Controlling three parallel pumps in a hybrid system using discrete fuzzy logic

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Abstract— **This work proposes a control strategy for a hybrid solar, wind and battery (PV-EOL BATT) system supplying hydraulic and electrical loads. The objective is to satisfy water and electricity needs while respecting operational constraints and safety. The system studied supplying hydraulic loads (pumps and tank) and electrical loads, notably income-generating activities – AGER-).**

The proposed strategy is based on the combination of pumps to be commissioned which operate at nominal power. The choice of pump combination is managed by fuzzy logic and the topology of the system by a rule-based algorithm. The command is tested on two scenarios, each comprising two successive days with clear or overcast skies. The clarity indices are: overcast sky 0.19 and 32, clear sky 0.72 and 0.74

The results show that water needs are met 100% and that the water level is maintained above the critical threshold defined whatever the scenarios. The electrical load coverage rate is 100% only for the best scenario

Keywords— **Include at least 5 keywords or phrases**

I. INTRODUCTION

Multi-source electrical energy systems management has been the subject of several scientific studies [1]. The main goal is to ensure that the system operates by optimizing operating costs or technical performance [2], [3], [4]

The supervision of combined water pumping and power supply applications is studied in many works.

The advantage of a variable power pump is widespread and gives an additional control possibility[5].The major disadvantage is using a variable speed drive having the same cost as the pump.

Several studies have proposed use several pumps in parallel. Approaches management are proposed: genetic algorithm, particle swarm optimization (PSO), fuzzy logic, predictive control, artificial neural networks, dynamic programming, etc.

In [3], a system of parallel pumps powered by controllable valves and variable frequency drives (VFDs) was designed for both energy savings and an increase in long service life.

optimization model based on the genetic algorithm is developed to compute optimal input parameters to ensure efficient and reliable operation of the pump system.

Results obtained indicate that developed model can indeed find the best operating point for each pump.

In [6], an optimization of four pumps in parallel by the genetic algorithm is studied. Flow rate is regulated by three different methods (throttling, bypass, and speed control). The results indicate potential for energy savings through variable speed control of all pumps in the system

Savic [7] applied a multi-objective genetic algorithm to optimize the combination of pumps in parallel to minimize operating costs.

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In [8], the particle swarm optimization method was adopted for a system of two identical parallel pumps equipped with variable speed drives. Power consumption is reduced and reliability is improved.
Using artificial neural networks, Zhang et al.[9] examined data mining methods applied to a wastewater pumping system with a view to optimizing it. The energy optimization model based on artificial neural networks resulted in energy savings of 6 to 14 \%.
In , a predictive control algorithm is proposed for a system of 3 parallel pumps. Each of these pumps is equipped with a variable speed drive which, on the basis of data, makes it possible to increase the system's efficiency. [10] used dynamic programming to optimize the number of pumps and their speeds for parallel pump systems with different pump types. Zhuan and Xia [8] used extended reduced dynamic programming algorithm (RDPA) to examine the control of optimal operating schedules of parallel pumps in a power station, taking into account energy and maintenance costs. The results show the feasibility of reducing operating costs.

The work in [11] presents a pressure control based on fuzzy logic applied to a pumping system operating in three configurations: a single pump, two pumps in series and two pumps in parallel. For the three configurations, the energy efficiency and robustness of the fuzzy controller to disturbances resulting from water consumption by a proportional valve were studied. The results show that the fuzzy controller performs well in all configurations, with the parallel configuration being the most efficient at 33.74\% compared with the other configurations at a pressure of 10 bar. In [5], [11], fuzzy logic was used to generate the power setpoint for a pump in a photovoltaic/wind/battery system supplying this pump and electrical loads.
In a previous work[5] the authors proposed intelligent energy management in a photovoltaic/wind/battery system supplying electrical loads and a pump. The contribution of this work is to study the service level and performance using three pumps in parallel without a variable speed drive.
The paper is divided into 4 sections. Section 2 presents the system studied and its modelling. The third section presents the methodological approach and the control developed. Section 4 is devoted to the case studied. The results are also presented. The last section is dedicated to the conclusion and perspective

II. . SYSTEM STUDIED ITS MODELING

A. *System Overview*

System studied fig.1 includes figure two photovoltaic and wind sources, storage batteries, electrical charges and energy management. The electrical loads are: a production unit for income-generating activities (IGAs), three pumps in parallel and the optional load sectionSystem studied its modeling

