Fuzzy Charge Controller for Stand-Alone Photovoltaic Systems

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Abstract

Charge regulators of the batteries are one of the parts most critical in stand-alone photovoltaic systems. The economic cost of the complete installation, for a long period of time, depends on their correct operation. This document presents a Fuzzy Logic Controller for the charge regulation in stand-alone photovoltaic systems. The optimisation, in energy management, obtained with this controller improves the life-time of the batteries, the operation of the photovoltaic system and the total cost, in long times, of the installation

Keywords: Fuzzy Logic Controllers, Rules Based Systems, Charge Controller, Stand-alone PV-Systems.

1 Introduction

Photovoltaic solar energy is, actually and in a small scale, a reliable and clean form of electrical energy production. The fundamental reason which has prevented the expansion this technology has been basically economic: a greater cost of solar produced kWh than its respective production using more conventional technologies (oil, nuclear, coal, etc).

Nevertheless, the growth of technology and the production of cheaper modules, the development of more advanced conditioning systems of power, the greater efficiency and reliability, etc., in association with the accomplishment of research projects, supported by national and international programs of financing and/or partial subsidy, allows to install increasingly effective and competitive systems with conventional generators of electrical energy. So, it is expected an increasingly use of this technology in the production of electrical energy in the world as a complement of conventional generation sources.

Furthermore, in several particular cases, i.e. in isolated installations with problematic access to the electrical network, the named Stand-Alone Photovoltaic Systems is used. A Stand-Alone Photovoltaic Systems is constituted by the following elements:

· **Photovoltaic Generator:** Produces electrical energy from the incident solar radiation.

· **System of energy accumulation:** Batteries inserted in the Stand-Alone Photovoltaic Systems are implemented in order to match different rates of production and demand of electrical energy.

· **Charge controller:** Its function consists on protecting the system of accumulation and avoiding extreme behaviour cases that could injure the batteries.

· **Inverter:** It is used when we want to manage loads that require alternate current.

· **Load:** Elements fed with electrical energy.

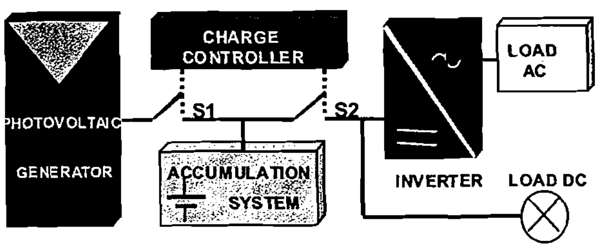

Figure. 1: Stand-alone Photovoltaic System.

2 Charge Controller

The generated electrical energy not only feeds the electrical load, but also, due to the surplus of generated energy, loads the accumulators. Therefore, the regulator system must avoid overcharges in the accumulator (because of an excessive voltage provided by the generator), and, on the other hand, prevent the overdischarging of the batteries (in case of an excessive feed to the load by the accumulation system).

In fact, the charge controller system must protect to the accumulator of extreme operation situations, independently of the size of the installation, of its design, and possible weather variations in consumption profiles, solar radiation and operation temperatures. All this, in order to achieve as final objective a longer useful life of the accumulating system.

It exists different kinds of charge controllers, but the most frequently used in Stand-Alone Photovoltaic Systems is the two-switched serial controller (Generation and Consumption).

In this serial controller, the generator switch disconnects the generator and the battery when the latter reaches to a value enough to overcharge itself. The consumption switch energy prevents to supply the voltage of the battery when it reaches to a minimal threshold.

The characteristic values in this type of controller are the following:

- Overcharging threshold voltage V_{SC}: Maximum voltage that the regulator allows to reach the battery. If $V>V_{SC}$ then the battery is disconnected of the generator.
- Charge rearming Voltage V_{RC}: It is the value of the battery voltage that enable the battery to the generator reconnection . In the Fig. 2 the overdischarging Histeresis cycle corresponding is presented.
- Overdischarge voltage threshold V_{SD}: It is the minimal value allowed for the battery voltage before disconnecting it from the consumption. If $V<V_{SD}$ then the battery will be unplugged from the consumption.
- Rearming voltage for discharge V_{RD}: It is the voltage value in the battery that causes the battery reconnection to consumption. In the Fig. 3 overdischarging Histeresis cycle is presented.

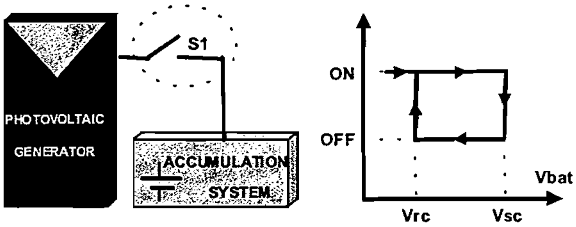

Figure 2: Overcharge Histeresis cycle.

