International Journal of Sciences and Techniques of Automatic control & computer engineering
IJ-STA, Volume 5, N° 2, December 2011, pp. 1576–1585.

Intelligent Energy Management in a Photovoltaic Installation Using Fuzzy Logic

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Abstract.*This paper addresses the problem optimal management of the energy production and its storage in a photovoltaic installation. To attain this objective, we propose at first a fuzzy maximum power point tracking algorithm. After that we propose a fuzzy supervisor to manage the power flow such that the load demand is satisfied and the problem of batteries overstressing is removed. Simulation results are given to show the efficiency of the proposed approach.*

Keywords. *PV system, fuzzy supervisor, maximum power point tracking.*

1. Introduction

Worldwide energy consumption has increased rapidly due to world population growth. Since amount of fossil energy source has no longer enough, renewable energy sources such as solar power, wind power, geothermal power, and fuel cell are considered to meet the global demand for energy. Aside from the unlimited amount of the sources, renewable energy has advantages such as no or low pollution emissions compared with fossil energy. Among these renewable energy sources, solar energy is one of the most appropriate and primary renewable energy [1, 2].
Development of PV system is generally focused on two areas: the PV cell manufacturing process and materials and the PV power management strategy. Techniques in manufacturing have had significant progress in terms of higher efficiency with lower cost. Regarding to PV power management, implementation of PV system with inappropriate strategy will result in low efficiency. Thus, PV power management strategy including energy conversion system is a very important part in efficiency improvement. One of the energy conversion strategies being developed is method to find maximum power of the PV module that known as maximum power point tracking (MPPT) method. The MPPT method automatically finds the maximum voltage or maximum current of a PV module at which it will operate to reach the maximum

This paper was recommended for publication in revised form by the editor Staff.
Edition: CPU of Tunis, Tunisia, ISSN: 1737-7749

poweroutput under certain temperature and irradiance. Then, several methods have been proposed in the literature: Perturb and Observe (P&O) [5], [6], [7], [8], Incremental method [9], or fuzzy logic based methods [10], [11], [12], [13].
Generally, a battery is inserted between the MPPT system and the load to ensure continuity and to compensate the power decreasing. Nevertheless, this structure allows to charge/discharge the battery all time witch leads to reduce the battery life.
Based on the fact that fuzzy logic allows to exploit efficiently the human knowledge, we propose in this paper a fuzzy supervisor capable to manage in an optimal way the power production, storage and use. For this, the battery is not used in series with the load but in parallel. Furthermore, the proposed supervisor uses a dissipation load to resolve the problem when the produced power is more than the load demand and the battery is full in the opposite of classical installation.

2. The installation Structure

The proposed structure is given by figure 1. The first DC-Dc converter is dedicated to tracking the maximum power point. This objective can be achieved using a fuzzy logic algorithm, which will be presented after. Since the battery is used in parallel, we have added an additional DC-Dc converter allowing fixing the output voltage to a desired value. The battery is connected using two switches S_1 and S_2 controlled by the supervisor. S_1 is activated (ON) when the produced power is lower than the load demand, whereas the switch S_2 is activated (ON) when the produced power exceeds the load demand and the battery is not fall. The additional load has been added to be used in the case where the produced power exceeds the demand and the battery is fall. The supervisor is introduced to manage optimally the production, the consumption and the storage of the energy. To exploit efficiently the human knowledge, we propose to use a fuzzy logic system.

