allow fuzzification in order to define the inferences based on the subsets: Low energy requirement and storage, Medium energy requirement and storage, and Maximum energy and storage requirement. Most of the injected energy are designed to be used with the same technique except with fuzzy subsets of 10 partitions.

Keywords: Quantity of energy, renewable energies, storage, fuzzy logic, injection, automation

1. Introduction

The energy is a vital element in the development of a country. Access to electricity, particularly in developing countries, has received increasing attention globally in recent years [REN21, 2011]. An alternative solution is the production of renewables energies [Jirama, 2016]. The injection of those energies which are produced at the different sites into the operating electricity grids.It requires a very specific strategy in order to ensure the operation of the network without causing a cut. This strategy can be automatic [Ratovomiharinjanahary and al, 2021].

The electrical energy is coordinating with production, storage and injection is more important to avoid load shedding. The theory of fuzzy logic [Zadeh, 1965] was introduced to study in many problems.

We have established new inferences through fuzzy logic for modeling energy quantities and making injection and storage decisions. For this, two decisions mode have been introduced.

It is important to descibe some constraints such as the optimization of the production in renewable energies, the priority of the sites for injection, real-time information from user consumption and communication between users, the production sites and the control center.
The goal of this study is first to improve the amount of energy to be injected and to automate the injection of the energy into the power grids that stored using the appropriate systems and the injection of the energies produced. To do this, we use to the theory of fuzzy logic.

2. Modeling of the amount of energy

2.1 Fuzzy logic approach

It is a question of determining the amount of energy to be modeled through power calculation. The hourly power to be injected is equal to zero if the power consumed is smaller than the average value taken as the value of the consumption threshold. Otherwise, it is equal to the difference between the power consumed and the average value. The hourly power data to be injected constitute the inputs to our fuzzy logic model with inferences from Mamdani [Pourjavad and al, 2019]. To have the data to a using data with learning the style, we calculate the average value of 24 hours of consumption.

We use an example of average data hourly consumption to the city of Antananarivo, Madagascar to dafine our approach (Table 1) and the average hourly power consumed (Figure 1).
Table 1: Hourly power under voltage during 2020 at Antananarivo, Madagascar.

Hour(UTC+3)	Average Power(MW)
6h	34,44
7h	41,33
8h	46,00
9h	48,11
10h	49,22
11h	48,88
12h	47,44
13h	46,66
14h	40,22
15h	39,55
16h	40,33
17h	40,22

Hour(UTC+3)	Average Power(MW)
18h	37,22
19h	45,88
20h	45,77
21h	40,77
22h	33,77
23h	28,33
00h	25,55
01h	24,11
02h	23,88
03h	24,00
04h	25,55
05h	33,22

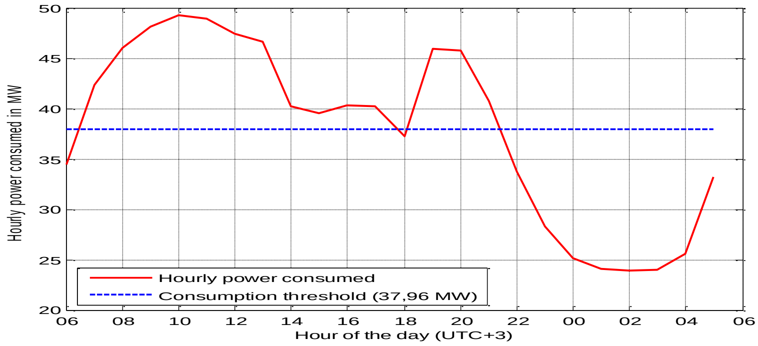

Figure 1: Hourly power consumed and consumption threshold (arbitrary choice)

2.2 Definition of the injection time

It is crucial to automate the injection of these energies when request arises. To do this, we set up a functional architecture of a system whose mostly has been simulated by using a computer programming.

2.3 Establishment inferences for the amount of energy

The CHEN method [Chen and al, 2004] is applied to obtain the 15 fuzzy inference rules for 10 partitions [Ratovomiharinjanahary and al, 2021]:

Rule N ° 1: If "A1" then "A4"
Rule N ° 2: If "A4" then "A7"
Rule N ° 3: If "A7" then "A9"
Rule N ° 4: If "A9" then "A9"
Rule N ° 5: If "A9" then "A8"
Rule N ° 6: If "A8" then "A7"
Rule N ° 7: If "A7" then "A7"
Rule N ° 8: If "A7" then "A3"
Rule N ° 9: If "A3" then "A2"
Rule N ° 10: If "A2" then "A3"
Rule N ° 11: If "A3" then "A3"
Rule N ° 12: If "A3" then "A1"
Rule N ° 13: If "A1" then "A7"
Rule N ° 14: If "A7" then "A3"
Rule N ° 15: If "A3" then "A1"

2.4 Establishment of inferences for injection and storage

We learn the consumption of the electrical networks of users and the state of injection in real time. This information is obtained from a fuzzy controller over WAN network.

