Control and Fuzzy Logic Supervision of a Wind Power System With Battery/Supercapacitor Hybrid Energy Storage

Youssef KRIM

Dhaker ABBES

Saber KRIM

Mohamed Faouzi MIMOUNI

Ecole Nationale
d'ingénieurs de Monastir

HEI
INGÉNIEURS
POUR LE MONDE

yncréa

L2EP
Laboratoire d'électrotechnique et
d'électronique de puissance de Lille

- **INTRODUCTION**

- **DESCRIPTION OF STUDIED SYSTEM**

- **MODELING AND CONTROL OF WIND DISTRIBUTED GENERATOR**

- **FUZZY LOGIC POWER MANAGEMENT SUPERVISOR**

- **CASE STUDY AND SIMULATION RESULTS**

- **CONCLUSION**

- Wind technology has become a favored form of the renewable energy technology because it is seen as sustainable and clean.

- However, wind fluctuation may cause excessive variations of the output voltage, power and frequency.

- Storage systems such as batteries have been used to design active generators, able to provide an energy reserve with less fluctuating power.
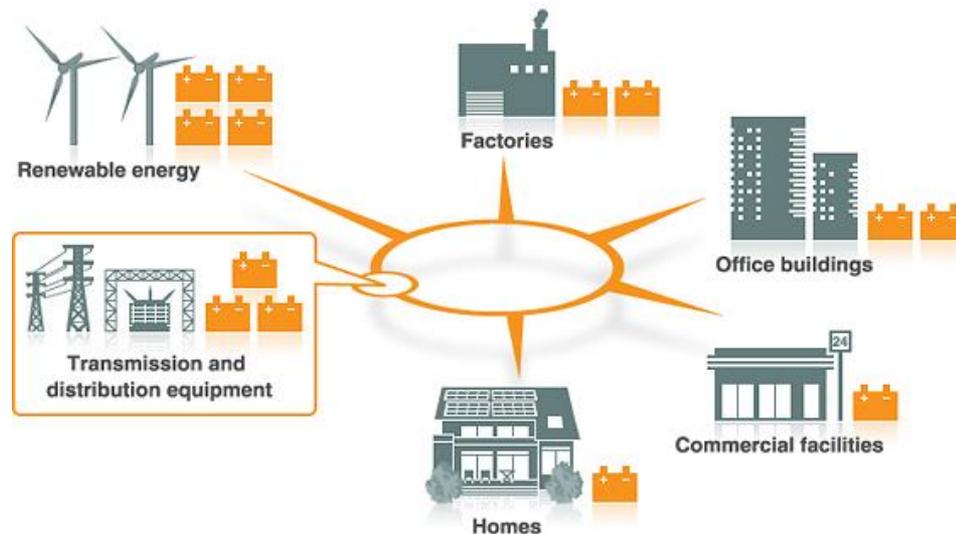
■ Modern batteries provide high discharging efficiency and higher energy storage density, but they suffer from a relatively low power density.

■ Supercapacitors (SCs) have low internal resistance and are well suited for short-term storage systems.

Source US Defence Logistics Agency

▪ **In this context, a fuzzy logic-based algorithm is proposed to ensure energy management and distribution between batteries and SCs respecting their State Of Charge (SOC) levels.**

▪ **Fuzzy logic supervisor (FLS) does not require complex mathematical models.**
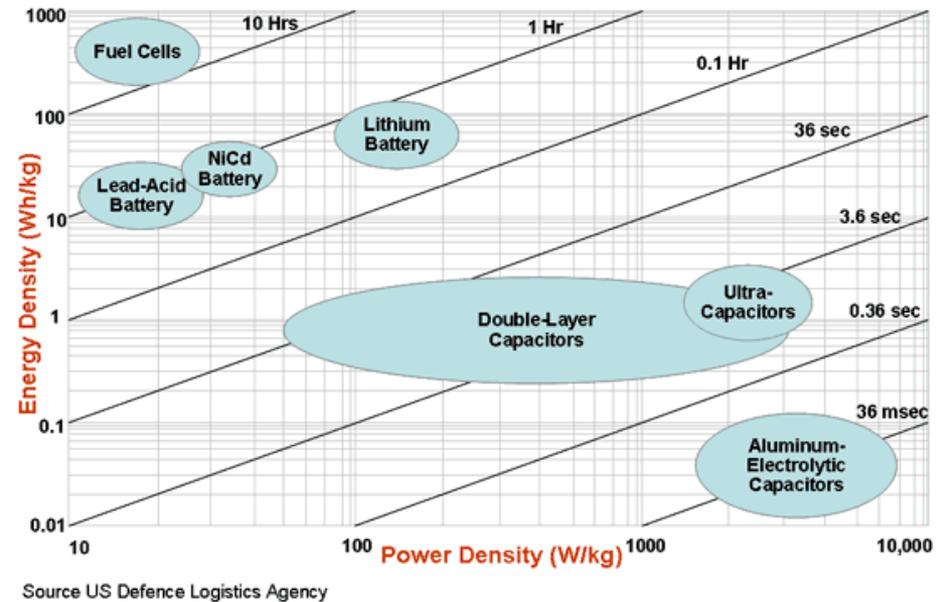
Architecture

