INTERNATIONAL JOURNAL OF
INNOVATIVE RESEARCH & DEVELOPMENT

ISSN: 2278 – 0211 (Online)

Permanent Magnet Synchronous Generator Voltage Control Using Fuzzy Logic Controller

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Abstract:

This paper presents a system in which a wind Permanent Magnet Synchronous Generator feeds an isolated load through a Boost Converter. The output voltage and frequency of the PMSG is variable in nature due to non uniform wind velocities. The fluctuating output is rectified and kept constant by means of a boost converter. A fuzzy logic controller is designed to set the duty ratio of the boost converter is varied to maintain a constant DC output voltage. Also to choose the moment to charge/discharge the battery and the moment to dissipate excess energy in a resistance.This converter output is converted to three phase ac using a three phase PWM inverter, which employs hysteresis current control to control the output voltage The power converters together with independent control systems can effectively improve the output voltage and frequency of the wind PMSG feeding an isolated load. The model has been demonstrated using MATLAB Simulink based simulations.

Key words: *Battery,Boost Converter,Fuzzy logic control, Hysteresis current control , Permanent Magnet synchronous Generator*

1.Introduction

Under the pressure of limited available renewable energy resources and environmental policies ,electrical power using renewable energy has rapidly increased in recent years[1]In India, a large number of remote rural or mountainous inhabitants have no access to the main electricity supply network so it is important to explore the local natural renewable energy resources such as wind or solar [2] for power generation, mainly for local consumptions. Due to the nature of intermittence of renewable energy, the use of the secondary energy storage such as batteries become inevitable which will compensate the fluctuations of power generation [3]. The use of a small size wind turbines could enable more households to have accesses to electricity.

A permanent magnet synchronous generator (PMSG) based variable speed wind turbine has received much attention in a standalone mode because of its simplicity, less maintenance, leading to a higher power factor and high efficiency[4].The wind turbine alone can not meet the load demand due to its nature. Some additional sources and sinks are in order to balance the the fluctuating nature of the wind.Different and local bodi es are connected at ACbus.which can operate in both grid and off-grid conditions, is formally called AC microgrid[5] the rapid development of renewable energy and power electronics technology, costreduction in energy storage and wider applications of microgridsystem, different control strategies and energy management systems have been proposed for wind integration [4]. Normally,microgrid is intentionally operated in off-grid mode in rural areas where the availability of grid is impossible due to technical, geographical and social reasons [5].

In this kind ofmicrogrid, diesel generator is the common controlled source.However, the off grid microgrid can be also used in urban areas to reduce the load stress and power congestion in weak grid and large demand power systems. Especially, in developing countries, where the load-shedding occurs due to extreme weathers, societal involvement and limited resources with increasing demand [6]. Similarly, in developed countries, the high penetration of unequal distribution of electric vehicle (EV) has created lots of challenges to the grid and ultimately affects the rating of the components and the peak load of the existing grid [7]. This problem can be reduced by charging EV independent of the grid. Therefore, the scattered microgrid forming with some renewable energy like wind, energy storage, dump loads and loads can be used in these urban areas to solely provide power to residential or commercial areas in the vicinity of grid.

The control of an inverter to present the customers with the balanced supply voltage is the main challenge in the stand-alone system. Moreover, voltage variations ,flickers, harmonic generation, and load unbalance are the major power quality problems that are occur in the wind energy conversion system. The voltage fluctuations are primarily caused by variations in the power from WECS due to the fluctuations to the wind speed. Unwanted harmonics are generated due to the power electronic interface (rectifier, inverter and dc-dc converter) between the wind generator and load. Those power quality problems may not be tolerated by the customers and require controllers. Unbalanced load will create pulsation in generator torque which will reduce the life of the turbine shaft. To meet the amplitude and frequency requirements of conventional loads ,the amplitude and frequency output of PMSG requires additional conditioning.Few papers have been published on maintaining DCL voltagein a standalone PMSG based VSWT [9-12]. Recently, M. Dali worked on the duty cycle of a boostconverter, managed in the same time the MPPT control and the load voltage by using a PI controller for currentand voltage [4].

Although conventional PI controller have been well developed and applied for industrial automation and process control due to their simplicity of operation, ease of design and effectiveness for most linear systems, it generally does not work well for nonlinear systems, higher order and time-delayed linear systems, and particularly complex and vague systems that have no precise mathematical models [7]. To overcome these difficulties, various types of controllers using artificial intelligent such as fuzzy logic, genetic algorithm... were developed lately [8].

