International Journal of Complex Systems – Computing, Sensing and Control
Vol. 3, No. 1, pp. 79-92, 2015

MICROGRID ENERGY MANAGEMENT SYSTEM USING FUZZY LOGIC CONTROL

LYDIE ROINÉ[1*], KAMBIZ THERANI[2],
YASHAR SAHRAEI MANJILI[3], MO JAMSHIDI[3]
[1]*Department of Electrical Engineering, Esigelec, Rouen, France,*
[2] *Irseem, Department of Electrical Engineering, Esigelec, Rouen, France,*
[3]*Department of Electrical and Computer Engineering, University of Texas at San Antonio, USA*
[*]*l.roine.10@groupe-esigelec.fr*

ABSTRACT—A microgrid is a small-scale grid designed to provide power to local communities and be able to connect or disconnect from the main grid, is studied. Considering solar panel and wind turbine as generators, the load is assimilated to a residential demand. The aim of this paper is the regulation of the energy management for a regular day in summer via intelligent control. The command approach used for fuzzy logic rules, considering electricity prices, renewable production, load demand as parameters. Furthermore, the command rules are developed in order to ensure a reliable grid taking into account the financial aspect to decide the load modification's level. We show the theoretical and simulation results in this paper.

Key Words: Microgrid Network, Energy Management, Fuzzy Logic, Solar Panel, Load Demand, Load Modification, Variable Electricity Price.

1. INTRODUCTION

Nowadays, more than ever, the power engineering domain is facing enormous challenges. The worldwide population continues to increase as way of life of the emergent countries, implying a considerable energetic demand rise. While, the growing interest in intermittent renewable energies is imposing a major of technical limitations and increases the vulnerability of power systems. An update of the actual grid is waiting to meet the future demand and electric needs to connect everyone to abundant, high quality environment and reliable electric power.

Smart Grid is the future power system. It is an intelligent network which supports intermittent low-carbon energy sources and provides consumer participation on load management. The structure connects every grid's users to affordable, efficient and reliable electric power. It could be adapted both for small and large area.

To control the power flow among the elements consisting a multi energy system (MES), an energy management system (EMS) must be designed. The EMS offers a flexible and low cost energy [1, 2]. The EMS is usually a central controller that drives all the elements [3, 4].

Customers taking part of it as power providers through interactive loads to adapt consummation to grid safety, ensure the best grid conditions, avoid blackouts and decrease environment impact at least cost.

The microgrid is adapted to a small islanded area interconnected with a larger one. They are independent but can interact together to maintain system reliability. The structure is for low voltage distribution system with intermittent energies, supported by energy storage. When the production is greater than the consumption, power could charge the battery or is sold to the connected grid.

In recent years, different methods have been proposed by the authors in the field of microgrid like this [5-6]. In this paper, the energy management and the modelisation of a microgrid system are studied. Subsequently, in Section 2 the energy resources models for a solar panel and a wind turbine are developed. The electricity consumption is simulated via a residential load. In Section 3 the control strategy structure is explained. The control approach used in this paper is fuzzy logic considering the evolution of prices during the day, the energy demand, the production and time. In Section 4 the model and the control are assembled to estimate the power flow evolution during the day and how his management could be improved and the results obtained are shown, there are analyzed in Section 5. Finally, a conclusion is developed in Section 6.

2. SYSTEM MODEL

A microgrid is a small-scale grid designed to provide power to local communities and be able to connect or disconnect from the main grid in order to operate in both grid connected or islanded mode. The proposed model is composed of a wind turbine and a solar panel as renewables energy resources and a generator in association with a load.

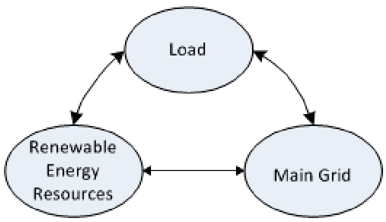


Figure 1. General Structure of Microgrids.