Following figure presents a synopsis of the considered Renewable Distributed Generation (RDG) system. It is composed by a wind power system associated with BT/SC HES. This RDG is connected with variable loads and to a fluctuating grid.
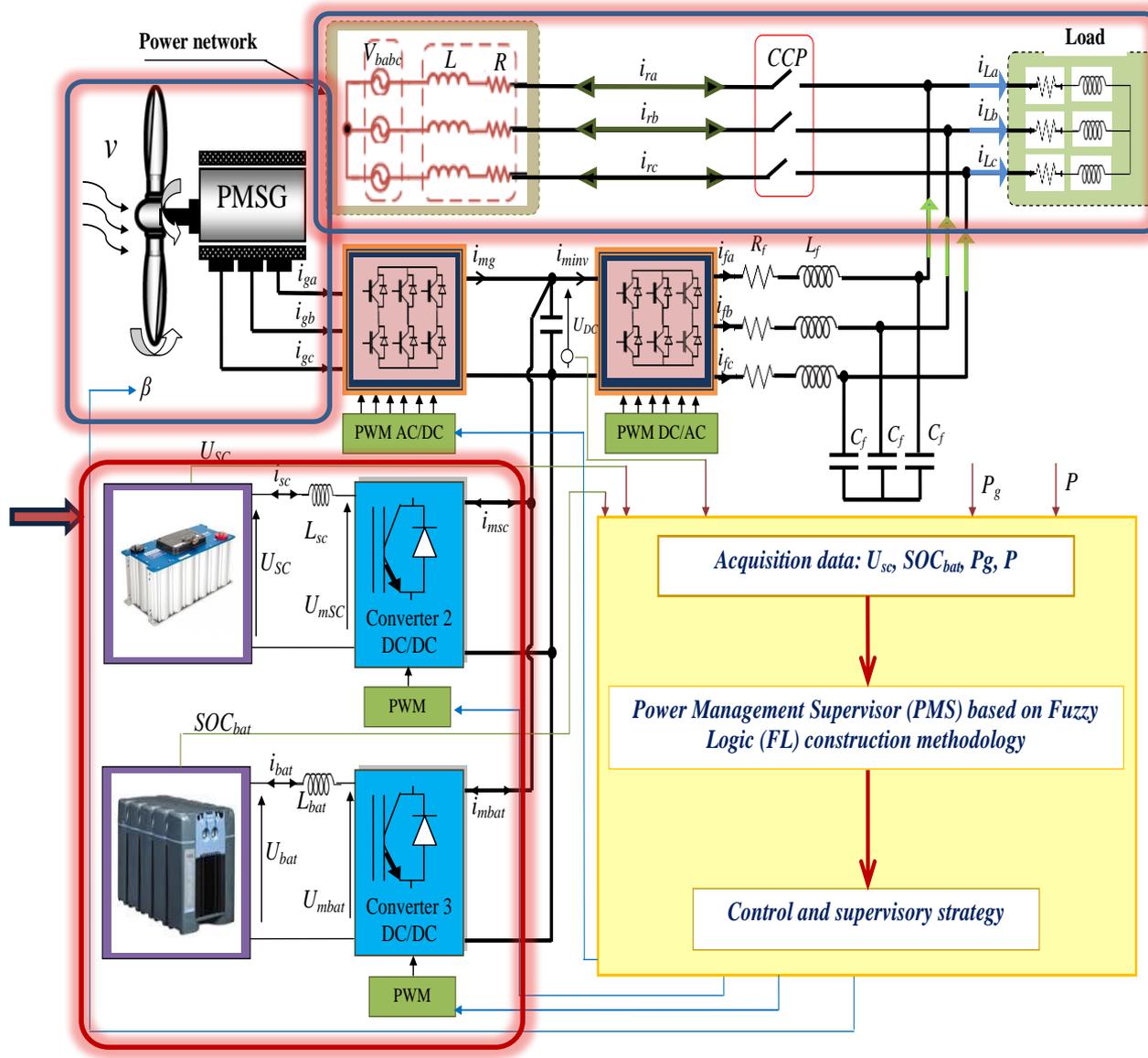
Wind turbine modeling and control

The aerodynamic power (P_w) that can be extracted from the wind and the aerodynamic torque Γw are determined by the following expressions:

$$P_w = \frac{1}{2}\rho\pi R^2 V_w{}^3 C_p(\lambda,\beta)$$

$$\Gamma_w = \frac{P_w}{\Omega_m} = \frac{1}{2}\rho\pi R^3 V_w{}^2 C_p(\lambda,\beta)/\lambda$$

Where Cp(λ,β) is the power coefficient given by (1) corresponding to the aerodynamic performance of the turbine:

$$C_p(\lambda,\beta) = 0.5179\left(98\delta - 0.4\beta + 5\right)e^{-21\delta} + 0.068\lambda$$

$$\delta = \cfrac{1}{\cfrac{1}{\lambda+0.089} - \cfrac{0.035}{\beta^3+1}} \qquad (1)$$

Ecole Nationale
d'ingénieurs de Monastir

HEI
INGÉNIEURS
POUR LE MONDE

yncréa

L2EP
Laboratoire d'électrotechnique et
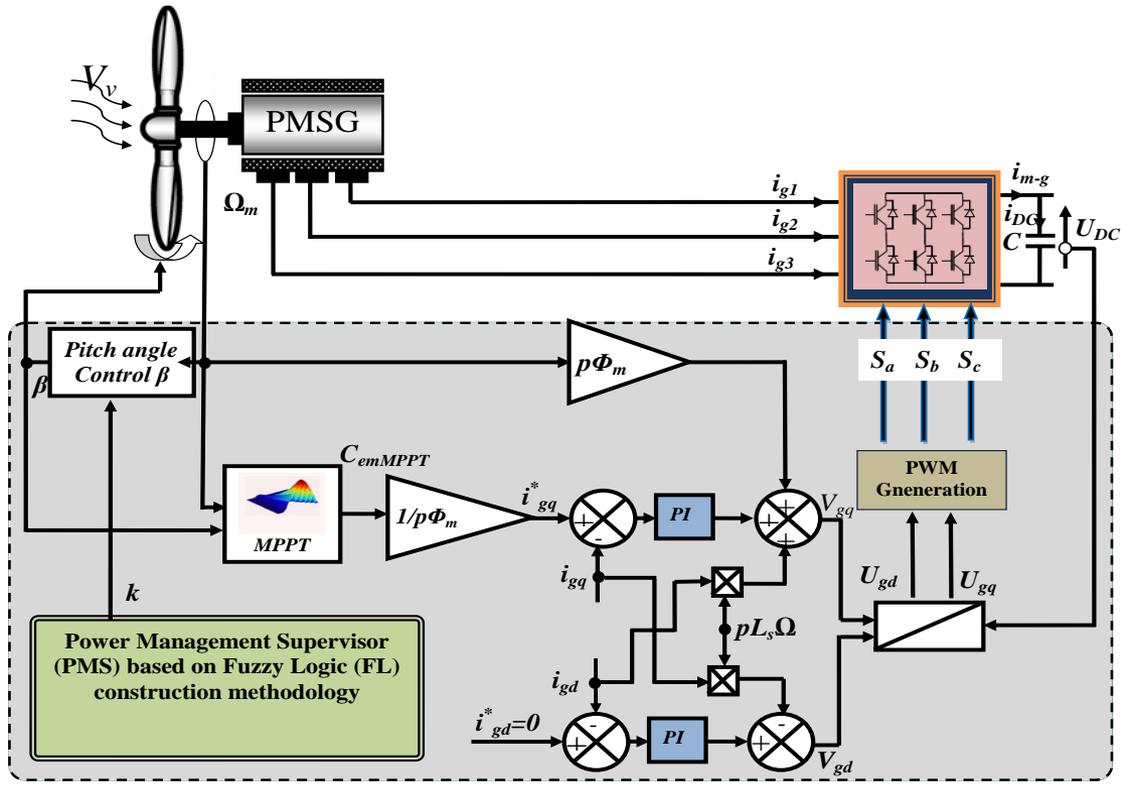d'électronique de puissance de Lille