In this paper, we propose a wind energy conversion system for remote site using a variable speed PMSG, a battery bank and a fuzzy controller to optimize the operation of both the wind turbine and the battery according to wind speed and load demand. we use fuzzy controller to set the duty ratio of the second boost converter (DC/DC) in order to

- adjust the DCoutput voltage,
- to choose the moment to charge/discharge the battery and
- the moment to dissipate excess energy in a dumb resistance.

2.Wind Energy Conversion System

Wind turbines converts aerodynamic power into electrical energy. In a wind turbine two conversion processes takes place. First the aerodynamic power (available in the wind) is converted into mechanical power. Next the mechanical power is converted into electrical power.

The conversion of the wind power to mechanical power by the wind turbine rotor can be simulated by the static relation:

$P_W = 0.5 A C_p A V_W{}^3$…… ………………(1)

The rotor mechanical torque can be calculated from P_w by

$T_W = \frac{P_W}{\omega_R}$ ……….. (2)

The rotor aerodynamic power coefficient, C_p, is the percentage of the kinetic energy of the incident air mass that is converted to mechanical energy by the rotor, and it is expressed as a function

$C_p = C_p\ (\lambda,\beta)$ ………………. (3)

where β is the blade pitch angle and λ the tip speed ratio of the blade, and defined as

$\lambda = \frac{R\omega_R}{V_w}$…………………………………(.4)

Using the above relations and the rotor $C_p(\lambda)$ characteristic, the rotor aerodynamic torque and power curves can be calculated.

Basically, the mass model of a PMSG is the same as that of a permanent magnet synchronous motor (PMSM). The voltage and torque equations the PMSM in the d-q reference frames are given by the following equations

$v_d = (R_a + PL_d)i_d - \omega_e L_q i_q$……….(5)

$v_q = \omega_e L_d i_d + (R_a + PL_q)i_q - \omega_e K$…….(6)

$T_e = K\{i_q + (L_d - L_q)\ i_d i_q\}$………… .(7)

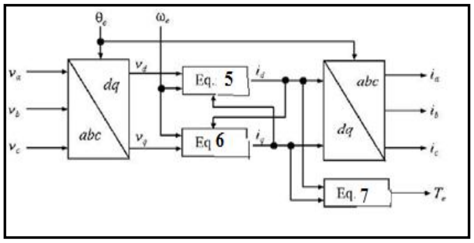


Figure 1: Model of drive train

Where

vd and vq are dq-axis voltage,

id and iq are dq-axiscurrent,

Ra is stator resistance,

Ld and Lq are dq-axis inductance,

ωe is electrical rotational speed, K is permanent magnetic flux, and P is differential operator.

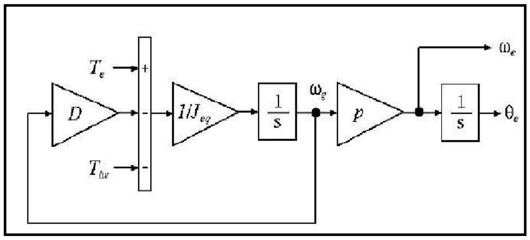


Figure 2: Model of PMSG

Generating operation starts when the electromagnetic torque *Te* is negative.

In addition, the motion equation of the PMSG is given by the following equation:

$T_e = J_{eq}\frac{dw_g}{dt} + D\omega_{g+T_{lw}}$……………………(8)

whereJ_{eq} is the equivalent inertia & ωg is the rotational speed.

3.System Description

The block diagram of the proposed system is shown in Fig. 3.

Our system consists of a PMSG (12 KW) to power a 2kW pump, a 3kW induction machine, a 4kW water heater, and a lead acid battery for backup storage. A diode bridge rectifier and a boost converter are used for MPPT purpose and for electrical production management

A fuzzy logic controller (FLC) is designed to adjust the DC voltage to a value suitable for battery charging and also suitable for the proper operation of the PWM inverter. If wind conditions are favorable, the wind turbine will be the main supplier for load. If the wind does not give enough power to load, and the battery capacity is sufficient, the battery will start to provide the necessary power..

