Photovoltaic - Battery Operated Electric Vehicle with an Energy Management Strategy

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Abstract. Hybrid energy storage systems have many advantages, including the use of multi-input converters, such as reduced part count, flexibility power, and absolute control of energy sources. In these systems, an Energy Management Strategy must wisely determine the power levels of the sources. Energy management strategy for photovoltaic/ battery including a bidirectional multiple - input converter electric vehicle is presented in this article. The proposed Energy management strategy not only regulates the state-of-charge of photovoltaic. The battery power profile is also smoothed by using a fuzzy controller and a rate limiter. Since the energy transfer between battery and Photovoltaic is free in this multi-input converter. This results in a hybrid energy storage system that is sustainable and has improved battery life. The feasibility of the proposed system is systematically tested by a simulation study and an observational framework involving an actual electric vehicle. In this paper the results proves that Energy Management Strategy for photovoltaic including electric vehicle is presented . The enhancement of the battery cycle-life is discussed because of the battery / PV hybridization based on experimental performance.

Key words: Photovoltaic, Batteries, Electric vehicle, Energy Management Strategy, DC-DC converter.

1. Introduction
Photovoltaic (PV)/ Battery hybrid energy storage systems have been thoroughly tested in electric vehicles (EVs), as this method of hybridization can fulfill the needs of an EV, including high power / energy capacity, long battery life. Power conditioning unit and energy conservation system play a key role in a hybrid energy storage systems. Among dc-dc converters used in hybrid energy storage systems, multi-input converters are popular since they are cost-effective, easy to control and can fully
control the ability of energy storage. Several works published in the literature regarding the EMSs for hybrid energy storage systems. The EMSs studied provide an effective but non-flexible approach to the issue of energy management, it basically applies the specified control principles through given rules according to the operating modes of the converter used [1]. Based on the frequency decoupling system that separates high-frequency and low-frequency power demand elements, the EMSs seek to shield batteries and Photovoltaic (PV) from sudden load shifts. For battery / PV HESSs, the principle of predictive control is used in the model, this method has the ability to forecast recent decisions are projected and operate according to these forecasts; however, an internal system-wide model is required. For a battery / PV hybrid system, an EMS based on the neural networks is reported, this approach often uses prior information gained from simulation results [2]. Hybrid systems use EMS in offline optimization techniques; these approaches are highly efficient if the load profile is well understood; but for real-time implementations, they are not suitable. It proposes EMSs focused on the Fuzzy Logic Controller (FLC). The Fuzzy logic controller can be used alone in an EMS or in combination with other techniques such as decomposition of wavelets and neural networks. A new MIC topology for EVs is suggested in a battery / PV HESS by a novel topology, a rule-based EMS is used in this paper to restrict battery power during propulsion, and to charge PV during regenerative braking. Although this approach is quite effective, it has two important disadvantages: The state-of-charge (SOC) of the PV is not taken into account and the rate of change in battery power is not limited [3, 4]. It is therefore reasonable to assume that due to too low SOC_{PV}, PV may be overwhelmed, and battery current may be too high at peak output, the battery / PV HESS may be non-operational. For a battery / PV HESS, an FLC-based EMS is given to eliminate related EMS problems provided in this paper and is checked through a simulation analysis and an experimental design with a real EV [5]. Thanks to the established FLC, the purpose of the EMS given is to control SOC_{PV} and reduce battery power peaks by means of a rate limiter. Based on experimental findings, this paper also aims to establish the impact of battery / PV hybridization on battery cycle life.

2. Proposed System

The power circuit diagram of the proposed topology is shown [6] in Figure 1. It is composed of four switches, namely, S₁, S₂, T₀, L₁, L₂ and an output capacitor denoted by C₀.