Wind turbine modeling and control

▪ Following figure shows the control strategy of the wind generator. This strategy is based on the vector control applied to PMSG to extract maximum power. The principle of this control is to impose a direct current reference i^*_{gd} equal to zero and a quadrature current reference i^*_{gq} proportional to electromagnetic torque reference given by the MPPT algorithm as follows:

$$\begin{cases} i^*_{gd} = 0 \\ \\ i^*_{gq} = \dfrac{T_{em_{MPPT}}}{p\phi_m} \end{cases}$$

▪Electromagnetic torque reference "T_{emMPPT}" is determined by the MPPT strategy as follows:

$$T_{em_{MPPT}} = \frac{1}{2} \frac{\rho C_{p\max} R^5 \Omega^2_m}{\lambda_{opt}^{3}}$$

Ecole Nationale
d'ingénieurs de Monastir

HEI
INGÉNIEURS
POUR LE MONDE

yncréa

L2EP
Laboratoire d'électrotechnique et
d'électronique de puissance de Lille

Control of the pitch angle

▪ When HES reaches its maximum SOC ''U_{sc-max}, $SOC_{bat-max}$'' and there is overproduction from wind generator, the voltage of SC and the SOC of the BT have not to exceed its maximum limit ''U_{sc-max} and $SOC_{bat-max}$''. In this situation, the wind turbine operates without MPPT to produce the amount of power needed to supply the load and share in the system services. This limitation is done by the pitch angle β as follows:

$$\beta_{ref} = \frac{\Delta \beta}{\Delta P}\left(P_g - P_L - P_{inj}\right) \; if \; k_d = 1$$

where k_d is the degradation factor deduced by FL PMS.
• In addition, the pitch angle β is used to limit the rotational speed to avoid the damage of the turbine and the electric machine.

HES modeling and control

Considered model of the battery is constituted by a voltage source in series E_{bat} with an internal resistance R_i as follows, where E_{bat} is expressed as a function of the (SOC) of the battery and n the number of cells which makes up the battery.

$$\begin{cases} V_{bat} = E_{bat} \pm R_i i_{bat} \\ E_{bat} = n\left(2.15 - SOC\left(2.15 - 2\right)\right); \ SOC = 1 - \dfrac{Q_d}{C_{bat}} \end{cases}$$

The capacity C_{bat} is defined as a function of temperature.

$$\frac{C_{bat}}{C_{10}} = \frac{1.67}{1 + 0.67\left(\dfrac{i_{bat}}{I_{10}}\right)^{0.9}}\left(1 + 0.005 \Delta T\right)$$

HES modeling and control

To improve the performance of the BT storage system, other storage organs such as a supercapacitors module is introduced. A realistic modeling of a super-capacitor is composed of a series capacitance C_{ssc} with a resistance R_{ssc}. Therefore, the total resistance R_{sc} and capacitance C_{sc} of the used supercapacitors module can be defined by the following expressions:

$$\begin{cases} C_{sc} = \dfrac{N_p}{N_c} C_{ssc} \\[4mm] R_{sc} = \dfrac{N_c}{N_p} R_{ssc} \end{cases}$$

where N_s and N_p are the number of super-capacitor units placed respectively in series and in parallel.

HES modeling and control

▪The control of each storage system is done by the control of the DC / DC converters.

▪A PI regulator is used to maintain the charge or discharge current of battery bank equivalent to its reference $i_{bat-ref}$. This reference is deduced by the PMS:

$$U_{mbat} = U_{bat} - PI\left(i_{bat-ref} - i_{bat}\right)$$

▪In order to fix the direction of charging or discharging current of the BT, the BT converter is controlled by this duty ratio as follows:

$$m_{bat} = U_{mbat}/U_{DC}$$

▪Same principle as the battery control, a PI controller is used to adjust the charge and discharge current i_{sc} of SC with the reference value $i_{sc-ref.}$ Subsequently, the SC converter is controlled by this duty ratio as follows:

$$\begin{cases} U_{msc} = U_{sc} - PI\left(i_{sc-ref} - i_{sc}\right) \\ m_{sc} = U_{msc}/U_{DC} \end{cases}$$