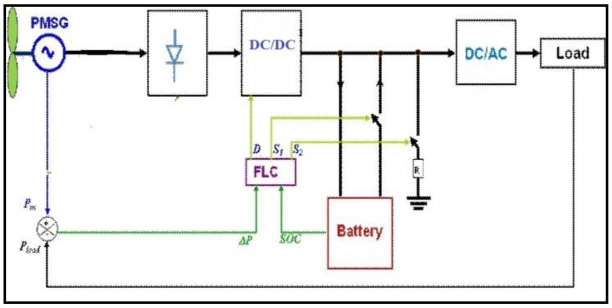


Figure 3: Block diagram

If the power of the wind turbine exceeds the load demand, the surplus is stored in the battery and if the battery is full, the surplus will be dissipated in a resistor. Thus, the battery is not the main supplier, so that the number of charge/discharge rate is reduced, and consequently the life of the battery is extended.

For this, we need two informations: the battery state-ofcharge(SOC) and the error between available wind

power and load demand (DeltaP). The controller will decide the value of the duty cycle (D), the moment to switch the battery (S1) and the moment to dissipate the excess in the resistor (S2).

3.1.Fuzzy Controller For The Production Process

Inputs for this controller are the battery state of charge (SOC) and the error power DeltaP (difference between wind power and load power). The outputs are the duty ratio D2 applied to the second boost converter for charging the battery (ensuring a safe and effective) and ensure that the input voltage is sufficient for the PWM inverter, the time to charge/discharge the battery and the time to dispel the surplus to a discharge resistor.

The linguistic term sets used for:

Power error DeltaP [Negative, Small Positive, Positive, Very Positive].

Battery's state-of-charge SOC [Empty, Average,Full].

Duty cycle D [Very Small, Small, Medium,Big, Very Big].

Switch S1 and S2 [Opened, Closed].

The method of inference rules is also the min-max inference and the implementation of the rules was based on fuzzy rules of Mamdani type [17]. Example: "If the error between wind power and load demand is Positive and battery state-of-charge is Full, then, switch 1 should be Opened and switch 2 should be Closed".

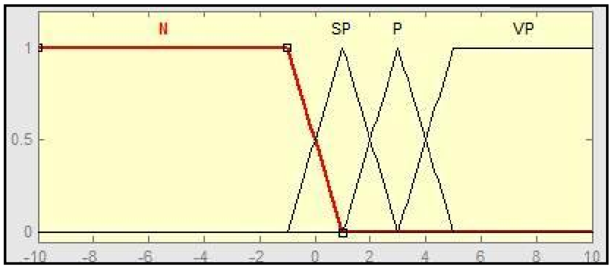


Figure 4: Four terms of variable "DeltaP"

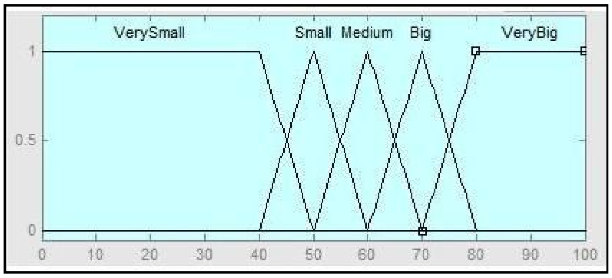


Figure 5: Five terms of variable D

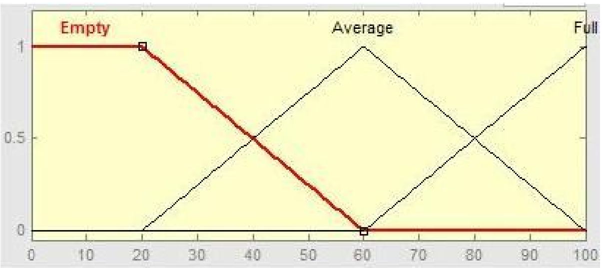


Figure 6: Three terms of variable "SOC"

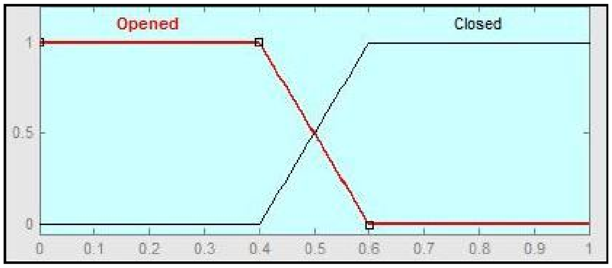


Figure 7: Two terms of variable "S1" and "S2 The fuzzy rules used in our FLC 2 are summarized intable 1,2 and 3