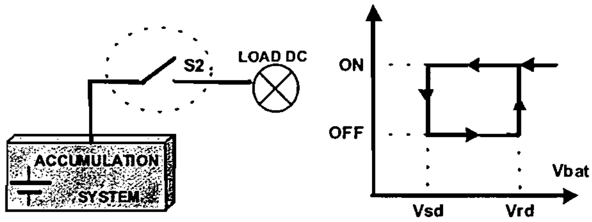

Figure 3: Overdischarge Histeresis cycle.

3 Problematic

The operation of the stand-alone photovoltaic systems depends not only on the individual quality of the element that compose it, interaction between the component also contribute to system action [4]. In this sense, the charge controller is specially important.

On the same way, control strategies followed by the charge controller are very important factor that directly influence the maintenance and the useful life time of batteries. Special care should be paid on batteries because they influencing considerably (20%- 30%) [5] in the accrued cost of the installation.

In spite of the apparent simplicity in the operation of the load controllers, in practice, it is observed that load control in real system present a relatively high mistakes rate, that is, load controllers do not show some necessary quality requirements in photovoltaic systems [3]. This circumstance should be debt mainly, to the fact that the operation of these controllers does not take into account all aspects related to the load and discharge processes. Thus, when lead-acid batteries are used [6], it should be desirable to acquire certain operational characteristics, some of the most important ones can be expressed as follows:

- Batteries that work in a high discharge rates, supply smaller capacities, since the internal transformations are superficial.

- Low rate batteries discharge, increase their capacity since it is produced a better and more complete use of active materials and acid.
- A positive aspect dealing with batteries, is that an adequate quantity of overcharge can avoid stratification problems.
- As a result of the battery obsolescence, its internal resistance increases, therefore the maximum load tension would have to increase in order to maintain the same load regime.
- It is interesting to accomplish flotation charges to preserve the batteries in a full charge state, even when they are not in operation; this action will compensate self-discharge losses.

As can be appreciated, these are desirable operation characteristics. Nevertheless, they are not remarkably specific, these characteristics can be modelled using an expert system. In this way, a fuzzy controller can be obtained with a knowledge base, whose rules can represent the previously mentioned characteristics [2].

4 Fuzzy Charge Controller

The structure of the Fuzzy Charge Controller (FCC) is showed in fig. 4. State of charge (SOC), generated current (Igen) and load current (Icharge) are the FCC inputs. The FCC output will determine the charge controller operation mode. The control system consists in a two engine inference, the first one controls the overcharge states (Acts on the switch S1) and the other one works on overdischarge states (Acts on the switch S2).

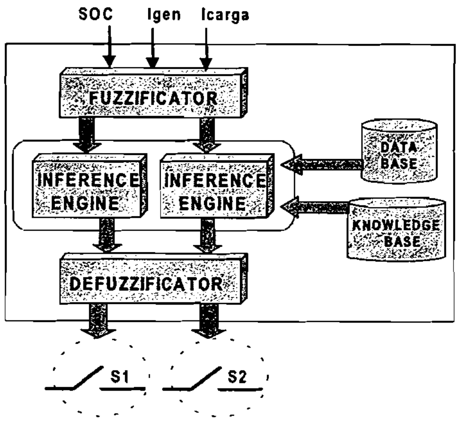

Figure 4: Structure of Fuzzy Charge Controller.

For a given system characteristics to be controlled, it is only necessary to act on the overcharge and overdischarge states.

The data base contains information about the Fuzzy sets associated with each input variable. Input and output variables Fuzzy sets of the control system for overcharge and overdischarge are showed in fig. 5 and 6 respectively.

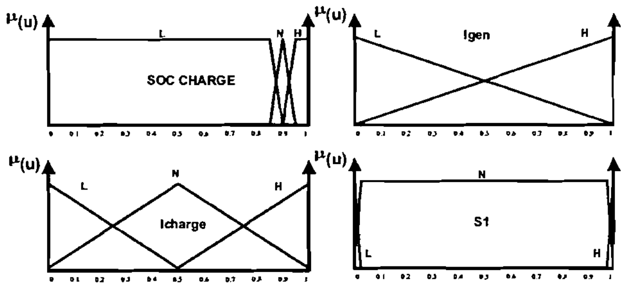

Figure 5: Fuzzy Set for overcharge control system.

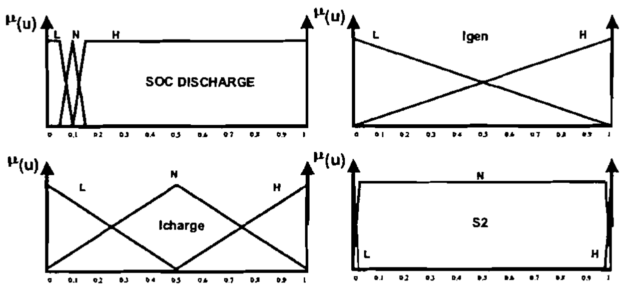

Figure 6: Fuzzy Set for overdischarge control system.