HES modeling and control

The control of the hybrid storage system is schematized by the following figure:
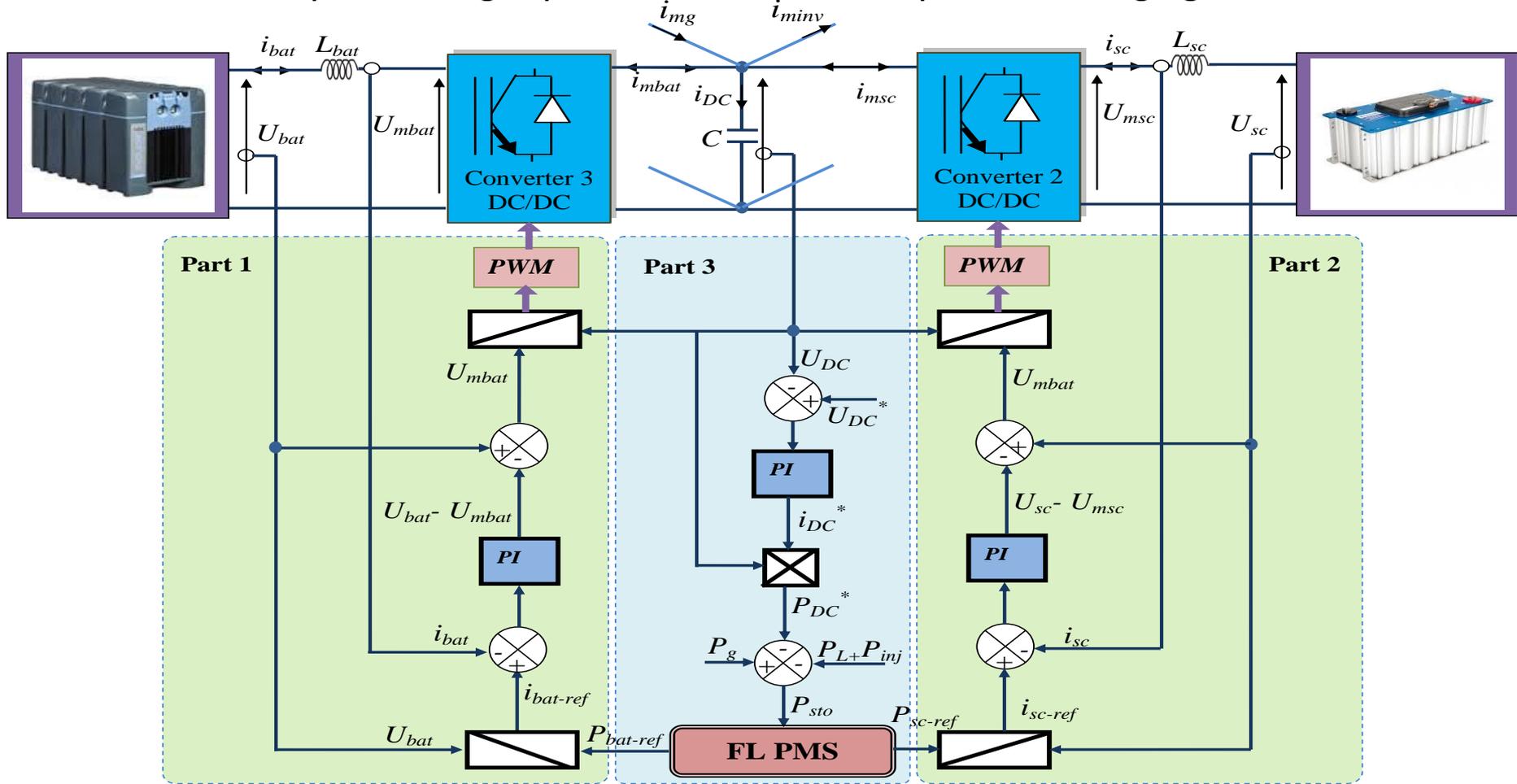
FLS developed in this study includes three inputs and three outputs :

❖ The inputs are the difference between the produced and demanded power "$P_{sto}=\Delta P$", the SOC of batteries (SOC_{bat}), and the voltage of the SC (U_{sc}).

❖ The outputs are the reference power of batteries "$P_{bat-ref}$", the reference power of SCs "P_{sc-ref}", and the degradation factor to limit de wind production k_d. Using the data available from these three inputs, the FLC determines the command for the regulation of the DC bus according to the different production scenarios.

The objectives of energy management are detailed as follows:

❑ To return a smoothed power to the grid to ensure its stability

❑ To deliver a continuous power corresponding to the load consumption.

❑ To ensure storage availability, i.e. to ensure that it does not reach its upper and lower limits.

❑ To keep stable the DC bus voltage.

Supervisor Structure

FL power management supervisor structure is summarized in the following figure:
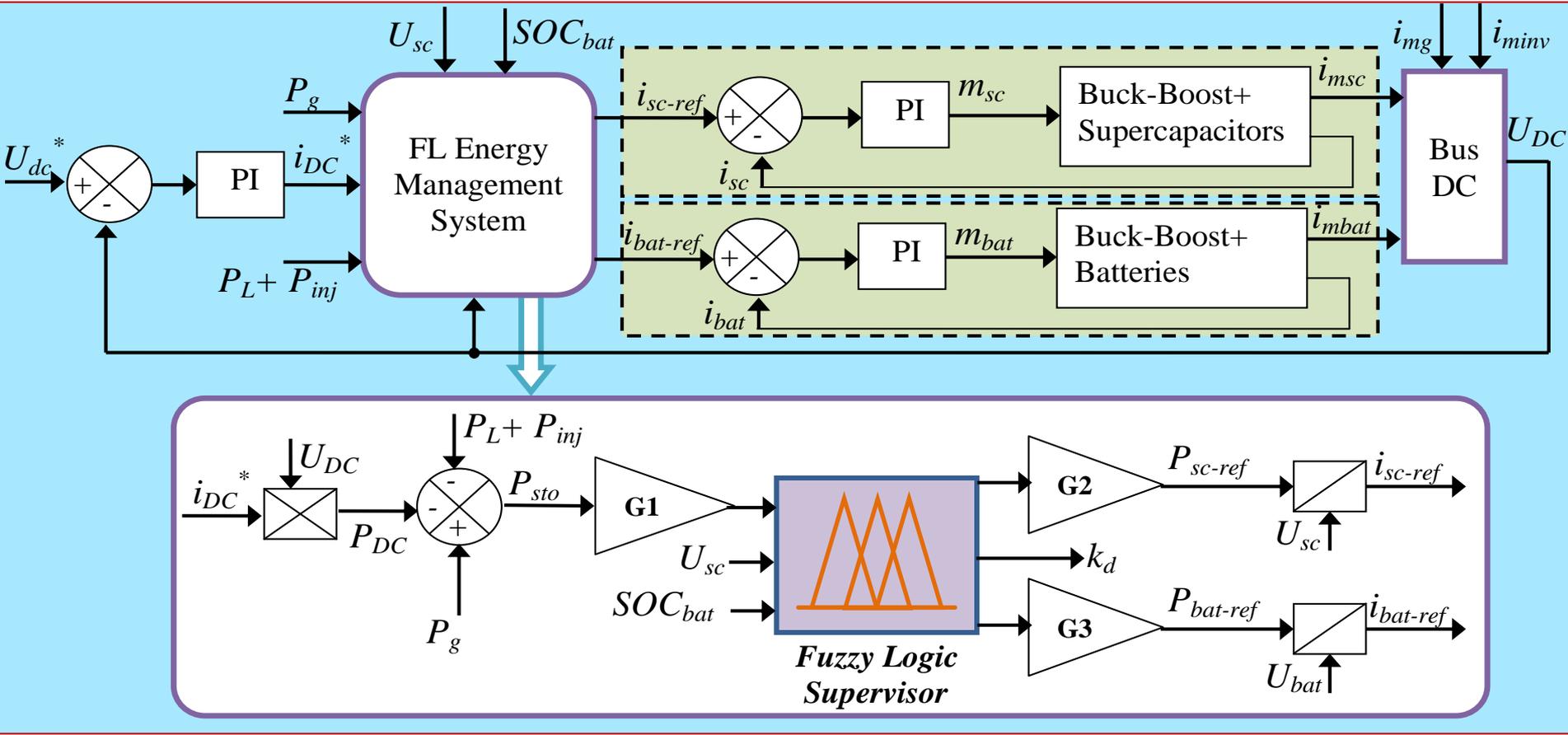
Membership functions