Considering that the system studied operates synchronously and in parallel with the main grid. The power flow comes from the main grid to the microgrid and vice-versa. It means that if the power exchange is from the main grid to the micro grid, the micro grid is consuming the main grid's energy; and therefore it must pay to the grid for each kilo-watt/hour. However, if the micro grid has more power than it needs, it can sell it to the main grid.

The connection to the main network is a three phase connection. It composes of a slack generator; carries out different level of power without any voltage drops. The slack bus computes voltage magnitude, intensity, active and reactive power. The transmission line is modelled by a resistance which simulates the distance traveled, and an inductance, smoothing the current. The electric bus represents distribution lines.

2.1 Solar Model

A solar panel is constituted of PV modules names cells. Also, the equivalent circuit of a PV cell is represented below is composed of a current source, a diode, a series resistance and a shunt resistance. Conventionally $R_S R_S$ is very large and R_{Sh} is very small. Considering the cell as ideal, resistances are neglected.

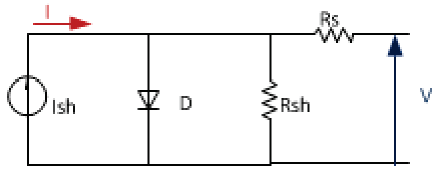


Figure 2. Equivalent circuit of PV cell.

The mathematical model is given as:

$$\mathrm{I} = I_{PH} - I_S\left[exp\left(\frac{q(V+IR_S)}{kT_CA}\right) - 1\right] - (V + IR_S)/R_{SH} \tag{1}$$

Determination of Model Parameters [1]:

The photocurrent I_{PH} is defined in function of the solar insolation and the cell's working temperature.

$$I_{PH} = \left[I_{SC} + K_1\left(T_C - T_{Ref}\right)\right]\lambda \tag{2}$$

where I_{SC} is the cell's short-circuit current at 25°C and 1kW/m², K_1 is the cell's short-circuit current temperature coefficient, T_C is the cell's working temperature °C, T_{Ref} is the cell's reference temperature °C and λ is the solar insolation in kW/m². The saturation current is defined in function of the solar insolation and the cell's working temperature:

$$I_S = I_{RS}\left({}^{T_C}\!/_{T_{Ref}}\right)^3 exp\left[\frac{qE_G\left({}^1\!/_{T_{Ref}} - {}^1\!/_{T_C}\right)}{kA}\right] \tag{3}$$

where I_S is the cell saturation, I_{RS} is the cell's reverse saturation current, q is the electron charge, $1.6 \times 10^{-19}C$, k is the Boltzmann's constant, $1.38 \times 10^{-23}J/K$, A is the Ideal factor dependent on PV technology and E_G is the Band-gap energy of the semiconductor used in the cell.

$$E_G = E_{G,0} - \frac{\alpha {T_L}^2}{\beta + T_L} \tag{4}$$

where, $E_{G,0}$is the Band gap at 0K, 1.1695 eV, T_L is the temperature in Kelvin,α and β are constants respectively 4.7×10^{-4} eV/K and 636K.

A solar panel is organized as in PV cells connected in series-parallel configuration.

The mathematical representation becomes:

$$I = N_PI_{PH} - N_PI_S\left[exp\left(\frac{qV}{N_SkT_CA}\right) - 1\right] \tag{5}$$

where, N_p is the number of parallel cell and N_S is the number of series cell.

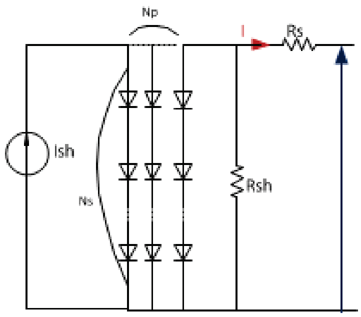


Figure 3. Equivalent model of solar panel.

At reference temperature and when the current output value is zero, the short-circuit current is supposed equal to the photocurrent. Consequently, the expression can be rewritten as follows:

$$I_{RS} = \frac{I_{SC}}{exp\left(\frac{qV_{OC}}{N_S kAT_C}\right)-1} \tag{6}$$

Furthermore, it is possible to change the characteristic of the cell by changing the values of Ns, Np, V and the temperature of the cell. However, we can modify the localization of our solar farm by changing the insolation curve. So, this model is adaptable to different environment.

