Energy Management of a Fuzzy Control System in a Microgrid

MELIANI Meryem[1,2,*], *EL BARKANY Abdellah*[1,*], *EL ABBASSI Ikram*[2], *ABSI Rafik*[2], *MAHMOUDI Morad*[1,2]

[1] Mechanical Engineering Laboratory, Faculty of Science and Technology, Sidi Mohammed Ben Abdellah University, B.P. 2202 - Route d'Imouzzer - Fez, Morocco
[2] ECAM-EPMI, 13 Boulevard de l'Hautil, 95092 Cergy Pontoise Cedex, France

Abstract. Micro-grids can be considered as the ideal way to integrate renewable energy sources into electricity generation and to give consumers the opportunity to participate in the electricity market as consumers and producers. Our study aims to implement a micro-grid with solar and wind power generation and storage systems. However, the integration of a battery storage system into a micro-grid requires a thorough control of charge and discharge techniques due to the different load conditions. In this study, the proposed system can transfer electricity to and from the main grid. Although, the objective of the simulation is to control at the same time the energy input and output of the principal grid in order to maximize the profit and minimize the cost. To cope with the uncertainties of the system, a fuzzy logic controller for charge-discharge as well as a scheduling of battery energy storage systems is simulated on Matlab, in order to ensure the energy availability on demand and to take a proper decision whether to store or sell energy.

1 Introduction

In terms of energy, micro-grid (MG) systems can provide real answers to the energy transition challenges. They offer an optimized access to renewable, sustainable and resilient energy. A MG system integrate loads, decentralized energy sources, Renewable Energy Sources (RES), control and storage system. It is connected directly to the main grid, certain units can work as stand-alone units in "island mode" in case of an outage. The benefits of using MG lie in optimizing the energy management, reducing energy costs, improving the environmental footprint, and increasing energy coverage [1]. However, besides producing electricity the system can also store electricity in batteries to be distributed locally, known as ESS (Energy Storage Systems.). Most conventional control methodologies for charge-discharge storage are generally associated with complexity, loading time cycle, efficiency, temperature, and self-discharge or overcharge problems. An approach to defeat these challenges is proposed as a fuzzy logic-based control system for BESS (Battery Energy Storage System) charge-discharge control.

In contrast to Boolean logic, fuzzy logic (FL) is a general logic where the truth of a variable is a real number from 0 to 1, rather than being true or false. It's a way to present the change or the imprecision in logic; a way of using the natural language in logic; an approximate reasoning. They exist many review studies on FL. In [2], the authors review some of the FL applications in hydrology and water resources. They suggest that the hybrid-fuzzy modelling approach performs well in several Hydrology applications in comparison to

---

* Corresponding author: meryemeliani@gmail.com , Abdellah.elbarkany@usmba.ac.ma

FL models. On the other hand, the authors of [3] present the advantages of Fuzzy sets, fuzzy logic and fuzzy based inference systems for wireless tracking problems. They review and discuss several techniques and methodologies related to fuzzification. While in the study [4], it reviews a number of fuzzy logic-based model applications for renewable energy systems. In the last few years, the FL based models are proved to be widely adopted for location assessments, PV/wind power installation, PV/wind power tracking points [5]. The review shows that FL control based systems provides an accurate results.

2 Fuzzy Logic model: case study

In this paper, we will represent a MG system consisting of diesel generators, fuel cells, wind turbines, photovoltaic panels, battery storage and local demand. The system is based in Fez, Morocco [6]. Consider the fact that the MG is connected to the main network. The system has about 8 solar photovoltaic panels. These PV modules are connected directly to a wind turbine to ensure the availability of energy during uncertain weather conditions.

- To calculate the output power of the solar modules we used this following equation [7-8]:

$$P_{PV} = P_{STC} \times (G_{ING} / G_{STC}) \times [1 + k\,(T_c - T_r)] \qquad (1)$$

$$T_c = T_{air} + (NOCT - T_{soc}) * G \;/ Gsoc \qquad (2)$$

Where, PPV: The output power of the module at irradiance GING; PSTC: The module maximum power at standard test condition (STC); GINC: The incident irradiance; Tc: The cell temperature; Tr: The reference temperature; Tair: The ambient temperature. We have assumed for our case the use of the solarex MSX-83 whose output features are shown in table 1.

Table 1: characteristics of the output [9].