Determination of the membership functions for fuzzification of the input and output variable of the energy supervisor is an important phase of the fuzzy algorithm. These functions are depicted by these following figures.
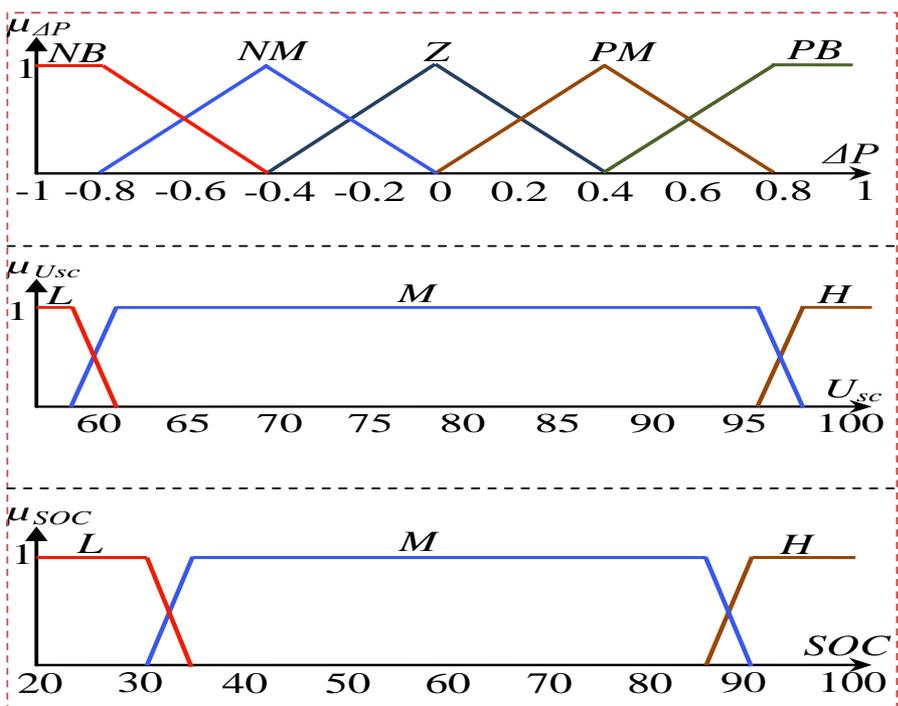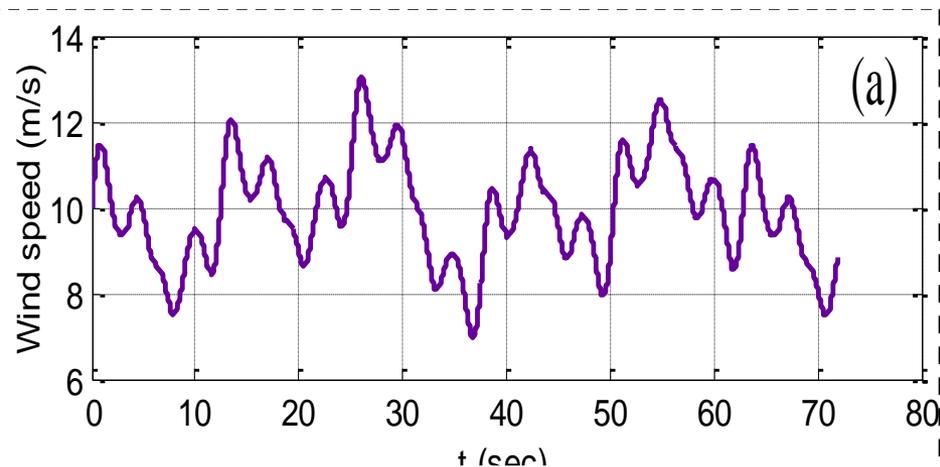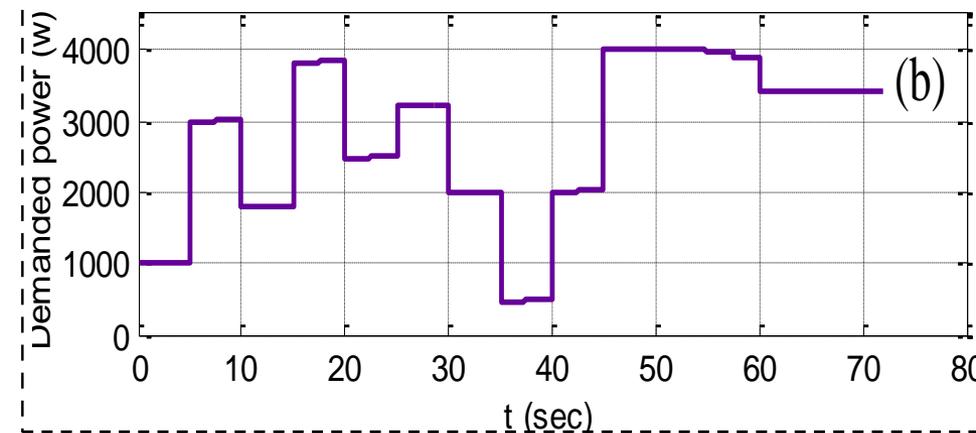