2.2 Wind turbine

The wind turbine respects usual model, as presented in block diagram in Figure 4.

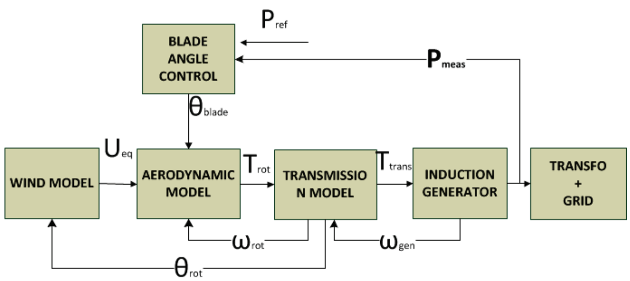


Figure 4. Model of Wind power system.

The wind model could be carried out as a constant input or in function of the observing wind speed at 10m [2]:

$$\overline{v_H} = \overline{v_{H10}} \times \left(\frac{H}{10}\right)^x \tag{7}$$

where, $\overline{v_H}$ is the average wind speed (m/s), $\overline{v_{H10}}$ is the average wind speed at 10m, (m/s), H is the height (m) and X, an exponent depended on the roughness of the ground. It could be expressed through turbulence, gust and ramp components [3]:

$$v_w(t) = v_{wa} + v_{wr}(t) + v_{wg}(t) + v_{wt}(t) \tag{8}$$

where, v_w is the wind speed at time t, v_{wa} the average value of the wind speed, v_{wr} is the ramp component, v_{wg} the gust component and v_{wt} is the turbulence component.

The turbine considered is composed of three blades of radius *R*, which are driving a generator through a transmission model. The wind power extracted from the wind is expressed as:

$$P_w = \frac{1}{2}\rho A {v_w}^3 \tag{9}$$

where, v_w is the wind speed (m/s) ρ is the air density equal to 1,225 kg/m^2 at sea level at T=288K and AA is the area swept by the rotor (m²). The power captured by the turbine, P_m, is explicit in function of the power coefficient C_p

$$P_m = P_w \times C_p \tag{10}$$

The power coefficient represents the aerodynamic ratio of the wind turbine.

$$C_p = \frac{1}{2}(\gamma - 0{,}022\beta^2 - 5{,}6)e^{-0{,}17\gamma} \tag{11}$$

where, β is the Pitch Angle (°) and γ the tip speed ratio of turbine assimilates to:

$$\gamma = \frac{R\omega_b}{v_w} \tag{12}$$

ω_b is the rotor angular speed (rad/s), *R* is the radius of the blade (m).

3. THE SYSTEM MANAGEMENT

The microgrid model is managed through Fuzzy logic concept. Results are not black or white values but multiple shades of grey. Fuzzy logic is certainly not a logical but a vague sense that adapts to the human being leaving a space between the certainty of the true and the false certainty. So, they are different level of power interaction with the main grid. The control strategy used is implemented on a block called fuzzy load management containing all the management commands, fuzzy rules. His role is to determine the amount of power exchange to the main grid in function of input's level in 15 minutes period.

The aim is to manage the load and power interaction with the grid in function of the actual state of the model considering the electricity price, time of day, load, excess demand and generation amount depending on weather forecast.

Our inputs are electricity price (EP, $ per kWh), time of day (T, hour), excess demand (ED, kW), load (L, kW per hour), wind power (Wnd, kW) and solar power (Sol, kW).

The time parameter is the output current simulation time at specified rate. During the day, the load profile could be modified in function of the electricity demand and power production. To represent this notion, the "excess demand" variable is included and defined by the following formula:

$$Excess\ Demand = Load\ Profile - Renewables\ Power \tag{13}$$

Its principle is explained below:

$$\textit{If the Excess Demand} > 0 \tag{14}$$

When ED is positive, extra power is required at the micro grid which should be provided using the main grid.

$$\textit{If the Excess Demand} < 0 \tag{15}$$

When the variable is negative, extra power is available on the micro grid side.