Parameters	**value**
Ppv,n Max power	83 W
Maximum voltage power	17.1 V
NOCT (The rated operating cell temperature)	47°C
GSOC (The irradiance during standard operating conditions)	800 W/m2
Gstc (The irradiance at STC)	1000 W/m2
Current at maximum power	4.85 A
TSOC (Ambient temperature)	20°C
Tstc	25°C
K (Approximate effect of temperature on power)	0.5 %/°C

- In the other hand the wind speed can be calculated using the following equation [10-11]:

$$P_{wind} = \begin{cases} 0 & U_Z \leq U_{ci} \text{ or } U_Z > U_{co} \\ \frac{U_Z - U_{ci}}{U_r - U_{ci}} \cdot P_t & U_{ci} \leq U_Z \leq U_r \\ P_t & U_r \leq U_Z \leq U_{co} \end{cases} \quad (3)$$

Where, Pwind: The potential wind power output; UZ : The wind speed at the hub height of Z. The following table 2, lists all variables selected for the above equation according to the V90-3.0 MW wind turbines.

Table 2: Parameters of theV90-3.0 MW wind turbines [12].

Parameter	**Value**
Z, Hub height	105 m
Ur (The rated wind speed)	15 m/s
Uci (The input wind speed)	3.5 m/s
Uco (The output wind speed of the wind turbine selected)	25 m/s
Pt (The rated wind power of the wind turbine)	3 MW

- And finally equation (4) is adopted to calculate the State of Charge (SOC) of the battery. Based on capacity, efficiency (>90%), size, cost, charging time and storage life cycle, we opted for the lithium-ion battery [13-14].

$$SOC = C \times 100/C_{Ref.} \quad (4)$$

Where, C: The battery capacity; Cref: The battery reference capacity.

3 Fuzzy Logic structure

We present (Fig. 1) a flowchart detailing the storage management approach phases to address the issue, figure 1. There are two parts defining the structure: the forecasting and the decision making using Matlab. For the first phase, to estimate the power generated by the PV and wind, we considered as input a real-time data of wind-speed, irradiations, and temperatures of Fez, Morocco. The forecasting is applied in Zaitun time series software. However, in the next phase, the storage decision is based on four options: charge batteries, discharge batteries, buy electricity, sell electricity. The decision is taken based on ΔP and the SOC (State of Charge).

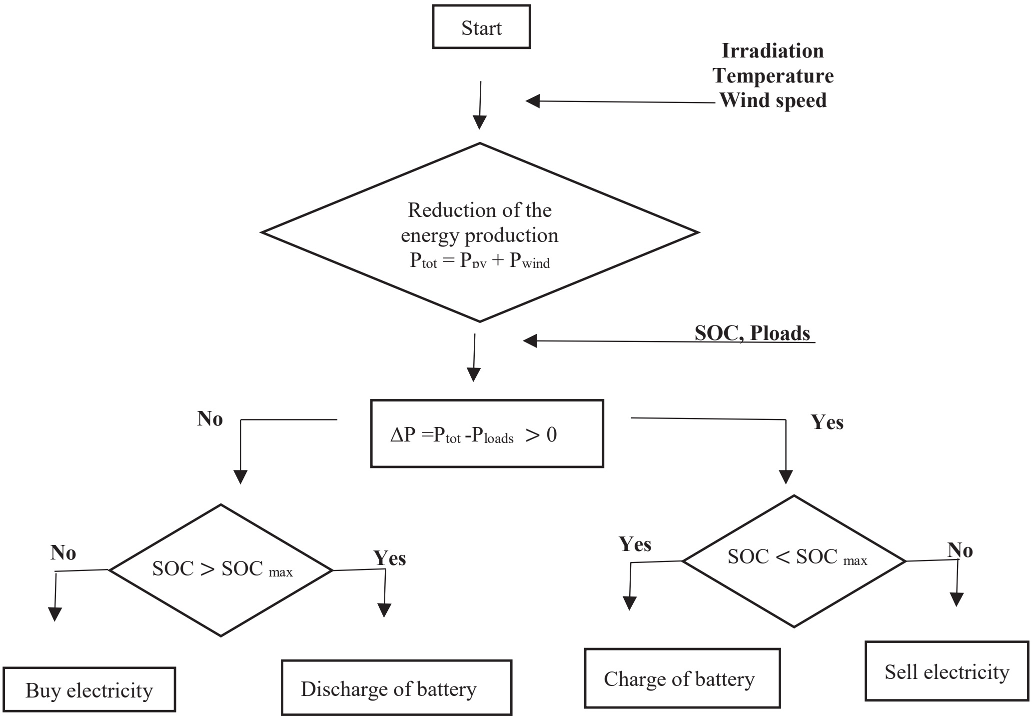

Figure 1: Flowchart proposed.