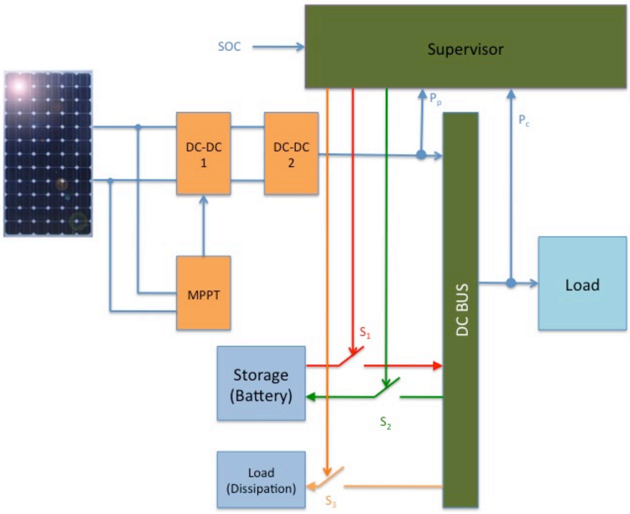

Fig. 1.: The studied PV installation

3. Maximum power tracking point algorithm (MPPT)

To track the maximum power point, we need the power and the voltage of PV installation P_{pv} and V_{pv} respectively. So, we use $E(k) = \frac{P_{ph}(k)-P_{ph}(k-1)}{V_{ph}(k)-V_{ph}(k-1)}$ and $\Delta E(k) = E(k) - E(k-1)$ as inputs of the fuzzy system. The output is the variation dD of the duty cycle, which will be added to the old value and applied to the converter. The fuzzy sets are chosen as indicated in figure 2 and 3. It will be noted that we have chosen the product a inference engine and the centroid for defuzzification. The fuzzy rule base used in our system is given in table 1.

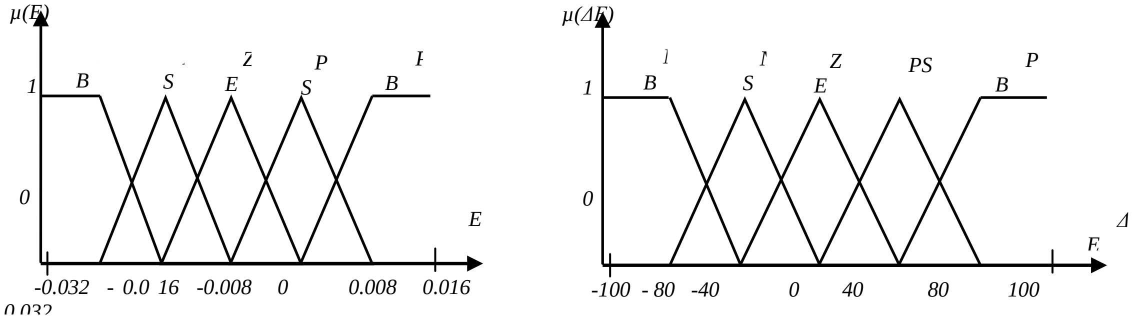

Fig. 2: Membership functions of the inputs

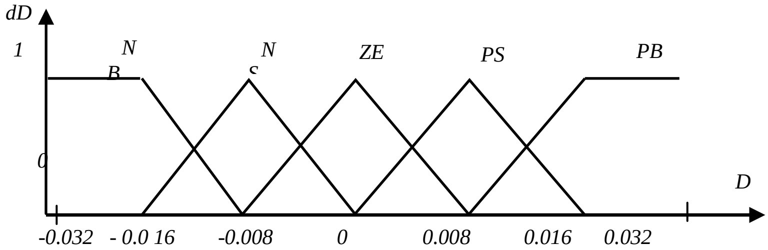

Fig. 3: Membership functions of the output dD

Table 1.Fuzzy rule base

E/ ΔE	NB	NS	ZE	PS	PB
NB	ZE	ZE	PB	PB	PB
NS	ZE	ZE	PS	PS	PS
ZE	PS	ZE	ZE	ZE	NS
PS	NS	NS	NS	ZE	ZE
PB	NB	NB	NB	ZE	ZE

4. Fuzzy Supervisor

To manage optimally the production, the consumption and the storage of the energy, we have chosen a Takagi-Sugeno fuzzy system. This choice is motivated by the fact this kind of fuzzy system requires less computing time than Mamdani systems [14]. To attain our objective, we propose to use only two inputs: $\Delta P = P_p - P_c$ (P_p: the produced energy, P_c: the load demand) and the state of charge of the battery (SOC), and three outputs for controlling the switches as presented in the figure 4.

