Review Article

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PLC-based control system for battery use time extension

Abstract

Batteries are the shortest lifetime components of the renewable energy systems, and more especially for standalone systems. In fact, their performances reduce faster than those of the other components. For example, solar panel may just lose about 20% of their performance after 25 years of functioning compared to batteries which performances drop after just about 5 years of usage. In this paper, we propose a Programmable Logic Controller (PLC) based control system for extending the batteries time of use. This system permit an adjustment of the existing storage system autonomy as soon as its capacity is getting drop with time, instead of taking it completely off. In fact, the storage system after a certain time of use usually just drop in effective capacity, or we may be in a need of adjusting the entire installation so as to follow the new power expectation and the desired autonomy of the adjusted installation.

Keywords: standalone energy system, battery set, power & autonomy extension, battery lifetime, economical constraint

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Introduction

Battery performances reduce faster than those of the other components of renewable energy systems. Considering solar system for example, solar panel may just lost about 20% of their performance after 25 years of functioning[1] compare to batteries which performances drop after just about 5 years of use.[2] This drop affects directly the initial autonomy duration of the system. In fact, basic criterions govern the design and installation of a standalone renewable energy system for a particular case study. Amongst those are the capabilities of a system to cover the off time of the batteries charging source (for example sun for photovoltaic system and wind for wind system); that is the period of time during which only batteries will be supplying the loads. The battery set of a standalone system is then usually calibrated based on that autonomy duration and also on the worst climatic conditions. When battery capacity are getting drop and by then not covering the initial autonomy period, the usual solution is to take off that set of batteries for a new one, since an equivalent battery from a mixture of used and unused batteries will adopt a lowest battery capacity. That solution consisting of taking off the inefficient set for the new one just because of the drop in initial capacity set for the desired autonomy has economical and environmental consequences. An economical consequence is that we are giving out a component which still has quite enough material to be used. An environmental consequence is that, in addition to the fact that we will spend energy to ensure a good handling of that set of battery so as to avoid environmental destruction by chemical materials, the energy invested to manufacture that set of battery may has not been payback by the time we are taking it off. The above described situation is what users are facing in Cameroon with the lead acid batteries which are by far the most available energy storage components.

It is then a good design strategy to propose a system to handle two sets of batteries which can function alternately so as to take care either of a drop in capacity or of a desire of extending the initial power installation. Also, the use of two different sets of batteries for an installation is in the line for tracking the climatic changing conditions which can be a factor of adjusting the initial battery set capacity; in addition when climatic conditions are good, even just some time during the worse season, the batteries are very quickly fully charged while sunlight in case of photovoltaic system still ongoing. In such cases, a control system can be used to switch from one set of batteries to another.

This proposal will of sure prolong the use time of the batteries, reduce the long run cost of a standalone system, facilitate the adjustment of the installation to track the climatic change, and reduce the request from the environment in term of input materials manufacturing regularity.

This paper is organized into five sections. Section 2 discusses the accumulator band challenges and constraints for standalone systems. Section 3 presents a brief functioning description of the proposed system. Section 4 presents the system calculations as well as the results from the experimental test. Finally, Section 5 draws the conclusion and future work.

Energy accumulator band for standalone systems and challenges

For a given solar system and considering the accumulator characteristics, there are exigencies to fulfill for the storage system to be charged, although it can be fully charged in a very short time by sunny days. In fact, the design of a solar system for a particular area is mainly based on its worse climatic conditions. The capacity of the storage system is then calculated so as to feed the charging request conditions from the manufacturer. Because of that, during a short period of good weather, the storage system is fully charged very early. Also considering the situation where there is a need of extending the storage system, the mixture of batteries (be it from the same manufacturer or not) of different ages as illustrated in Figure 1[3] is not allowed because the limit of charge as well as the limit of discharge will be limited by the old batteries or by one type of battery (set of batteries having the same age but different manufacturers). In fact, in most of countries where manufacturers are not based, it is rare to get the same type of batteries on sale for even just few months.

The available types are very fluctuating all the time depending on the making profit of selling companies. It becomes necessary to design a system capable of monitoring different sets of storage batteries so as to accompany classical charge regulator having only one terminal dedicated for only one set of batteries.

For this above described issue, the proposed PLC based control system is to help in switching from one set of batteries to another when necessary.

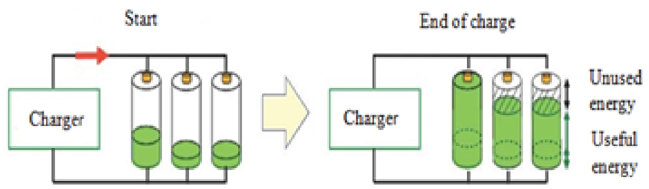

Figure 1 Effect of charging and discharging coupled batteries with different characteristics.[3]

Functioning description

The block diagram is presented in Figure 2. A PLC is used as a control system and the switches are all n-type MOS transistors. The system should keep sensing the battery currently being discharged and disconnect it (connecting the second set if charged) as soon as its discharge has reached a desired limit. This is important because failure to do it may cause an over discharge of accumulators or the load to be disconnected (eventually by the inverter).

As soon as one set is relatively full, the PLC switches the charge controller to the empty one when it stops being in use. In order words, the unused battery set is being charged while the other one supplies the load. As soon as the battery being charged gets full, we do not wait for the other set to be fully discharged rather; we switch the load to fully charged batteries while charging the second set. Moreover, if for any reason both batteries get fully discharged (during the night for instance in standalone solar system), the control system maintains one set of batteries to the charge controller until it will be fully charged before the load can be supplied.