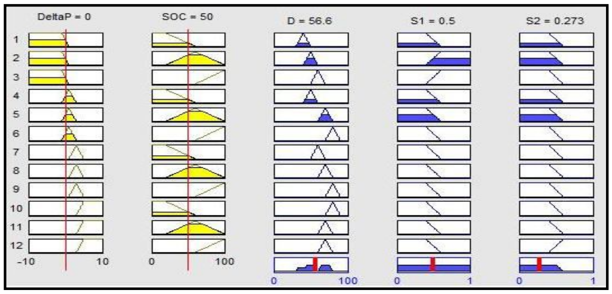
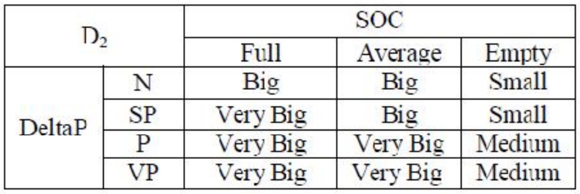
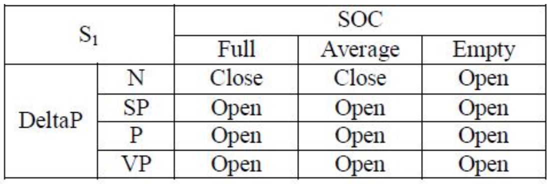


Figure 8: Defuzzification in case DeltaP=0 and SOC=50%



D_2		SOC		
		Full	Average	Empty
DeltaP	N	Big	Big	Small
	SP	Very Big	Big	Small
	P	Very Big	Very Big	Medium
	VP	Very Big	Very Big	Medium

Table 1: Rules of D



S_1		SOC		
		Full	Average	Empty
DeltaP	N	Close	Close	Open
	SP	Open	Open	Open
	P	Open	Open	Open
	VP	Open	Open	Open

Table 2: Rules of S1

S_2		SOC		
		Full	Average	Empty
DeltaP	N	Open	Open	Open
	SP	Open	Open	Open
	P	Open	Open	Open
	VP	Close	Open	Open

Table 3: Rules of S2

The overall fuzzy subset representing output control variable is defuzzified using centre of gravity method

$$\mu_C = \frac{\sum_i \mu_C(x_i).x_i}{\sum_i \mu_C(x_i)}$$

Where *xi* is a point in the universe U of the conclusion (*i* = 1, 2…), and *μc(xi)* its membership of the resulting conclusion set.

3.2.Hysteresis Based Current Controller

Hysteresis based current controller is implemented in the current control scheme. The reference current is generated as in and the actual current is detected by current sensors that are subtracted for obtaining current errors for a hysteresis based controller. The ON/OFF switching signals for IGBT of inverter are derived from hysteresis controller.

When the actual (measured) current is higher than the reference current, it is necessary to commutate the corresponding switch to get negative inverter output voltage.

This output voltage decreases the output current and reaches the reference current. On the other hand, if the measured current is less than the reference current, the switch commutated to obtain a positive inverter output voltage. Thus the output current increases and it goes to the reference current. As a result, the output current will be within a band around the reference one.

$$i_{sa} > (i^*_{sa} + HB) \rightarrow S_A = 1$$

$$i_{sa} < (i^*_{sa} - HB) \rightarrow S_A = 0$$

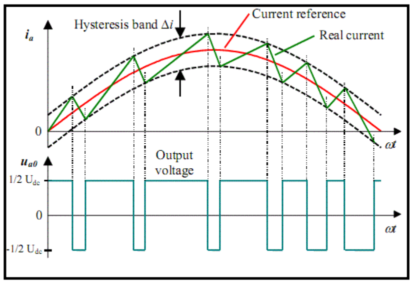


Figure 9: Control Strategy for Inverter

The advantages of this technique are high simplicity, good accuracy, outstanding robustness and a response speed limited only by switching speed and load time constant.

4.Simulation Result

The proposed model is simulated using MATLAB7.14 and the simulation model is shown in Fig. 10.