The FL control input, ΔP, can be calculated by equation (5), as it's the difference between the load demand and the total available power from the distributed sources. In our simulation, the decision depends on ΔP. For example, in the case where ΔP is positive, then we will have enough power to use and a surplus to store.

$$\Delta P(t) = PT(t) - PL(t), \qquad (5)$$

$$\text{With} \quad PT(t) = PPV(t) + PW(t). \qquad (6)$$

4 Results

To represent the first input ΔP we considered four functions in our simulation: very small (VS); medium small (MS); medium large (ML); very large (VL). Then, there are supposed to be five other functions for SOC: Very Small (VS); Medium Small (MS); Normal (N); Medium Large (ML); Very Large (VL). As for the output Decision, we have four functions: Microgrid power supply (MGS); Battery discharge (DB); Battery charge (CB); and Power sale to the grid (SE). The selected member functions MFs are illustrated in Figure 2.

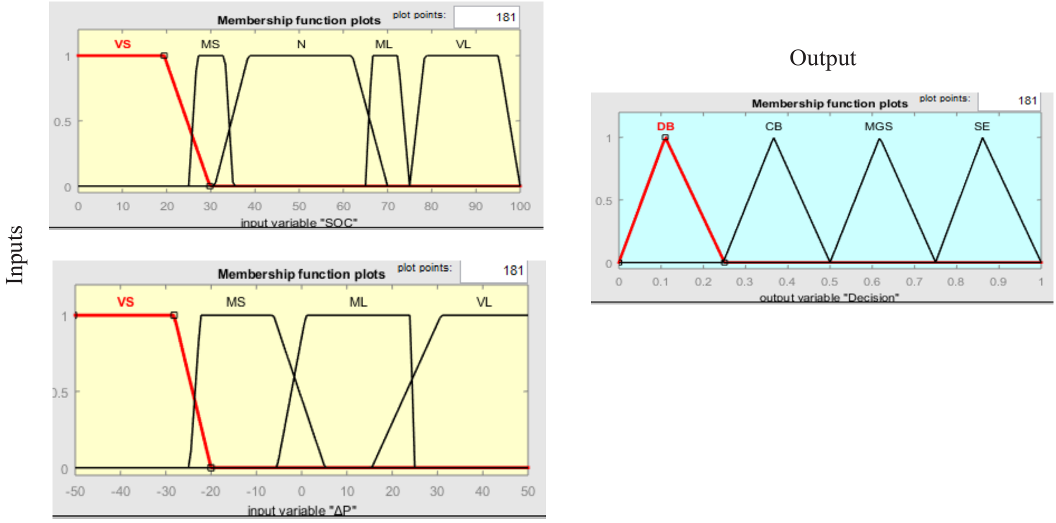

Figure 2: MF of the FIS Input and the Output Variables.

The fuzzy rule controller set is presented in table 4. Whenever, there isn't a sufficient energy for the load, the batteries have to be discharged. Seen that there is five SOC features and four representing ΔP, it gives twenty rules in total for the output decision I. the selected fuzzy implication, the validity level of the premise's propositions, and the member-functions of the propositional fuzzy set, are defined as the three factors on which the results of the fuzzy rule application depends.

Table 4: Rules of the fuzzy controller.

Decision		ΔP			
		VS	MS	ML	VL
SOC	VS	VS	VS	VS	VS
	MS	VS	VS	ML	ML
	N	MS	MS	ML	ML
	ML	MS	MS	ML	VL
	VL	N	N	ML	VL

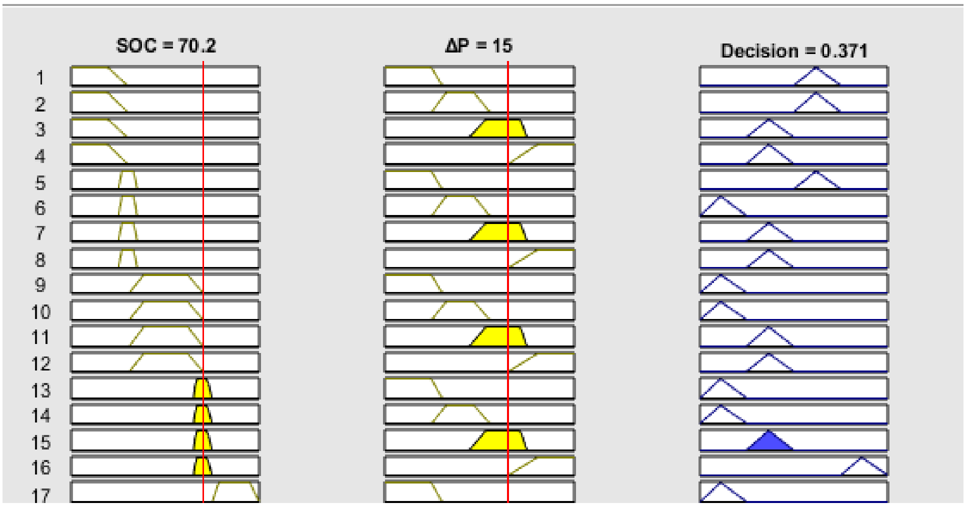

Figure 3: Rule simulation interface from Matlab.