Fig. 4. The structure of the proposed fuzzy supervisor.

For the fuzzyfication, the fuzzy sets shown in figure 5 have been chosen as follows:
For inputs: ΔP: Negative (N), Middle Positive (MP), Positive (P)
SOC: Empty (E), Middle Fall (MF), Fall (F).

For outputs:S_1, S2, S_3: On, Off.

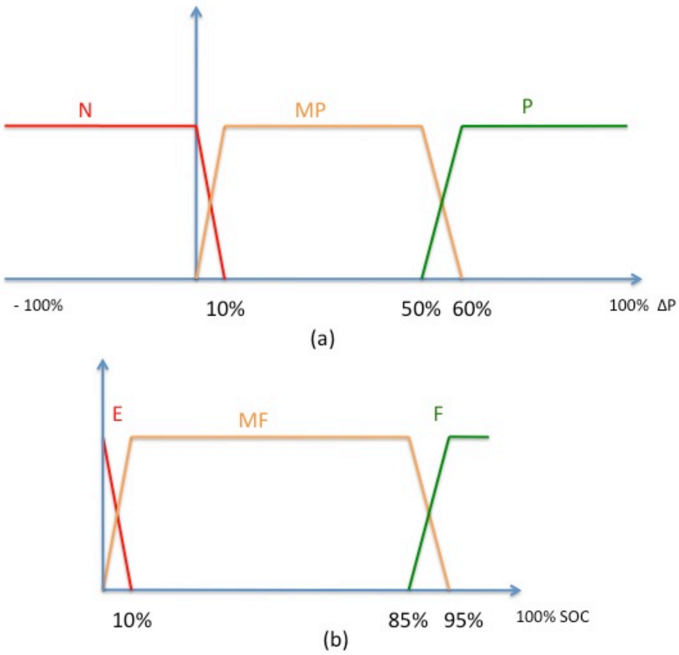

Fig. 5. The fuzzy sets of the inputs: (a) ΔP, (b) SOC.

The fuzzy sets of the inputs are chosen singletons such that 0 for Off and 1 for On.

To compute the system outputs, we propose to use the following fuzzy rules:

IF [Δ P is N **AND** SOC is F] **THEN** [S_1=On **AND** S_2=Off **AND** S_3=Off]
IF [Δ P is N **AND** SOC is MF] **THEN** [S_1=On **AND** S_2=Off **AND** S_3=Off]
IF [Δ P is N **AND** SOC is E] **THEN** [S_1=Off **AND** S_2=Off **AND** S_3=Off]

IF [Δ P is MP **AND** SOC is F] **THEN** [S_1=Off **AND** S_2=Off **AND** S_3=On]
IF [Δ P is MP **AND** SOC is MF] **THEN** [S_1=Off **AND** S_2=Off **AND** S_3=On]
IF [Δ P is MP **AND** SOC is E] **THEN** [S_1=Off **AND** S_2=On **AND** S_3=On]

IF [Δ P is P **AND** SOC is F] **THEN** [S_1=Off **AND** S_2=Off **AND** S_3=On]
IF [Δ P is P **AND** SOC is MF] **THEN** [S_1=Off **AND** S_2=Off **AND** S_3=On]
IF [Δ P is P **AND** SOC is E] **THEN** [S_1=Off **AND** S_2=On **AND** S_3=On]

We can note that there is some redundancy in the rule base made to avoid abrupt jumps between states which can destabilize the system and especially if you use an inverter (frequency problem).