This data is used as input to our system for a decision. The system must be able to know the truth associated with this information, which can deduce three consequences: need for storage, stop injection and reinjection. This brings up a new issue of priority between different electrical production sites that will be defined from a perspective work.

We can also introduce data fuzzification in order to establish basical inferences on subsets:

(1) Consumption "NULL": indicates that the injection of new energies is no longer necessary;
(2) Injection stop STRONG: indicates normal consumption;
(3) Reinjection STRONG: indicates the injection of new energies into the networks is immediately;
(4) Nominal storage LOW: indicates that the state of charge of the storage system is low;

The decision is to store, stop and re-inject these energies is activated when the combination of the 4 subsets of fuzzy logic that is optimal which will be defined empirically during a learning phase of the system.

2.4 Determination of the decision instant

To measure the confidence attributed to each subset, we define a confidence criterion C such that $0 \leq C \leq 1$ and which will be evaluated by using the difference between two successive of information that reported by the system with a fuzzy controller through the networks WAN. This information can be simulated by using a time measurement [Totozafiny, 2017].

$$d(t) = \mathrm{Cons}(t) - \mathrm{Cons}(t + \Delta) \quad (2.1)$$

With Cons (t) is the consumption at time t and Δ is a time parameter of one hour.

We can apply the fizzufication mechanism in fuzzy logic theory using a fuzzy operator such that:

$$nz = \mathrm{NonZero}(d(t)) \quad (2.2)$$

Where *NonZero* indicates the fuzzy logical operator. Therefore, nz represents the state of the 4 subsets. Each time nz is close to zero, we decrease the confidence C to indicate the change in the behavior of the system. It is important to note that it is impossible to predefine an optimal law for changing (increasing or decreasing) confidence. We define two fuzzy subsets:

- nz belongs to the subset: “NULL”,
- nz belongs to the subset: “POSITIVE LARGE”

We define the rules to allow the critaria to evolve:

$$\begin{cases} \text{If nz is "NULL" then C is decreased} \\ \text{If nz is POSITIVE LARGE then C is increased} \end{cases} \quad (2.3)$$

The "nz is NULL" premise is characterized by the µNull membership of nz in the "NULL" subset. Likewise, µPG represents the membership of nz in the "POSITIVE LARGE" subset.

The conclusions of the first rule of equation (2.3) are defined by αNull + for "C is strongly decreased" and αNull− for "C is weakly decreased". The output value βNull is given by following rule:

$$\beta_{Null} = \frac{\mu_{Null} \times \alpha_{Null+} + \mu_{PG} \times \alpha_{Null-}}{\alpha_{Null+} + \alpha_{Null-}} \quad (2.4)$$

Where αNull + = 0.9 and αNull− = 0.1 for the experiment.

Since we want to decrease confidence, the can use the following formula:

$$C_{NULL} = \beta_{Null} + C - \beta_{Null} \times C \quad (2.5)$$

The conclusions of the second rule of equation (2.3) are defined by αPG + for "C is increased strongly" and αPG− for "C is increased weakly". The output value βPG is given by following rule:

$$\beta_{PG} = \frac{\mu_{Null} \times \alpha_{PG+} + \mu_{PG} \times \alpha_{PG}}{\alpha_{PG+} + \alpha_{PG\_}} \quad (2.6)$$

αPG + = 0.1 and αPG− = 0.9 for the experiment.

Since we want to increase confidence, the can use the following formula:

$$C_{PG} = \beta_{PG} * C \qquad (2.7)$$

Indeed, neutral AND does not allow to obtain an increase in C if βPG is equal to C because it gives the minimum value. In this case, the information contained in βPG is not taken into account. The value of C is determined from reasoning and using the true outputs:

- If CNull is true then the output is ”Decrease” or -1
- If CPG is true then the output is ”Increase” or +1

The value of C is obtained by following formula:

$$C = \frac{C_{Null} \times (-1) + C_{PG} \times (+1)}{C_{Null} + C_{PG}} \qquad (2.8)$$

3. Results and Discussions

3.1 Data simulation

The data is simulated by using the computer tools which are shown in Figure 3.

For production:

- The value 1: indicates the maximum production;
- The value 0: indicates the production is minimal;

For consumption:

- The value 1: indicates heavy consumption;
- The value 0: indicates the minimum consumption;

For storage:

- The value 1: indicates the maximum storage or reached only one that can be launched the injection ;
- The value 0: Storage in progress without unnecessary loss

3.2 Amount of energy

The results of modeling the amount of energy by fuzzy logic are shown in Figure 4. In red, we have the power to be injected and in blue the power to be injected as predicted by the model. Applying the center of gravity method, we get the value 4.79 MW. This value matches to the power to be injected predicted by the model at the instant (t + 1) hour.