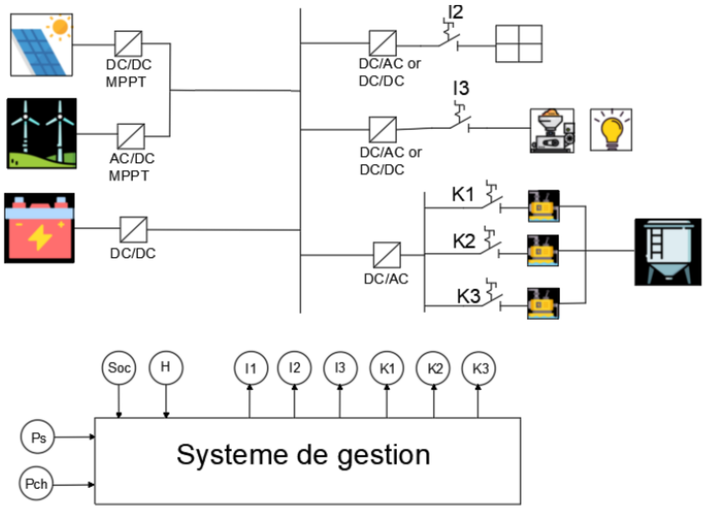

Fig. 1 Overall system architecture: The system architecture is characterised by a permanent connection between the battery and the DC bus. The sources and loads can be disconnected. Each source is associated with an MPPT converter. The loads are supplied either by a DC/AC or DC/DC converter connected to the DC bus. Switch I1 connects or disconnects the common output of the energy sources to the DC bus. Switch I2 connects or disconnects the IGAs load. Switch I3 connects or disconnects the optional load. Switches K1, K2 and K3 are used to connect or disconnect the pumps..

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B. Aivailable power

Maximum power available at the output of a module can be calculated from equation 1.

$$Ppv = Vmp \times Imp + Peol \qquad \textbf{(1)}$$

Vmp : voltage at maximun power point
Imp : current at maximun power point
Peol : available power of the wind turbine (W)

Quantities calculations details Vmp, Imp and Peol are given in our previous work

C. Electrical Load

It consists of pumps, IGAs and auxiliary load Note Ki the pump i working status 1 is on and 0 is off.. The power rate of all pumps is given by equation (2)

$$P_{CH} = \sum_{i=1}^{n} K_i \times K_{ni} + P_{AGD} \qquad \textbf{(2)}$$

Pumps power rate α and total flow Q_T are given respectively by 3 and 4

$$P_{CH} = \frac{\sum_{i=1}^{n} K_i \times P_{ni}}{\sum_{i=1}^{n} P_i} \qquad \textbf{(3)}$$

$$Q_T = \sum_{i=1}^{n} K_i \times Q_{n_i} \qquad \textbf{(4)}$$

Pni : pump i rated power . i ∈ {1;2;3}
Qni : pump i flow. i ∈ {1;2;3}
Ki : switch i status i ∈ {1;2;3}

III. CONTROL STRATEGY

Pumps combination choice is activated by fuzzy logic whitch requires only defining the fuzzy variables and inference rules.

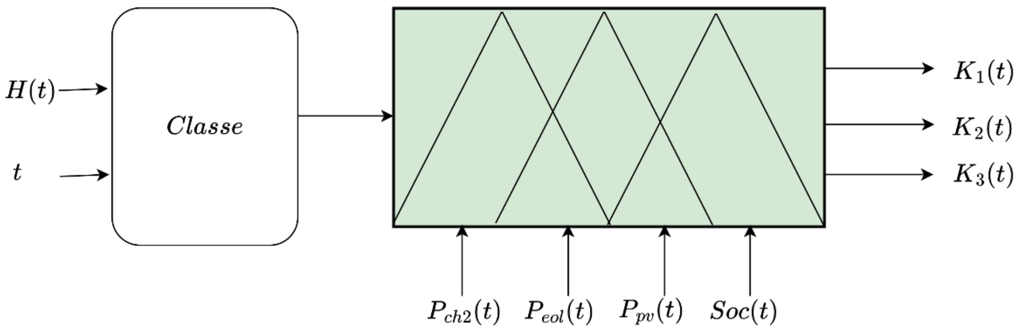

Fig. 2 Management organisation

system studied Operating classes C1 to C6 of the are defined as a function of t time operation and the water level in the tank as detailed

A. Calculating electrical load

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Main and auxiliary loads distribution is directly related to the operating classes defined in table 1. Operating classes C1 to C6 of the studied system are defined according to the operation and tank water level . More details is in previsious work

Table 1 Operating classes value

	$t \in [t_1 ; t_2]$	$t \notin [t_1 ; t_2]$
$H \leq H_{min}$	C1	C4
$H_{min} < H \leq H_{max}$	C2	C5
$H \geq_{max}$	C3	C6