The knowledge bases used in the FCC are shown below.

Table 1: Knowledge base of FCC for overcharge.

N°	ANTECEDENTS	S1
1	IF "SOC=L "	H
2	IF "SOC=N" and "IGEN="L"	H
3	IF "SOC=N" and "IGEN="H" and "ICAR=L"	N
4	IF "SOC=N" and "IGEN="H" and "ICAR=N"	H
5	IF "SOC=N" and "IGEN="H" and "ICAR=H"	H
6	IF "SOC=H"	L

Table 2: Knowledge base of FCC for overdischarge

N°	ANTECEDENTS	S2
1	IF "SOC=L "	L
2	IF "SOC=N" and "IGEN="H"	H
3	IF "SOC=N" and "IGEN="L" and "ICAR=L"	H
4	IF "SOC=N" and "IGEN="L" and "ICAR=N"	H
5	IF "SOC=N" and "IGEN="L" and "ICAR=H"	N
6	IF "SOC=H"	H

5 Simulation Results

The results have been obtained simulating a 6Wp photovoltaic generator, and a 100Ah and 2V battery. The charge profiles considered have been from 19:00h to 24:00h with a 6Ah consumption for the overdischarge state and 2Ah for the overcharge state. For the radiation and temperature data, we have used real measured values in the locality of Jaén (Spain).

Special attention should be paid to the elected battery model, since it is the element that is intended to protect with the charge controller, so its correct modelling will directly affect the cogency of the obtained results. The battery model that has been used is proposed it by Copetti [6], this model represents precisely the variation of the main parameters of the battery during the charge and discharge processes.

Below simulation results are presented for the overdischarge states (figure 6) and overcharge states (figure 7). In these figures the evolution in the time of the charge of state (SOC), current of the battery (Ibat) is showed during a simulation time of 10 days.

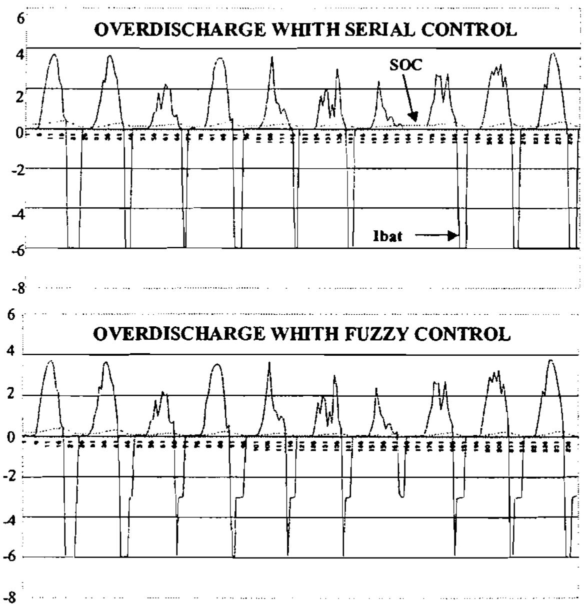

Figure 7: Simulation in the overdischarge state.

Some of the remarkable advantages that have been obtained using the Fuzzy Controller, is the increase of the quantity of current delivered to the battery, (negative Values of Ibat). Furthermore, the time evolution of the load state has been softened, this fact will allow a smaller battery deterioration.

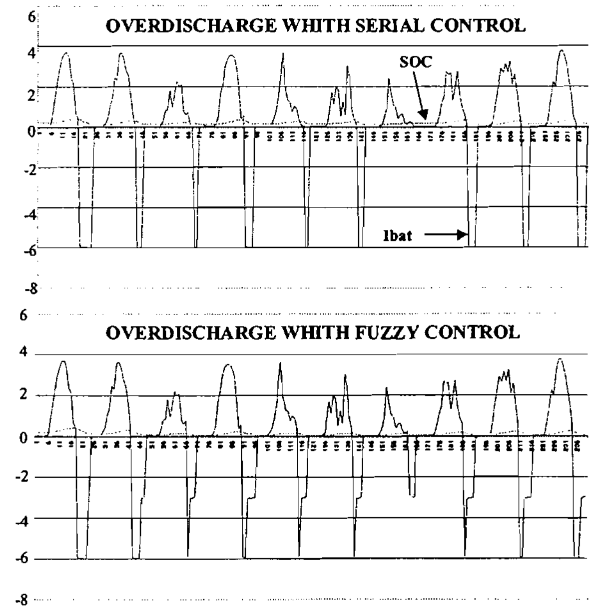

Figure 8: Simulation in the overcharge state.

6 Conclusions

The FCC proposed is an easy implementation controller and that improves of previous designs reliability. One of the most important characteristics of the FCC is the intrinsic flexibility of fuzzy controllers, which allow to incorporate new knowledge with the alone incorporation of new rules in the knowledge base. Future actions will include incorporation of a higher quantity of input variable, (Temperature, previous operation Mode, etc), this will lead to improvements in the decision process.

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