Table 2: Results of fuzzification with 10 partitions.

Schedule	Injected power (MW)	Fuzzy set	Schedule	Injected power (MW)	Fuzzy set
06h	0	$\check{A}_1$	18h	0	$\check{A}_1$
07h	4,37	$\check{A}_4$	19h	7,92	$\check{A}_7$
08h	8,04	$\check{A}_7$	20h	7,92	$\check{A}_7$
09h	10,15	$\check{A}_9$	21h	2,81	$\check{A}_3$
10h	11,26	$\check{A}_9$	22h	0	$\check{A}_1$
11h	10,92	$\check{A}_8$	23h	0	$\check{A}_1$
12h	9,48	$\check{A}_7$	00h	0	$\check{A}_1$
13h	8,7	$\check{A}_7$	01h	0	$\check{A}_1$
14h	2,26	$\check{A}_3$	02h	0	$\check{A}_1$
15h	1,59	$\check{A}_2$	03h	0	$\check{A}_1$
16h	2,37	$\check{A}_3$	04h	0	$\check{A}_1$

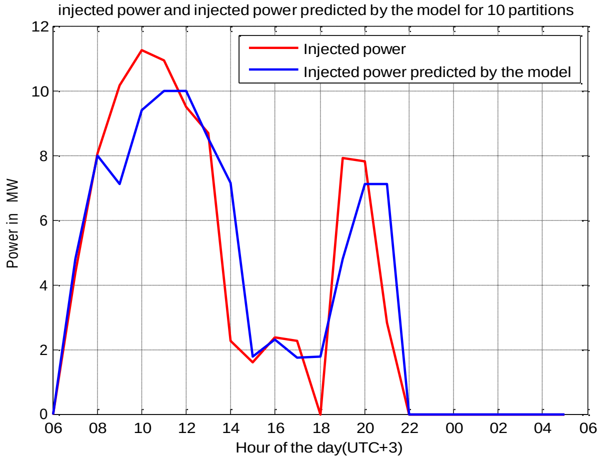

Figure 4: Power to be injected results with 10 partitions.

3.2 Automation of injection

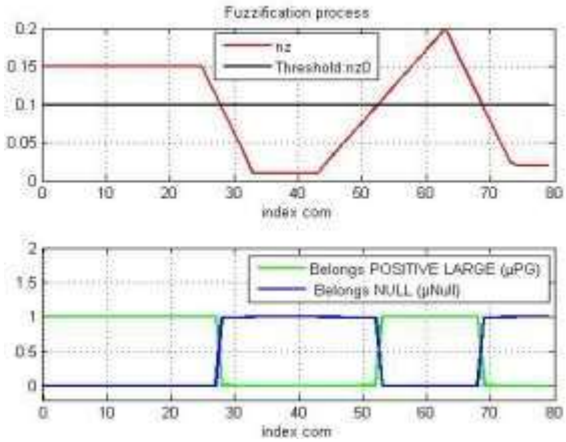

Figure 5: Fuzzification of nz to µPG and µNull.

We use the same simulation data described in [Totozafiny et al., 2019]. The Sugeno inferences from fuzzy logic allows the automation of storage, stopping of injections and reinjections of energy to electrical distribution network without carrying out load shedding. And this through the evolution of these four parameters such as: Consumption, Storage, Injection stop and Reinjection.

Time To Decision (TTD) is determined when those parameters are optimal. In the case of this study, we use a threshold to extract the TTD. Once the TTD has been determined, it comes down to choose the production site to start the injection. This brings up another priority issue. Our method by logic makes it possible to choose the best site for the injection but it is not efficient if we want to launch the injections of electrical energies simultaneously. Secondly, they constitute the entry points of our algorithm (Figure 5 and Figure 6).

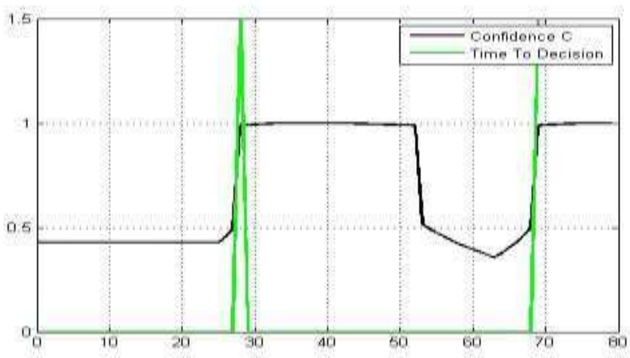

Figure 6: Confidence associated with the energy consumption of users.

4. Conclusion

The fuzzy logic inferences make a possibility to automate the injection, the stopping of the injections and the reinjections of energy to the electrical networks in operation without carrying out load shedding. The amount of energy was defined using fuzzy logic according to user consumption. Four parameters (Consumption, Storage and injection shutdown and Reinjection) were taken into account in this study for the modeling of the amount of energy and its injection.

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