B. Fuzzy logic control

This fuzzy algorithm is characterized by four input quantities (Ps(t) , H(t) , ε(t) and soc(t)) and three output quantities (K1, K2, K3). by Each variable is characterized by its name, values range , and linguistic values. Figures ?? to ?? define the membership functions. The language variables are represented in the table I

Table 2 language variable

Variable	**Values range**	**laguages value**
Ps(t)	[0; inf[	{weak, great}
H(t)	[0; 10[	{low, medium, higth}
ϵ(t)	]−inf; inf[	{negative, low, large}
soc(t)	[0; 1[	{low, max}
K1,K2,K3	[0; 1[	{off, on}

C. Performance criteria

System management strategy performance indicators are: non-coverage rate of electrical load (LPSPE), non-coverage of the hydraulic load ((LPSPH)), energy production excess ((EP)) and exchanged energy by battery (Eex)) . They are given respectively by the equation 5-8

$$\mathrm{LPSPE}(\%) = 100\frac{\sum_{t=1}^{n} \delta P(t) \times \Delta t}{\sum_{i=1}^{n} P_{CH2}(t) \times \Delta t} \quad \textbf{(5)}$$

δP : Electrical load not covered over the interval
Electrical load not covered over the interval in question;
T : intervals Number over the study period

$$\mathrm{LPSPH}(\%) = 100\frac{\sum_{i=1}^{n} [\mathrm{Qs(t)} \times \Delta \mathrm{t}]_{\mathrm{H(t)=0}}}{\sum_{i=1}^{n} [\mathrm{Qs(t)} \times \Delta \mathrm{t}]} \quad \textbf{(6)}$$

Qs : required water flow rate over the interval considered.

$$\mathrm{EP}(\%) = 100\frac{\sum_{i=1}^{n} \mathrm{P}_{CH3} \times \Delta \mathrm{t}}{\sum_{i=1}^{n} \mathrm{P}_{s} \times \Delta \mathrm{t}} \quad \textbf{(7)}$$

Pch3 : excess power over the interval under consideration.

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$$Eex(\%) = 100 \frac{\sum_{i=1}^{n} |Pbat(t)| \times \Delta t}{\sum_{i=1}^{n} P_s \times \Delta t} \quad \textbf{(8)}$$

PBat : power received or supplied by the battery over the interval considered. It is positive when the battery is charged and negative when it is discharged. Total energy production is given by and the gap between production and demand ε(t) (10)

$$Ps(t) = Peol + Ppv \quad \textbf{(9)}$$

$$\epsilon(t) = Ps(t) - Pch \quad \textbf{(10)}$$

IV.. CASE STUDY

A. . System settings and data

Case study is a farm covering 10 ha of agricultural land located 16 .45 owest 15,96oNorth. System sizing is presented in our previous work.[5]. Hydraulic components characteristic are showed on tale III

TABLE III: Characteristics of hydraulic components

Components	Characteristics
Pump 1	1 kW 18.75 m3/h
Pump 2	3 kW 56.25 m3/h
Pump 3	5 kW 93.75 m3/h
Tank	240 m2 × 4m

In order to assess the management strategies, a comparison was made between a scenario with favourable metrological conditions and a scenario with adverse weather conditions. Clarity Index (Kt) is a reliable metrological index for classifying sky types from overcast to clear . The days 12 February, 13 February, 23 May, and 24 May are chosen Their respective clarity indies of 0.19, 0.32, 0.72, 0.74

B. Results and discussion

Simulation results relate to power generation, power storage, load utilization, and management strategy performance. Powers extracted from photovoltaic and wind sources, on favourable and unfavourable days, are presented in the figures 5-6. Pump and IGA load daily requirements amount to 95 kWh. Sources daily energy production in scenario 1 is an average of 336 kWh and that of scenario 2 is an average of 53 kWh.