Suppose that the battery state-of-charge is 95% (Full), in this case we can verify the dissipation of surplus power to prevent the battery from gassing (operation of switch 2). First the water heater and pump function (request for a total load of 6 kW). After 4 seconds the machine is started (total load 9kW) and 8 seconds later, the heater is disconnected (total load 5kW). The wind speed decreases from 9m/s to 8m/s at the 8th second, then increases to 10m/s at the 16th second (Fig. 11, 12)..

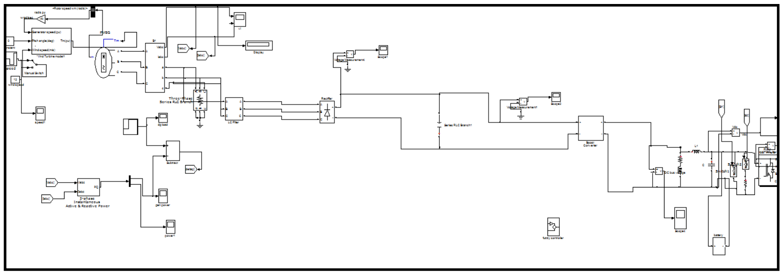


Figure 10 : MATLAB/Simulink Simulation model

In the first four seconds, the load is 6kW. The wind speed is 9m/s, while the error power DeltaP = 0.7kW (Small Positive), so S1 is opened (S1 = 0). D is 74% which causes a voltage of 715VDC at the output of the boost converter, then the battery is charged.

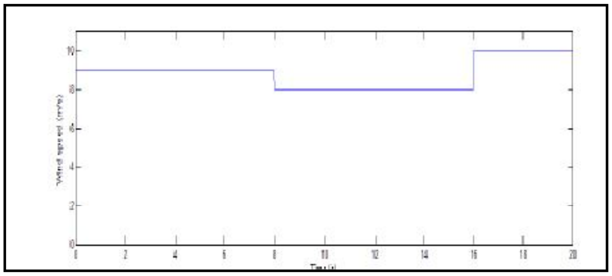


Figure 11: Wind speed (m/s)

the next four seconds, the induction machine operates, load demand now is 9kW, DeltaP is -2.2kW (Negative) then the battery is activated by the closure of S1 (S1 = 1) to give necessary power to load.

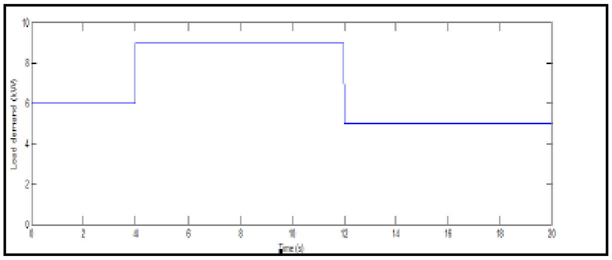


Figure 12: Load demand (kW)

We use both fuzzy and PI controllers to compare the resultsbetween these two controllers.

After 8 seconds, wind speed decreases to 8m/s, in which Wind turbine power decreases to 5.2kW while the power required by the load is still 9kW, then the battery gives more power to load.

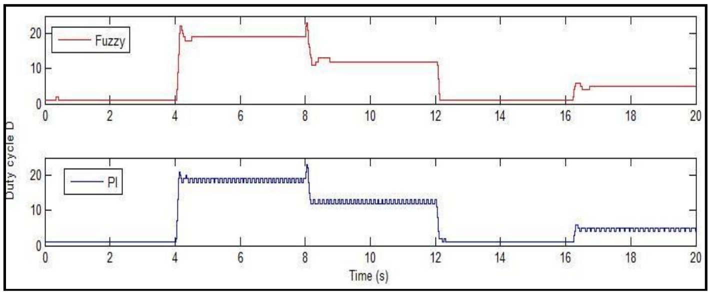


Figure 13: Duty cycle of the boost converter D(%)

we can see that fuzzy controller is more stable while PI controller has more ripple (noise). Moreover, with the PI controller, we have to choose a suitable value of kp, ki when system parameters change, while fuzzy controller works wellwith all system parameters.