![Figure 1. Proposed Battery/PV HESS](image)

2.1. Photovoltaic Model

In this paper [7], a generalized simulation model of solar devices is adopted. The standard solar cell model is shown in Figure 2.
Figure 2. Equivalent PV Cell Prototype Circuit

\[ I_c = I_{ph} - I_D \left( \exp \left[ \frac{q(V + R_I)}{AKT} \right] - 1 \right) - (V + IR_0)/R_{sh} \] (1)

I\(_{ph}\): Photocurrent.
I\(_D\): Current of parallel diode
I\(_{sh}\): Shunt current
I\(_c\): Output current
V: Output voltage
D: Parallel diode
R\(_{sh}\): Parallel resistance
R\(_S\): Series resistance

2.2 Modes Of Operation

This MIC primarily has three distinct modes of operation, as seen in Figure 2 [8]. The first mode of operation is called as the discharge mode. In this mode, according to S1, S2, and T0 states, the output is fed by input sources. Power diodes D1 and D2 run in addition to S1 and S2, respectively. Depending on their voltage levels, regenerative braking power charges ESSs in this mode by Q0 power [9-11]. A switch labeled Q1 is attached to the battery output to be tracked in this situation. In regenerative mode, D1 and D2 are still OFF, while T0's body diode retains the inductor currents, while Q0 is OFF. The charging / discharging mode is considered the third mode of operation; this mode is caused when single input power outperforms the output power. In this case, the backup control of the other signal source is maintained. In this case, either S1 or S2 is checked for the corresponding input current to be changed to its reference value, while the T0 switch is checked for dc bus monitoring.

In Figure 3, which illustrates the active components, the associated analogue circuits for these modes are illustrated. For discharge, regenerative and charging / discharging modes, the relation between input source voltages and output voltages can be described [11, 12], based on the premise that Q1 is OFF and that only in restorative mode, PV is charged. The stable state of output, battery, and PV voltages are denoted by V\(_0\), V\(_{bat}\), and V\(_{PV}\), respectively, while d\(_{s1}\), d\(_{s2}\), d\(_{sh}\), and d\(_{Q0}\) are the duty cycles of S\(_1\), S\(_2\), T\(_0\), and Q\(_0\), respectively. Note that d\(_{s2}\) becomes 1 for charging / discharging mode, since body diode of S\(_2\) becomes ON for PV charging apparent Power in the circuit and, in the closed interval, the dimensionless number is -1 to 1. Active power is the ability of circuit to perform work at a given time. For same amount of available power transmitted, In an electrical power
system, a load with a low power factor generates more current than a load with a high power factor.

Figure 3. Operation Modes Of MIC

3. Energy Management Strategy Depending on Multiple Operating States

The Energy management strategy has a significant impact on distributed generators' fuel economy [13], dynamic performance and service life. For the proposed DC micro grid, the primary objective of the energy management plan making sure that the energy is injected into the load [14-16] and the energy used are equivalent. In particular, increasing the life of power systems and reducing the system’s cost are also important control objectives. The proposed energy conservation strategy should specifically achieve the following goals: To retain the DC bus potential reliability.

- Maintain the PV array generator running under different environmental states at the maximum output power.
- To secure the battery bank against overcharging and deep discharging.
- To prevent the output power of the PEMFC system from frequent fluctuations.
- Reducing the consumption of hydrogen by sustaining the PEMFC device and the storage battery running as much as possible at the maximum efficiency stage.

Based on multiple functional states, an effective most favourable energy management approach is proposed, Coordinating the regulation of various goals in this paper. The PV array operates mostly in MPPT mode in the usual working state. The suggested technique to effectively deliver to meet the demand power requirements [17-19] manages the PV panels and also the storage battery. The strategy will focus on multiple operating states, which are determined by the SOC battery states, net requirement for power of the system, and the distributed generation limit points.

The storage bank's SOC is split into 3 states: large SOC, standard SOC, and small SOC. Furthermore, to prevent frequent switching of the battery bank's operating condition, Applying four SOC thresholds (SOC min & SOC max are the lowest and highest SOC levels, and SOCnom1 & SOCnom2 are the top and bottom limits of its chosen SOC battery area), shifts between different states based on these two stages of hysteresis were expected. In this work, the PV / battery bank can have potential differentials between the load power and the output potential of the PV series, based on the addressed energy management strategy [20].