Block diagram of the proposed inputs FLS
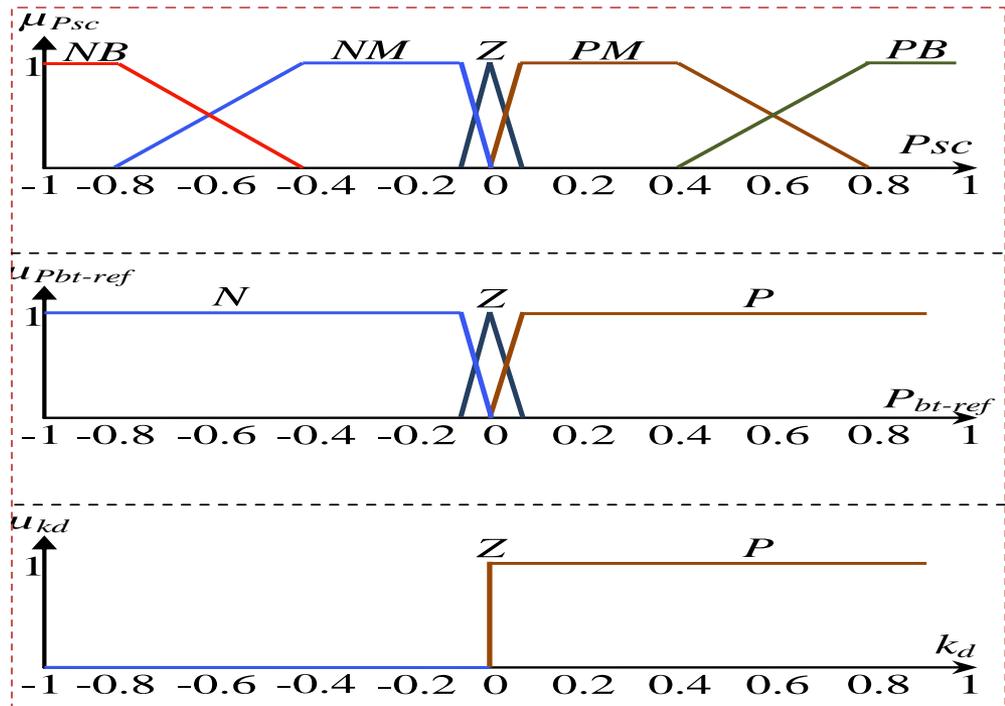
Block diagram of the proposed outputs FLS

Studied system has been implemented with different operating conditions in the MATLAB/SIMULINK environment.

**Profiles for tests are shown in these figures :**

Wind speed

Demanded power

The low rate of charge of batteries is 30% and the high rate of charge of batteries is 90%, the low rate of charge of SCs is 58V and the high rate of charge of SCs is 98V.

Following figure shows the response of the proposed control strategy to the SC. The proposed FL PMS avoids the deep discharge and the overcharge of the SC.

(a) **SC reference power**
(b) **SC current**
(c) **SC voltage**
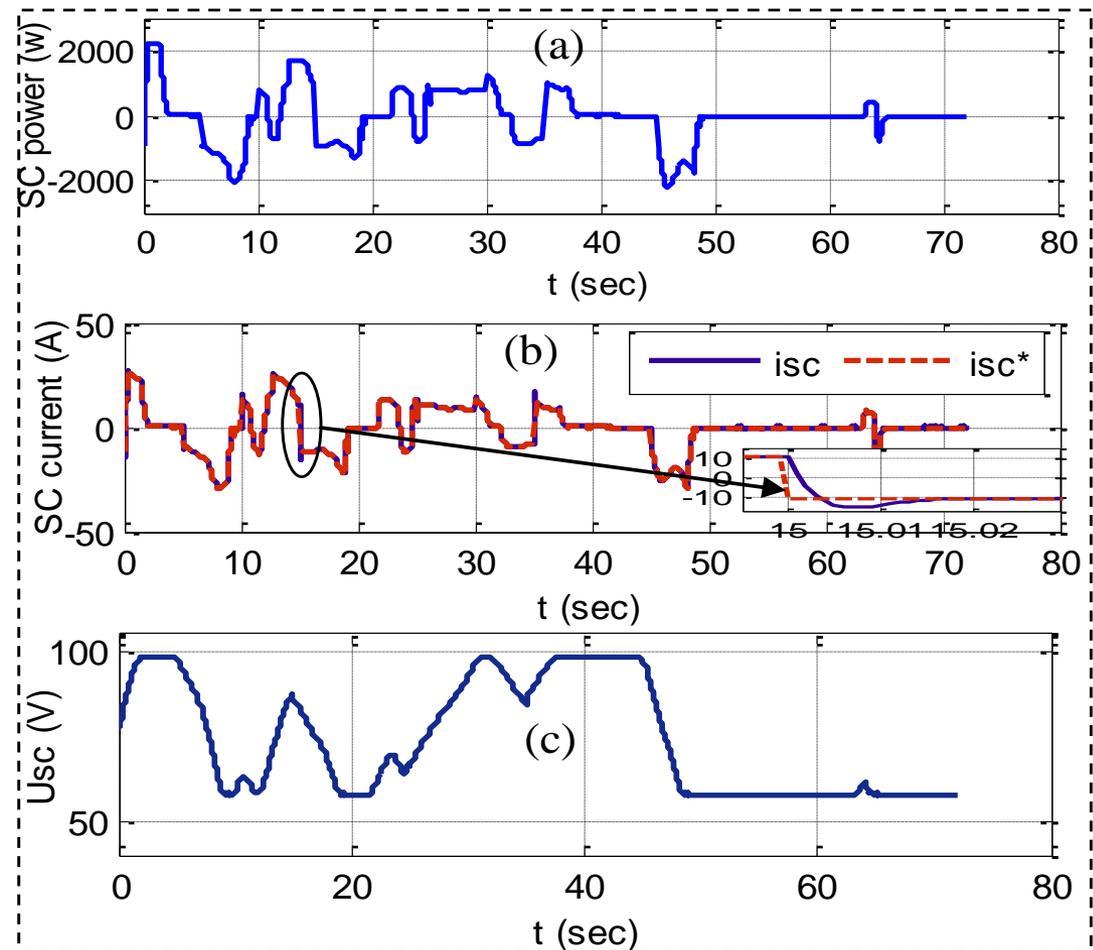
Following figure shows the response of the proposed control strategy to the BT. Proposed PMS based on FL avoids the deep discharge and the overcharge of the BT and reduces the peak power demand, charge/discharging cycle.