Furthermore, the outputs are MP (modification percentage of the load profile), *LD* (load drop), *ML* (modified load) and *Exchng_P* (power exchange between micro grid and main grid). These variables are defined as following:

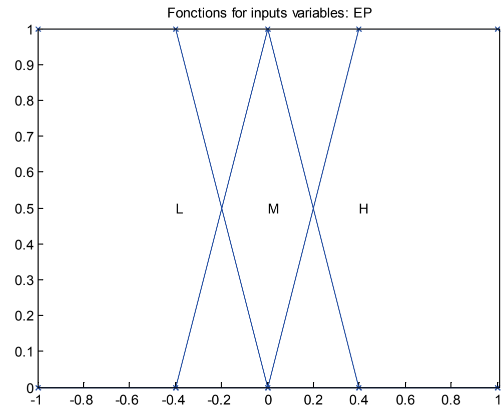
$$LD = L \times MP \tag{16}$$

$$ML = L \times (1 - MP) \tag{17}$$

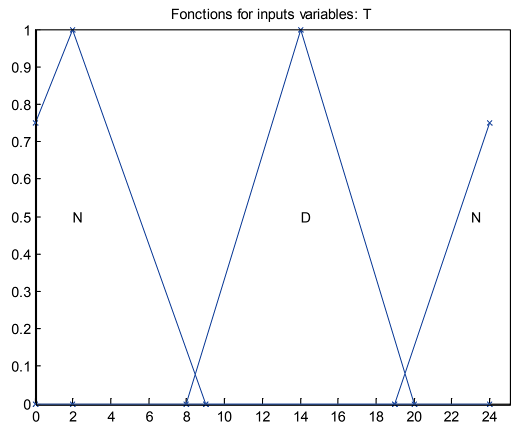
$$Exchng\_P = (ML - Sol - Wnd) \tag{18}$$

The membership functions are defined on [0; 1], fuzzy set inputs and output are represented on Figure 5:

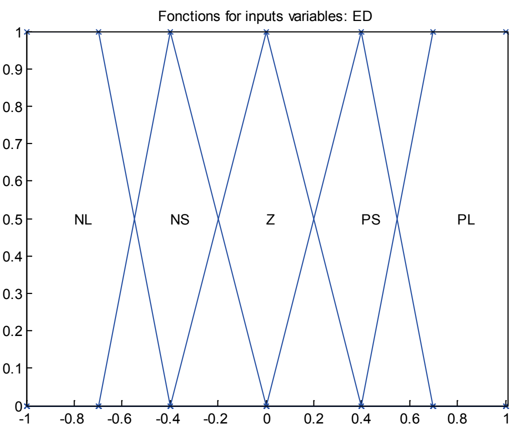
- EP: Low (L), Medium (M), High (H)
- T: Day (D) (8 am to 2 pm to 8 pm), Night (N) (7 pm to 2 am to 9 am)
- ED: Negative Large (NL), Negative Small (NS), Zero (Z), Positive Small (PS), Positive Large (PL)
- MP: Extremely High (EH), Very High (VH), High (H), Medium (M), Low (L), Very Low (VL), Extremely Low (EL)



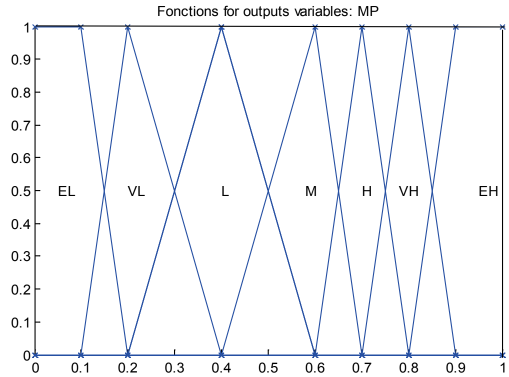
(a). Electricity Price input.