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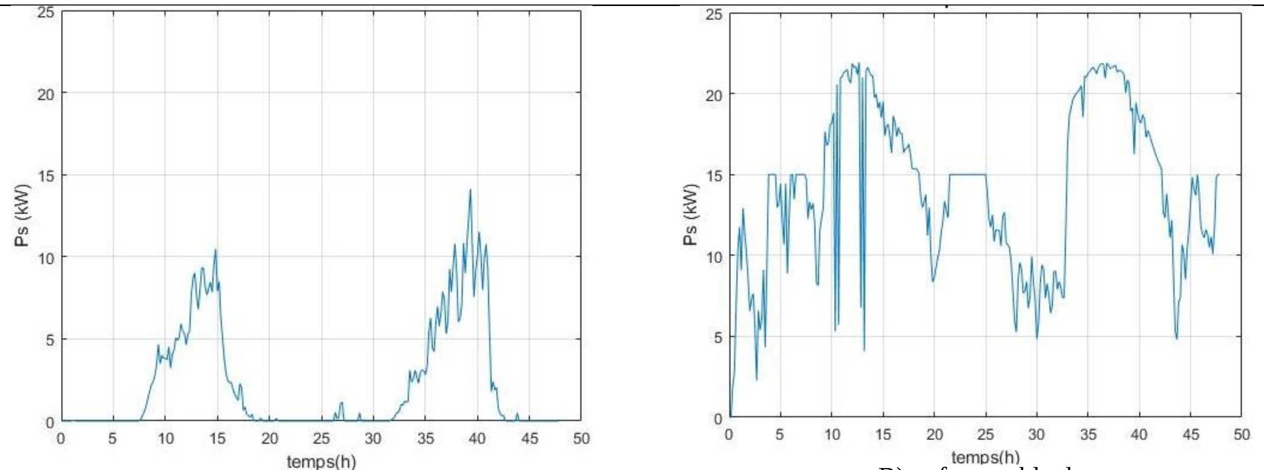
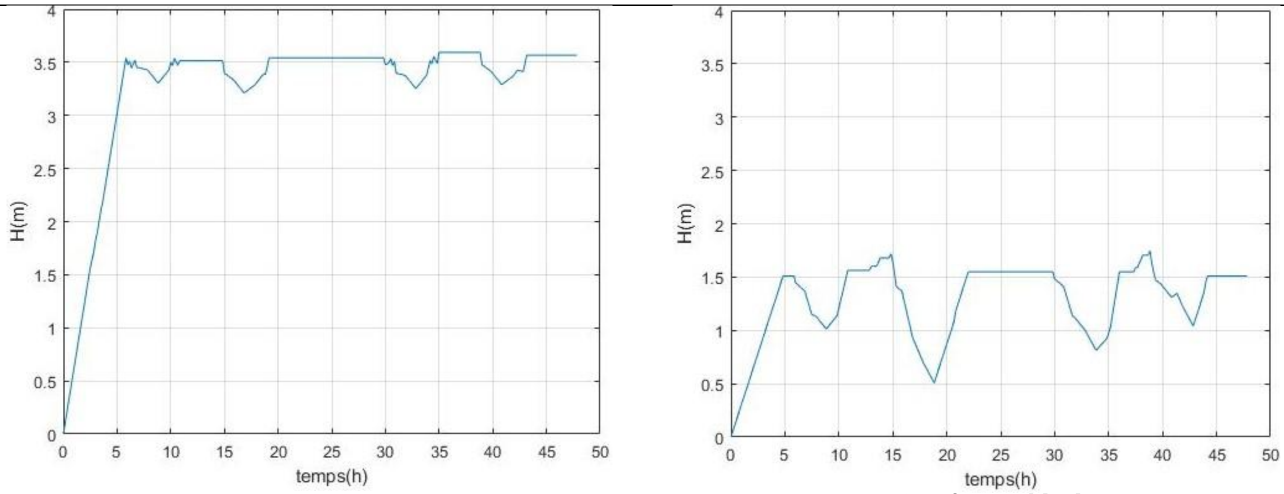


A) on favourable day B) unfavourable day

Fig. 3 Energy generated

Figure 4illustrate the evolution of the power required by the battery storage system in scenarios 1 and 2, respectively. Scenario 1 involves higher exchanged powers and more charging phases compared to discharging or storage phases. 2.

The reservoir fills to over 87%. Despite the demands, the reservoir level oscillates around 87%. In scenario 2, the water level is maintained around 1.5m and experiences significant variations. It remains at approximately 1.5m at the end of both days. Figure 5 illustrate the evolution of the reservoir water level for each scenario.



B) on favourable day B) unfavourable day

Fig. 4 Water level evolution

The management strategy shows a load non-coverage rate of 19.39%. There is no excess energy production in this scenario, but the rate of energy exchanged by the battery is twice as high as in scenario 1.

TABLE IV Performances indicators

	PSPE(%)	LPSPH(%)	EP(%)	Eex(%)	H/Hmax(%)
Scenario 1	0	0	0	66.92	89
Scenario 2	19.39	0	0	177.9	37.75

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V. Conclusions

This work proposes a control system based on discrete fuzzy logic for the combination of pumps to be put into service. The choice of pump combinations. The performance of the management strategy for three pumps in parallel was evaluated using data measured at the Gandon site. The choice of pump combination is managed by fuzzy logic and the topology of the system by a rule-based algorithm. The command is tested on two scenarios, each comprising two successive days with clear or overcast skies. The clarity indices are: overcast sky 0.19 and 32, clear sky 0.72 and 0.74. In the perspective of this work, the determination of the number of pumps and their characteristics. An approach based on overall energy efficiency can be considered.

VI. Bibliographie

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