Figure 3 represents the plot results of our fuzzy simulation. There are 20 rules in all which define one rule for every plot line. By shifting the red lines on the inputs, its output decision value might be varied or re-generated. If we consider Figure 3, SOC equals 70.2 with ΔP 15, and both inputs within the very large row, resulting an output decision where the system must charge the battery. The output rows identify the combination from all rules to provide an aggregated and defuzzified output. In this example, it's shown a defuzzified value of about 37%.

4 Conclusion

In this paper, we estimated a MG supplied by a RES and batteries for efficiency optimization. First, we predicted the RES produced energy with the help of Zaitun time series software. Afterward, a fuzzy logic technique were used to choose one among four decision options possible, that would meet the cost benefit ratio to a minimum. This study focus is to improve the performance of battery energy storage system, and thus ensure MG reliability by effectively managing the battery state of charge.

References

1. M. Meliani, A. el Barkany, I. el Abbassi, A.M. Darcherif, & M. Mahmoudi, *Control system in the smart grid: State of the art and opportunities*, in 2020 IEEE 13th International Colloquium of Logistics and Supply Chain Management, LOGISTIQUA, pp. 1-6, 2020 December.
2. S. KAMBALIMATH, et P.C. DEKA, *A basic review of fuzzy logic applications in hydrology and water resources*. Applied Water Science, vol. 10, p. 1-14, 2020.
3. M. ALAKHRAS, M. OUSSALAH, et M. HUSSEIN, *A survey of fuzzy logic in wireless localization*, EURASIP Journal on Wireless Communications and Networking, p. 1-45, 2020.

4. L. SUGANTHI, S. INIYAN, et SAMUEL, A. Anand, *Applications of fuzzy logic in renewable energy systems–a review*. Renewable and sustainable energy reviews, 2015, vol. 48, p. 585-607.
5. M. Meliani, A.E. Barkany, I.E. Abbassi, A.M. Darcherif, & M. Mahmoudi, *Energy management in the smart grid: State-of-the-art and future trends*. International Journal of Engineering Business Management, vol. 13, p. 18479790211032920.2021.
6. M. Meliani, A. el Barkany, I. el Abbassi, A.M. Darcherif, & M. Mahmoudi, *Smart grid implementation in Morocco: Case study*. Materials Today: Proceedings, 2021.
7. M. Faisal and H. Koivo, *Modelling and environmental/economic power dispatch of microgrid using multiobjective genetic algorithm optimization*, Fundamental and Advanced Topics in Wind Power, vol. 20, pp. 361–378, 2011.
8. G. Migan, *A.Study of the Operating Temperature of a PV Module*; Lund University: Lund, Sweden, 2013.
9. Solar Electric Supply. SOLAREX-PHOTOVOLTAIC SOLAR MODULES n.d. Available online: https://www.solarelectricsupply.com/solar-panels/solarex (accessed on 9 May 2017).
10. T. Burton, N. Jenkins, D. Sharpe, E. Bossanyi, *Wind Energy Handbook*, Wiley: Hoboken, NJ, USA, 2011.
11. Y. Zhang, Y. Zhao, X. Shen, & J. Zhang, *A comprehensive wind speed prediction system based on Monte Carlo and artificial intelligence algorithms*. Applied Energy, vol. 305, p. 117815, 2022.
12. Vestas. Vestas|Wind It Means the World to Us n.d. Available online: https://www.vestas.com/(accessed on9 May 2017).
13. A. Hassan, Y.M. Al-Abdeli, M. Masek, & O. Bass, *Optimal sizing and energy scheduling of grid-supplemented solar PV systems with battery storage: Sensitivity of reliability and financial constraints*. Energy, 238, 121780, 2022.
14. G. Graditi, M. G. Ippolito, E. Telaretti, and G. Zizzo, *Technical and economical assessment of distributed electrochemical storages for load shifting applications: An Italian case study*, Renew. Sustain. Energy Rev. vol. 57, pp. 515523, May 2016.