(b). Time input.



(c). Excess demand input.



(d). Modification Load Profile outputs

Figure 5. Fuzzy Membership function for inputs and outputs fuzzy controller.

Artificial intelligence follows our human conception, and our capacity to take decisions. Inputs combination corresponds to one output defined by fuzzy rules. Also, the load profile modification could be extremely high, very high, high, medium, low, very low and extremely low in order to regulate the power exchange. The control strategy will be able to limit meteorological impacts on production and grid reliability.

To explicit the concept, one of the command rules is:

IF the ***excess of demand*** is ***Negative Small*** AND the ***electricity price*** is ***Low*** AND during the ***Day*** THEN the ***modification percentage of the load profile*** is ***Very High***.

In this situation, the production is lower than the electricity demand. The microgrid requires more power and prices are low. So, the modification load profile will be less important than if the prices were high. On a financial point of view, it will be more profitable to buy power from the main grid than interrupt load which decreased users' comfort and used reserves. If the situation is reversed, this would be better to disconnect loads, so as to decrease the excess demand and take back to a reliable state. The time parameter takes in account the demand conditions, on the day the consumption and earlier at night are critical points. The load could be stopped more easily after midnight than around 7pm. The load management will have less impact on users during business hours and night. A second case could be:

IF the ***excess of demand*** is ***Positive Small*** AND the ***electricity prices*** are ***Low*** AND during the ***Night*** THEN the ***modification percentage of the load profile*** is ***Low***.

The power production is greater than the demand and the electricity prices are low. In this situation, the excess power could be sell to the grid or the number of load could increase to adapt to the production. Therefore, the fuzzy logic control strategy orders right load schedule to ensure the grid reliability though users and suppliers interactions.

4. SIMULATION RESULTS

The system under concerns is the same as presented in Section 2. The power flow evolution between the microgrid and the main network is developed considering a photovoltaic generator and a wind turbine associated with a load. To achieve simulation real data measures came from the Western Regional Climate Center website and more precisely from a weather station in San Antonio. It's assumed that the data point vary during the day. The main consumption peak point is shown on Figure 8 around and 8pm. Capacity to regulate a load via control strategy using fuzzy rules is examined.

The power consumption is supplied by the solar panel and wind turbine, which are connected to the main grid to compensate if the production is lower than the demand.

Wind speed and solar radiation are shown in Figures 6 and 7 respectively.

In Figure 8, the profile of electricity price shows that there are two peaks, one around 10 am and the second one corresponding to the consumption peak around 8 pm. As expected, the solar production reaches his maximum when the sun is at its zenith around 3 pm. Following the excess demand description, when the variable is negative, the production is greater than load demand and vice versa when the value is positive.

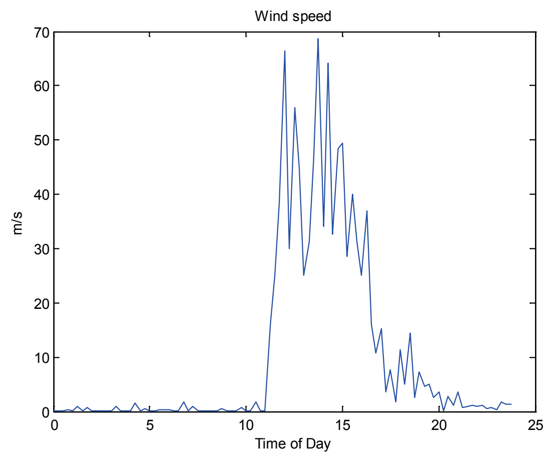


Figure 6. Wind speed.