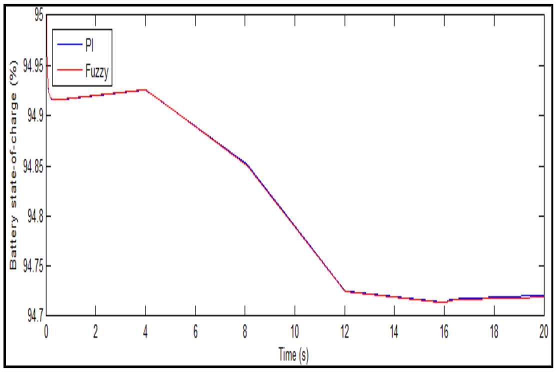


Figure 14: Battery state-of-charge SOC (%)

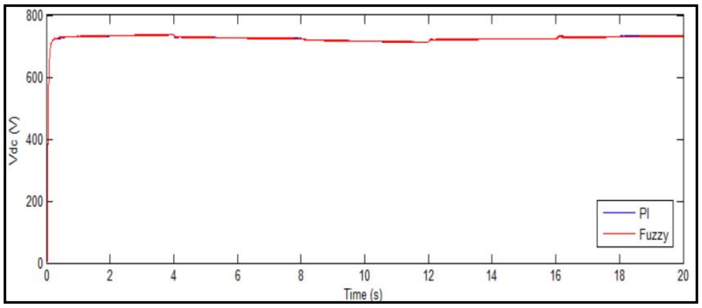


Figure 15: DC voltage input of PWM inverter (V)

In the load side, the voltage input to the PWM inverter is maintained at a suitable value (Fig. 15), thus the quality of the charging voltage is maintained correctly in any wind conditions (Fig. 16).

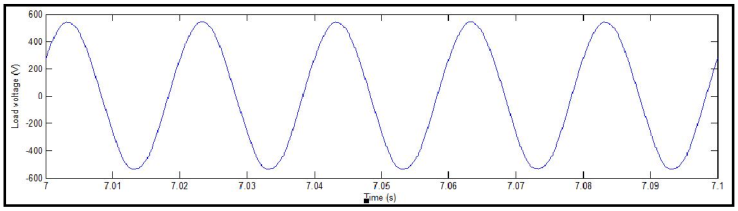


Figure 16: Load line voltage (V)

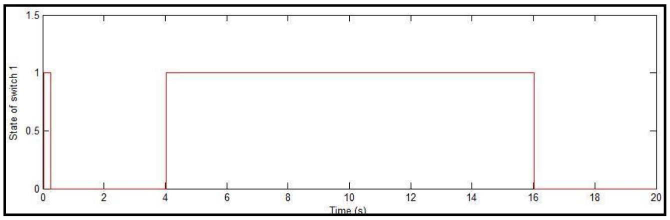


Figure 17: State of switch S1

From 12th to 16th second, the water heater stop, the load is reduced to 5kW,DeltaP remains Negative (-0.2kW), so S1 is still closed.

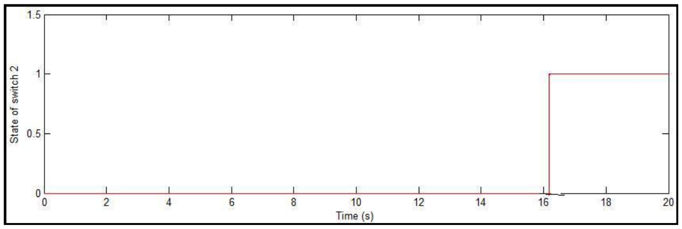


Figure 18: State of switch S2

The last four seconds, the wind speed is increased to 10m/s, so the wind gives a maximum power of 9.7kW. So DeltaP is 4.2kW (Very Positive) while the battery is fully charged (SOC = 94.7%), keep on charging may cause gassing phenomenon, thus S2 is closed to dissipate the surplus to a discharge resistor.

These simulations show that our proposed controller has good results. It assured the load demand, despite the wind conditions with good strength and quality of the battery with the charging process of the battery to prevent a release of hydrogen and oxygen and/or sulfating.

5.Conclusion.

This paper presents the control system using fuzzy logic for the distribution of electricity for stand-alone system. With information about load demand, battery state-of-charge and simple rules of fuzzy logic, control signals were generated for a maximum power recovered from the wind in respect of load demand, and can extend battery life.

The simulation results show good behavior of our controllers to achieve these objectives.

As perspective, we will develop this system by adding an additional source (solar, fuel cell) and optimize the distribution of energy for remote sites.

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