5. Simulation and Results

We consider that the PV installation is configured such that we can satisfy 100% of load demand and the batteries are also able to give the same power. To show the efficiency of the proposed approaches, we consider that the power load varies as given in figure 6. variation evolution of the load power

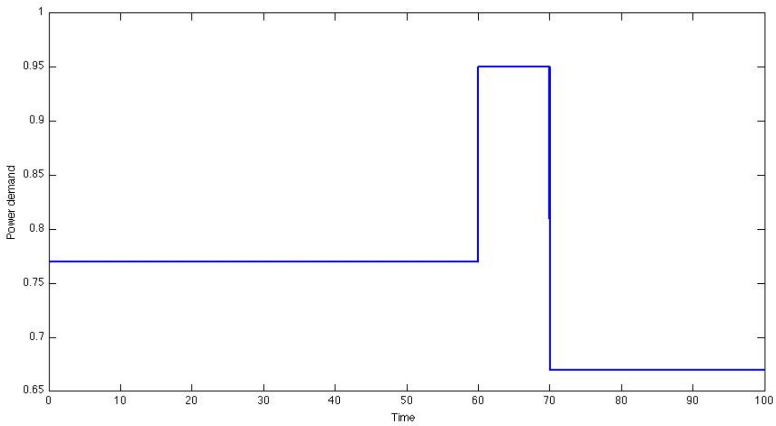

Fig. 6. Reference of the load power evolution.

Simulation results are given by figures 7 to 11. Figure 7 gives the power produced by the power system whereas figure 8 show the load demand. Analyzing the power flux in the batteries shown in figure 9, we remark that the batteries compensate for the lack of power that would be provided by photovoltaic panels. For the batteries, we notice that at first the batteries compensate for the lack of energy up when the panels are able to respond effectively to demand. Then, we notice that the power flow is zero between time 60s and 70s, which is due to the fact that the batteries are still full and we have a surplus production that is sent to the load dissipation. After that, we remark that we have a negative flow of power that reflects the phenomenon of battery charge. Figure 11 provides the states of switches to achieve these objectives.

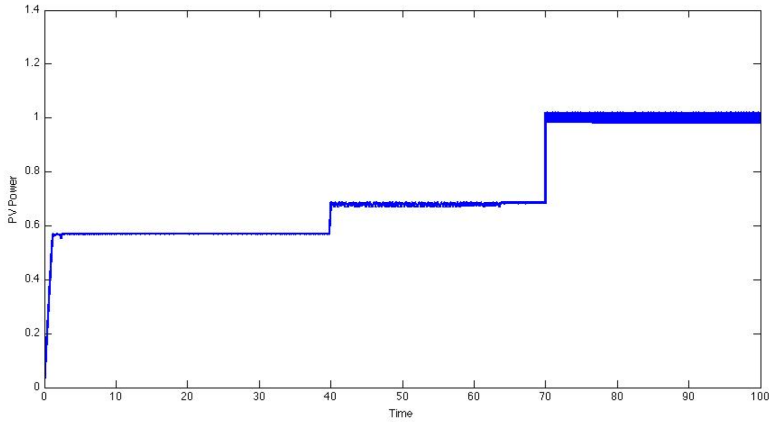

Fig. 7. Power produced by the PV system.

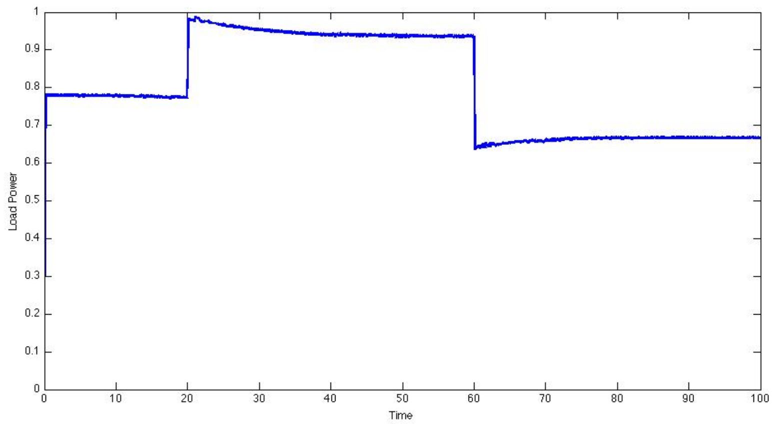

Fig. 8 Power load.