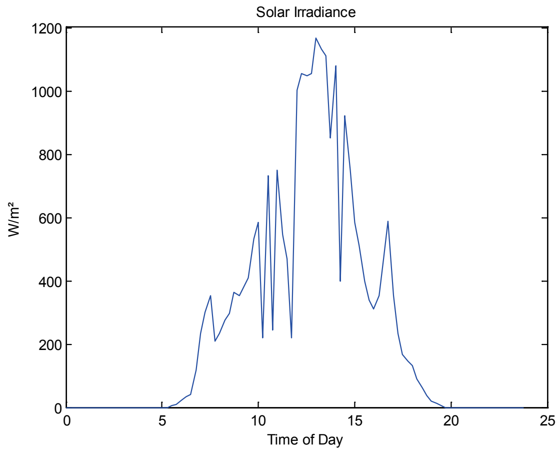


Figure 7. Solar Irradiance.

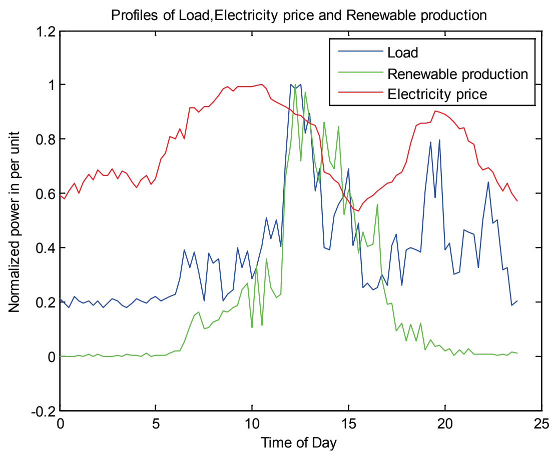


Figure 8. Profiles of Load, Price and Production.

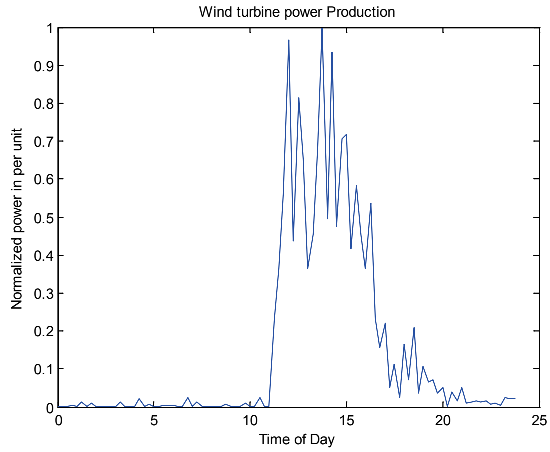


Figure 9. Wind turbine active power production.

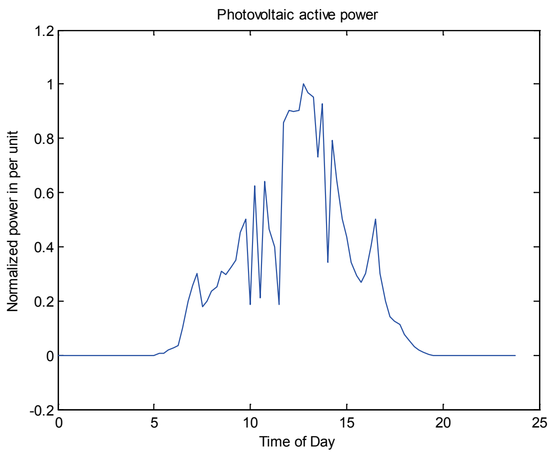


Figure 10. Photovoltaic active power.

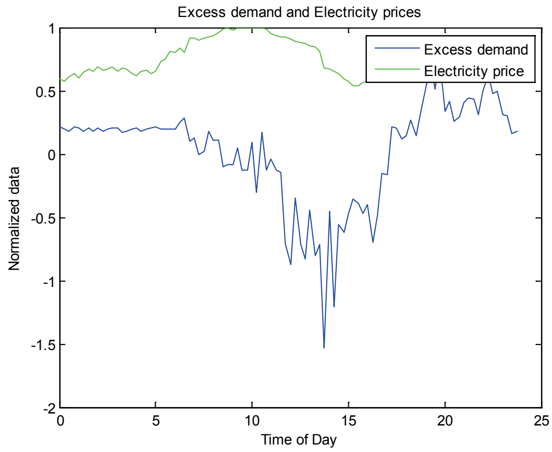


Figure 11. Excess demand and electricity prices.