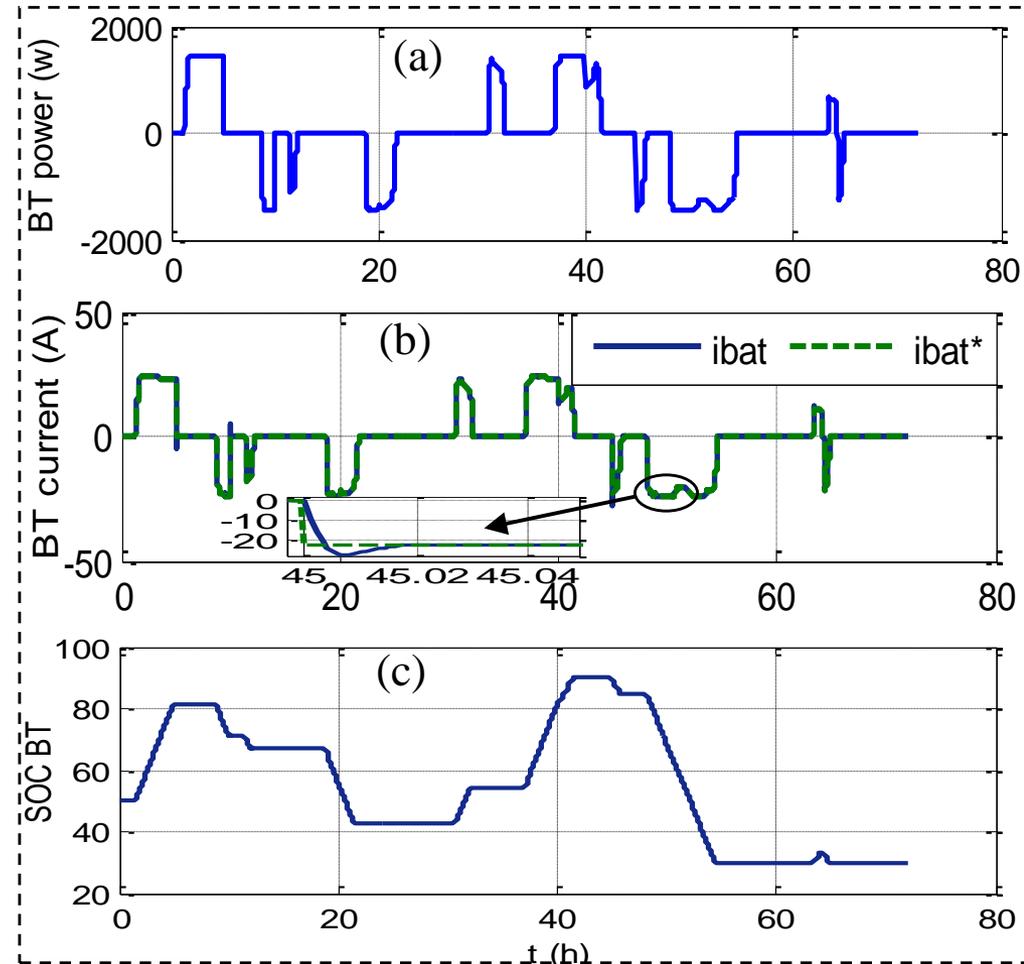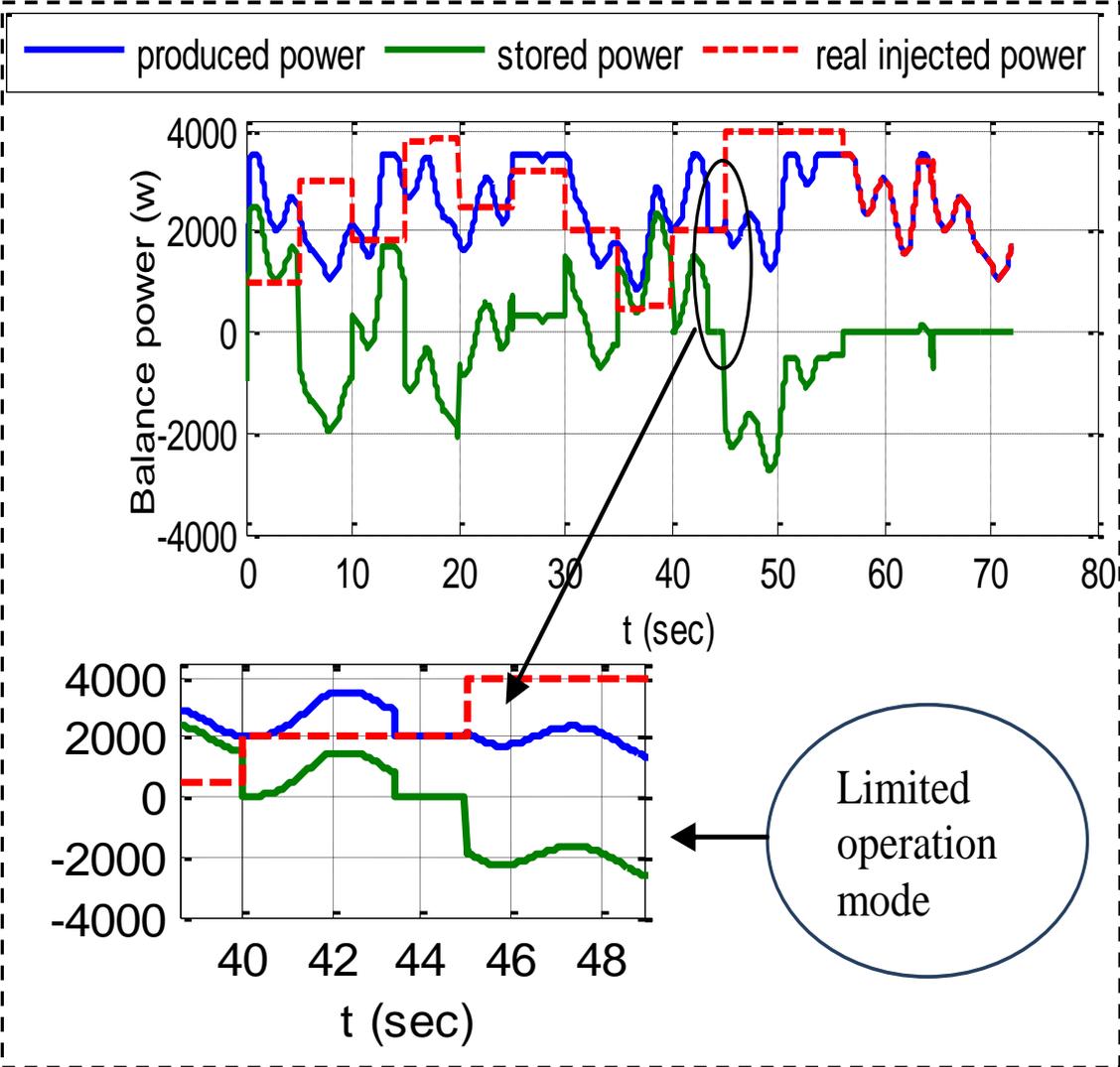*(a) Batteries (BT) reference power*
(b) BT current
(c) BT SOC