To keep the SOC of the battery in an appropriate range, the net demand power of the device in this strategy is described as $P_{\text{net}}$. As in low SOC condition, the PV device and storage battery will charge the battery to increase the SOC battery and provide the demand power of the system [12]. The PV device and storage battery as in high SOC state can disperse the power to decrease the SOC battery
and provide the demand power of the system. In a separate SOC condition, which would be represented as Equation (2), $P_{\text{net}}$ could be determined in real-time basis.

$$P_{\text{net}}(t) = \begin{cases} P_{\text{Load}}(t) - P_{\text{PV}}(t) + P_{\text{batopt}} & \text{LOW SOC} \\ P_{\text{Load}}(t) - P_{\text{PV}}(t) & \text{NORMAL SOC} \\ P_{\text{Load}}(t) - P_{\text{PV}}(t) - P_{\text{batopt}} & \text{HIGH SOC} \end{cases}$$

3.1 Low SOC

The battery bank expected to operate in the charging mode as much as possible to lift the SOC to an appropriate limits. In this scenario, proposed energy management method distributes reference power of the PV [21, 22]. Depending on the hysteresis cycles and the power consumption of the PEMFC system, to avoid frequent fluctuations, it works at three constant levels.

3.2 Normal SOC

The battery bank tries to maintain the SOC within the appropriate range in the second case. [23]. In other cases, the PV system will operate more at the optimum performance point to the capacity of low net demand capacity, based on the energy management plan, and operate at the control of the total energy consumption.

3.3 High SOC

In this case, to achieve an acceptable stage, the battery bank operates in the optimum performance discharge mode. In order to minimize hydrogen usage, the PV module must primarily run at minimum power levels [24, 25]. The PV will work to offer a higher output power point when the net demand power increases. In addition, situations such as a fully charged battery or a depleted batteries must be strongly regarded in the energy conservation strategy to overcome the extreme case. The battery stops loading unless the SOC batteries was really large, if the PV device stops operating at the same time with the full Energy output of the PV array $P_{\text{PV}} > P_{\text{LOAD}} + P_{\text{Cmin}}$, the PV converter switches to the mode of consistent potential from the MPPT mode of the supply of the power load. On the otherway, the batteries would stop unloading when the battery is depleted, as well as the responsive load must be withdrawn from the unit. The PV module’s total output power $P_{\text{PV}} < P_{\text{LOAD}} - P_{\text{Cmax}}$ is simultaneous.

Based on a successful optimal energy management approach, in this DC micro grid, there are different functions for the PV module, as well as the PV system[27-29] for the rechargeable battery. With a view to making full use of renewable energies, the PV module primarily operates at the usual operating condition in MPPT mode [30,31]; and in the mode of continuous potential changes to intense performing conditions. Battery bank’s charging and discharging is regulated by the Strategy of Energy Management to realise the fair distribution of power between the PV and battery. Meanwhile, in constant voltage mode, the PV converter works to preserve the DC link potential reliability and helps to balance the flow of power. The PV reference potential $P_{\text{ref}}$ is the output of the energy management system (EMS) supply, discrepancy among the $P_{\text{ref}}$ peak load as well as the $P_{\text{ref}}$ standard potential of the PV gives the $P_{\text{bat}}$ storage reference output voltage. To get the battery bank reference current, $I_{\text{bat}}$, the storage reference potential $P_{\text{bat}}$ is separated by the bus frequency or frequency of the battery. Eventually, the discharge or loading current is altered to this value by an internal regulator.

4. Simulations and Results

The typical model of the converter is proposed in this paper and developed in the MATLAB / Simulink context. Moreover, the battery and PV are designed in the same way. The battery parameters are shown in Table 1. A Li-ion battery with a rated 110-Ah capacity and a rated voltage of 100 V and...
a rated voltage of 125 V are considered here. In the simulation, the battery and PV are modelled by (3)-(5) and (6)-(8), respectively,

\[ i_{\text{BAT}}(t) = i_{L1}(t) d_1 \]  \hspace{1cm} (3)

\[ v_{\text{BAT},OC}(t) = v_{\text{BAT},OC}(t_0) - \frac{1}{C_{\text{BAT}} \cdot t_0} \int_{t_0}^{t} i_{\text{BAT}}(t) \, dt \]  \hspace{1cm} (4)

\[ v_{\text{BAT}}(t) = v_{\text{BAT},OC}(t) - R_s i_{\text{BAT}}(t) \]  \hspace{1cm} (5)