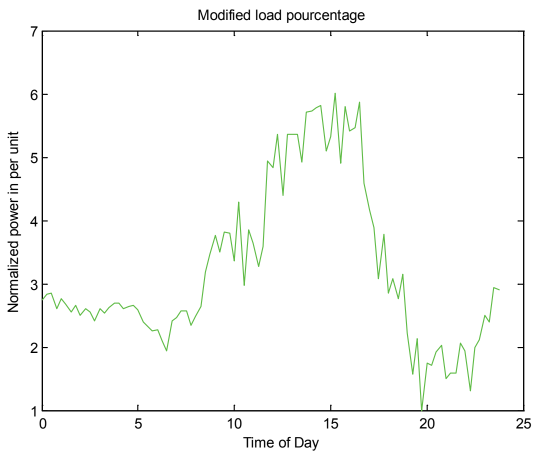


Figure 12. Modified load percentage.

5. RESULTS ANALYSIS

Regarding the excess demand of the microgrid, it is forced to assume that when the demand is lower than the production until 3pm, the excess demand is negative and the prices are higher on this period. Also, the load modification is more important on this section than earlier in the morning.

Considering the excess demand, the curve is positive when the photovoltaic panel stops producing. While electricity price from the main grid are higher. So, the objective is to keep a reliable network, the less expensive possible. Figure 12 shows that under these constraints the load modification is smaller in order to ensure the consumer comfort contrary to the first case, where producers are rather restricted to modify the grid parameters.

5. CONCLUSION

In this paper, a typical microgrid is studied. The model of two generating power, solar panel and wind turbine are developed. Also, an energy management's control strategy is presented with electricity prices, consumption and renewable production as inputs parameters. The approach used in this paper is fuzzy logic; the output depends on rules' combinations which optimize the load consumption in order to ensure an affordable grid. As aforementioned on the simulation results, the fuzzy logic rules is a conclusive solution to regulate the load profile taking in account exterior parameters, supply and demand to reduce costs.

The proposed work could consider the atmospheric pollution input to make the model more realistic. The energy storage could be implemented via a battery to study the microgrid in an islanded. Also, the smarter load management will be developed. This will be the subject of a future work.

REFERENCES

1. J. Lagorse, M. G. Simões, and A. Miraoui, "A Multiagent Fuzzy-Logic-Based Energy Management of Hybrid Systems", IEEE Trans Industry Applications, Vol. 45, No. 6, pp: 2123-2129, Dec 2009.
2. S. D. J. McArthur, E. M. Davidson, V. M. Catterson, A. L. Dimeas, N. D. Hatziargyriou, and F. Ponci, "Multi-agent systems for power engineering applications—Part I: Concepts, approaches, and technical challenges," *IEEE Trans. Power Syst.*, vol. 22, no. 4, pp. 1743–1752, Nov. 2007.
3. S. D. J. McArthur, E. M. Davidson, V. M. Catterson, A. L. Dimeas, N. D. Hatziargyriou, and F. Ponci, "Multi-agent systems for power engineering applications—Part II: Technologies, standards, and tools for building multi-agent systems," *IEEE Trans. Power Syst.*, vol. 22, no. 4, pp. 1753–1759, Nov. 2007.
4. A. L. Dimeas and N. D. Hatziargyriou, "Operation of a multiagent system for microgrid control," *IEEE Trans. Power Syst.*, vol. 20, no. 3, pp. 1447– 1455, Aug. 2005.
5. H.S.V.S. Kumar Nunna, S.Doolla," "Energy management in microgrids using demand response and distributed storage-A multiagent approach", Power Delivery, IEEE Transactions on, vol: 28, no: 2, pp: 939-947, April 2013.
6. J. Quanyuan, X. Meidong, G.Guangchao, "Energy management of microgrid in grid-connected and stand-alone modes", *Power Systems, IEEE Transactions on,* vol: 28, no: 3, pp:3380-3389, Aug. 2013.
7. H-L. Tsai, C-S. Tu, and Y-J. Su, "Development of Generalized Photovoltaic Model Using MATLAB/SIMULINK, Proceedings of the World Congress on Engineering and Computer Science, WCECS 2008, Oct 22 - 24, 2008, San Francisco, USA.
8. Electrical Systems by S.N Bhadra, D.Kastha, S Banerjee, Edition Oxford, Published 2005.
9. Wind Power in Power Systems, Edited by Thomas Ackermann, 2005.