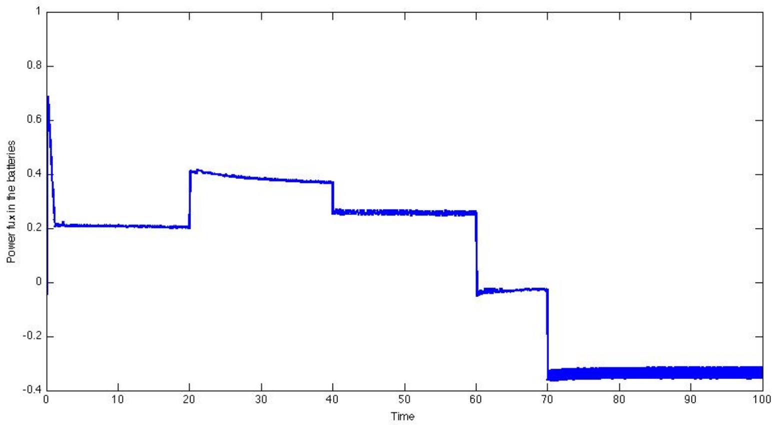

Fig. 9. Power flux in the batteries.

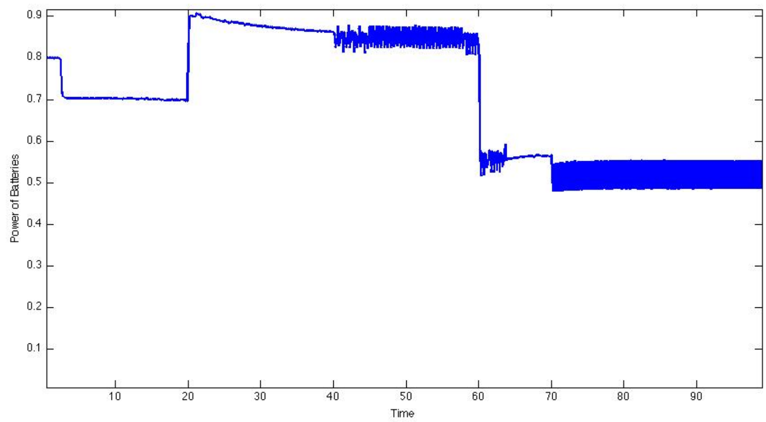

Fig. 10. Charge state of the batteries.

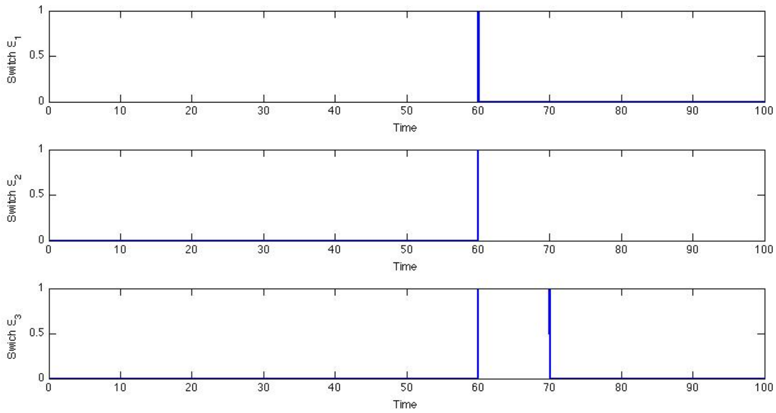

Fig. 11. State evolution of the switches.

6. Conclusion

In this paper, we have proposed to approaches allowing to : (i) track the maximum power point using a fuzzy logic algorithm, (ii) obtain a rational management of energy using a fuzzy supervisor. The proposed approaches allows to respond to the energy demand and to resolve the problem batteries overstressing, which leads to extending their life using. The simulation results presented have shown the effectiveness of the proposed approaches.
In the future, works we are working on integrating consumption constraints in the fuzzy supervisor to treat the case when the PV installation and storage cannot satisfy load demand.

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