Design, implementation, tests and results

Design and Implementation

The block diagram of Figure 2 is the entire standalone energy production source integrating that PLC control system for batteries monitoring.

This solar energy production source is a 24V DC. The switching system consists of three 3 main circuits:

Sensor circuit: The sensor circuit provides DC signals indicating the current state of the batteries. As characteristics, the sensor output control signal is a 24V DC from PLC. The reference voltages set at 22V indicate "battery discharged". The full charged state is handled only by the charge regulator and is not of major importance in this sub-battery monitoring system. In fact, although the discharged state of batteries is also handled by the charge regulator, it is necessary for the sub-system to take control so as to switch from an empty battery set to the one with more energy.

Power switches: The design of any of the power switch unit indicated in Figure 2 by S1, S2, S3 and S4 consists of many NMOS connected in parallel so as to share the high current flowing through. Three were connected in parallel for each switch unit in this experiment. When the gate signal arrives, depending on the condition, a pair of switches closes and connects one set of batteries to the charge regulator and the other set to the load. From the datasheet of the NMOS (IRF540) used,[4] a minimum of 10V for V_{GS} is required for full conduction. Considering the presence of the batteries at the source, the control voltage V_G should be giving by

$$V_G = V_S + 10V$$

Considering this above relation expressing V_G, for a discharged battery at 22V, the least V_G expected for full conduction of switches is then 32V. Giving that the expected switch control voltage from the PLC is only a 24V, we have used the boost converter to adjust it to the level able to control the power switches.

Boost converter: As indicated above, this circuit is to boost a 24V to at least 32V required to control the power switches. The proposed circuit has adjusted that signal to a 36V DC. The main circuit and equations governing the boost converter have been exploited from [5] in order to deduce its components values. We use 12kHz as the boost transistor control frequency, the inductor ripple current of 0.02A, a capacitor ripple voltage of 0.08V and 10kOhms for the resistor R.

Considering these pre-define values, we evaluated a duty circle D of 0.5, the inductor L of 25mH and a capacitor of 0.9375µF.

For the oscillator generating the 12 kHz for the boost transistor control frequency, we have used the 555 timer.[6]

Test and results: A series of tests have been conducted and the result obtained is presented in Figure 3. The switching between two sets of accumulators is presented for a discharge limit of 21.2V; the response time obtained is 55.52µs as we can see from the oscilloscope captured screen of Figure 3.

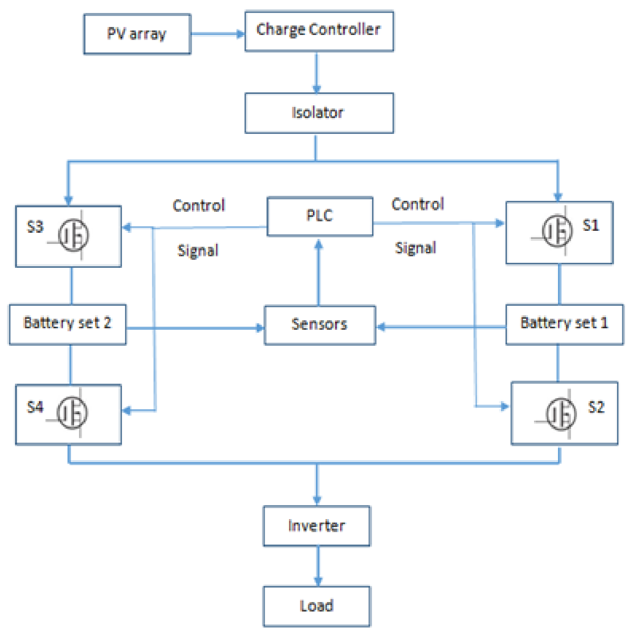

Figure 2 Energy production source block diagram integrating the proposed switching system.

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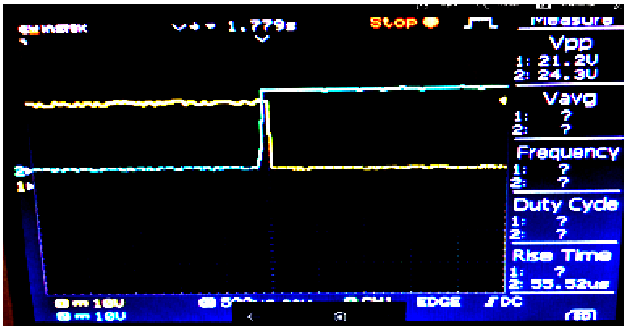

Figure 3 Switching time response between the two sets of batteries.

Conclusion

In most developing countries like Cameroon, the installation of a standalone system remains a luxury reserved for rich family although the need in rural area is critical. Considering the fact that batteries are one of the most expensive components of standalone system, the above controlled switching system giving a possibility of two ports for eventual different batteries connection will leave open a possible adjustment of existing accumulator bands. The particularity of this switching system is that it firstly permits the accumulator band capacity to be adjusted without getting completely off the old one since it may have just dropped in effective capacity; it secondly leave open a possibility of adjusting an existing installation so as to meet the new requirement either because of the climate change or to meet the new requested power; it thirdly avoid a battery set to be both under charging and discharging process simultaneously. Although this switching time response of 55.52µs can be improved, it is small enough so as to ensure the continuity in the supplying of the load during the transition from one supply source to another.

In future scope, we are working out to integrate this proposed switching system in the existing one battery terminal charge regulator so as to have a charge regulator model with two ports for battery sets.

Acknowledgements

None

Conflict of interest

The author declares there are no conflicts of interests.

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