Figure shows the dynamics of the active powers when changing the different operating modes. The hybrid energy storage system absorbs or supplies the difference between the power requirement and the generated wind power with its fast, dynamic power.

(a) Power balance to the bus voltage

As shown, (Fig. (b)) the DC-bus voltage is well regulated and the power requirements from loads and grid are well achieved.

In limited operation mode (Fig. (c)), the wind turbine operates without MPPT thanks to the pitch angle control (Fig. (a)). It provides only the needed power for load supply and system services, since there is an excess of production and the storage system is totally charged.

(a) pitch angle β
(b) DC bus voltage
(c) Kd factor
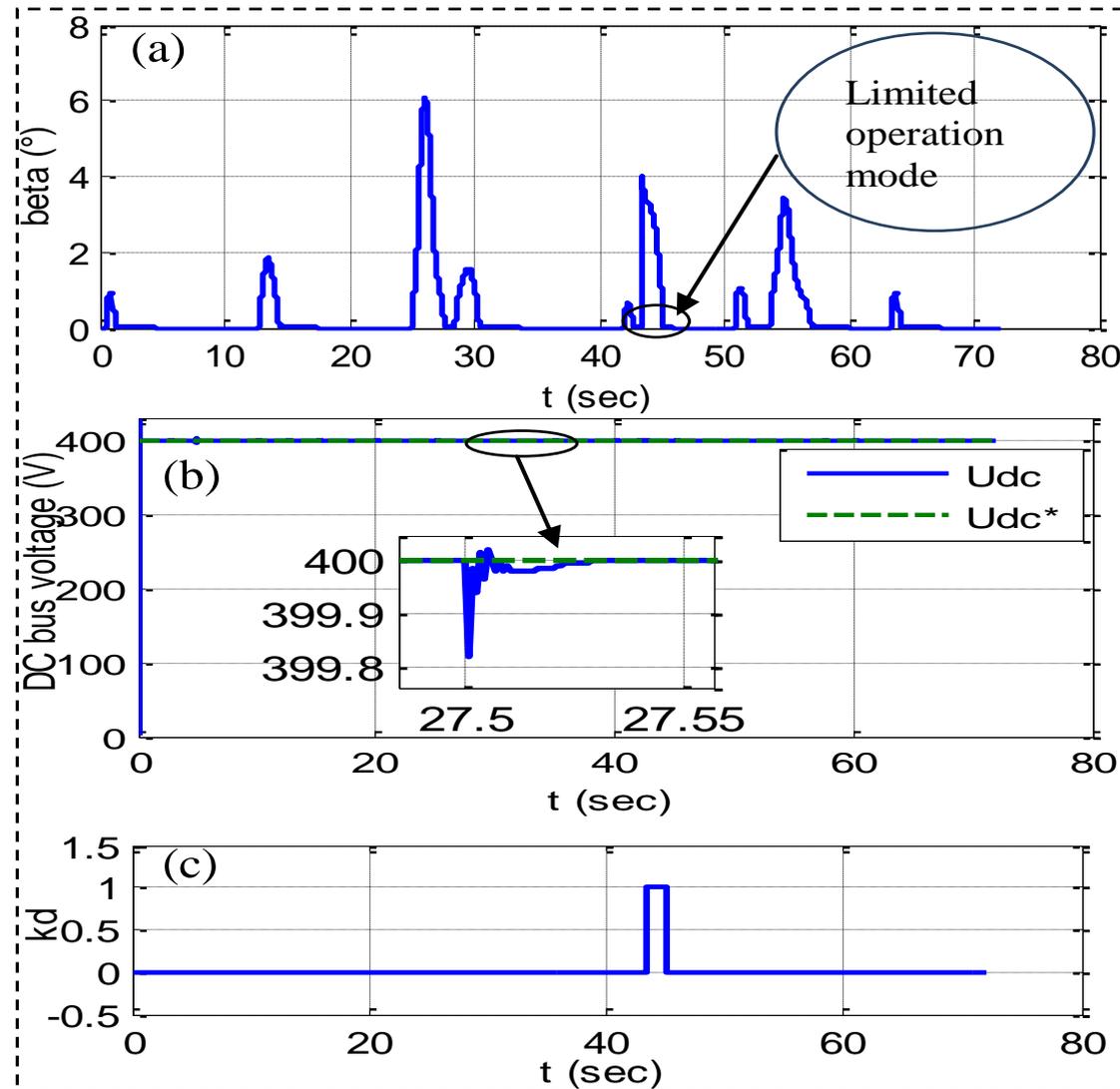
❖ In this paper, a management strategy of wind energy storage, using battery–SC combination, has been developed. It is based on FL.

❖ The control technique helps to deal with the variation of the power demanded by load and system services and the fluctuation of the wind speed. It also ensure DC bus regulation.

❖ Simulation results with different values of load and different values of wind power prove the effectiveness of the proposed strategy energy management.

❖ In future work, we will validate this work in our test bench in L2EP HEI Lille.

END OF PRESENTATION

THANK YOU FOR YOUR ATTENTION