ABOUT THE AUTHORS

Lydie Roiné was born in Pertuis, France. She received the M.S degree in electrical engineering from ESIGELEC, in Rouen, France, in 2013 and currently working for a European company in the power systems domain.
Her research interests include energy management, microgrid and fuzzy logic.

Kambiz Tehrani was born in Tehran, Iran, in 1978. He received his B.S. degree in Electrical Engineering from Arak University, Iran, in 2002. He received his M.S. and Ph.D. degrees from the University of Nancy (INPL), Nancy, France, in 2006 and 2010, respectively. He is currently an associate professor in Power Electronics Systems at ESIGELEC in Rouen, France. His research interests include power electronics, energy system optimization, control systems and multilevel inverters. He serves as a reviewer for the IEEE Transactions on Industrial Electronics. He is an associate editor for the Autosoft journal.

Y. S. Manjili (Student Member, IEEE; Member, Iranian Inventors Association) received BS in Bioelectrics from Amirkabir University of Tech. (AUT) in 2004, MS in Control from Petroleum University of Tech. (PUT) in 2007, and PhD in electrical engineering-systems and control from the University of Texas at San Antonio (UTSA), San Antonio, TXz, USA in 2014. He is the co-owner intellectual property, a provisional patent and has (co-)authored over 15 academic and technical publications in peer-reviewed journals, conferences and book chapters. His research interests include control systems and renewable energy technologies.

Mo M. Jamshidi (Fellow IEEE, Fellow ASME, A. Fellow-AIAA, Fellow AAAS, Fellow TWAS, Fellow NYAS, Member HAE) received BS in EE, Oregon State University, Corvallis, OR, USA in June 1967, the MS and Ph.D. degrees in EE from the University of Illinois at Urbana-Champaign, IL, USA in June 1969, and February 1971, respectively. He holds honorary doctorate degree from University of Waterloo, Canada, 2004, Technical University of Crete, Greece, 2004 and Odlar Yourdu University, Baku, Azerbaijan, 1999. Currently, he is the Lutcher Brown Endowed Distinguished Chaired Professor at the University of Texas, San Antonio, TX, USA. He has been an advisor to NASA (including 1st MARS Mission), USAF Research Laboratory, USDOE and EC/EU (Brussels). He has advised over 65 MS and 55 PhD students. He has also directly or indirectly through funded research helped 120 America's minority graduate students. He has over 730 technical publications including 68 books (11 text books, see www.wacong.org/freepublicationsbymojamshidid)), research volumes, and edited volumes in English and 7 foreign languages. He is the Founding Editor or co-founding editor or Editor-in-Chief of 5 journals including *IEEE Control Systems Magazine* and the *IEEE Systems Journal*. He is an Honorary or Visiting Professor at Deakin University (Australia), Birmingham University (UK), Obuda University (Hungary), Loughbrough University (UK) and at three Chinese Universities (East Normal, Nanjing and Xi'an, China). He has received numerous honors and awards, including IEEE Centennial Medal, IEEE Millennium Awards, and the IEEE's Norbert Weiner Research Achievement Award, the 2014 IEEE-USA Systems Engineering Career Award, and 2014 WAC Medal of Honor, among others. He is a member of the University of the Texas System Chancellor's Council since 2011. He is currently involved in research on system of systems control engineering with emphasis on cloud computing, robotics, autonomous vehicles, and sustainable energy systems, including smart grids and big data analytic.