\[ i_{\text{PV}}(t) = i_{L2}(t) d_2 \]  \hspace{1cm} (6)

\[ v_{\text{PV},OC}(t) = v_{\text{PV},OC}(t_0) - \frac{1}{C_{\text{PV}} \cdot t_0} \int_{t_0}^{t} i_{\text{PV}}(t) \, dt \]  \hspace{1cm} (7)

\[ v_{\text{PV}}(t) = v_{\text{PV},OC}(t) - R_{s,\text{PV}} i_{\text{PV}}(t) \]  \hspace{1cm} (8)

In (3)–(8), current values of battery, PV, \( L_1 \), and \( L_2 \) are represented by \( i_{\text{BAT}} \), \( i_{\text{PV}} \), \( i_{L1} \), and \( i_{L2} \), respectively. In general, \( V_{\text{BAT}} \) and \( V_{\text{PV}} \) are the battery and PV terminal voltages, while \( V_{\text{BAT},OC} \) and \( V_{\text{PV},OC} \) are the battery and PV open-circuit voltages. \( C_{\text{BAT}} \) denotes the equivalent battery power and \( R_s \), Serial resistance (ESR) equivalent of the battery, while \( C_{\text{PV}} \) signifies the normalised PV capacity; \( R_{s,\text{PV}} \) and \( R_{p,\text{PV}} \) are the parallel resistance of ESR and PV, collectively. This simulation analysis considers the urban dynamometer driving schedule (UDDS). UDDS has been created by the United States Environmental Protection Agency to determine the use and emissions of fossil-fuel vehicles; it illustrates the conditions of urban traffic, including Accelerations and regular pauses. The power demand as per the UDDS is shown in Figure 4. Two examples are taken into account here. The initial \( \text{SOC}_{\text{PV}} \) is 0.95 in the first case, while the initial \( \text{SOC}_{\text{PV}} \) is 0.85 in the second case. The goal of taking these two cases into consideration is to emphasize that the suggested solution is able of managing PV voltage. Make sure that the base power on the decision boundary of the FLC is 60 kW, taking into account the maximum power of output as per the UDDS. The reference output voltage is 144 V, and the original voltage of battery is 110 V.

The PV power and PV average power differences in both cases. The PV manages to experience drastic modifications in the demand for production capacity. from varying PV power profiles. In addition, the average PV power in the first case is 0.83 kW, although In the second case, it is-1.12 kW. Figure 4 displays the simulation results of the curve of IV.
Figure 5 displays the curve of PV in two instances. The first finding that can be derived is that the battery power is never negative. In addition, one can see that the description of PV and battery power levels shows that battery power is substantially finer than expected. It can be noted that the average battery power values in the first scenario and the second instance are 4.75 and 7.09 kW respectively. Compared to the first case in the second instance, greater battery capacity is noted because the built FLC allows the battery to also charge the PV in the second case. In both cases, SOC\textsubscript{PV} variations are shown in Figure 6. It can be shown that in the first case SOC\textsubscript{PV} has a steady decline while in the second case it has a growing trend. This means that the PV is generally discharged in the first case, but it is usually compensated by remembering the assumptions in the second instance from figures 4 and 5.

In addition, oscillations in SOC\textsubscript{PV} indicate instances of charging of battery and discharging of battery; increasing and decreasing SOC shows PV charging and discharging, respectively. While PV requires to be charged in the second instance, it is worth noting that, due to the rate limit, it is also discharged and used in the suggested technique, as well as a consistent battery power profile.

5. Conclusion

For a Battery / PV HESS, this paper offers a FLEMS. The HESS consists of a non-isolated bi-directional multiple input dc-dc converter that can generate power flow through each source of input and output terminal. An EMS was required to achieve the state of charge PV while filtering the battery power profile. By implementing this EMS, intended to make sure the hybrid system's achievability and to reduce the peak of battery capacity, thereby increasing the life of the battery cycle. After evaluating the suggested method, their performance was tested through a UDDS-based simulation analysis. Then an experimental system was developed using an EV definition is based on a control scheme to analyse the proposed rules of the EMS and control strategy and to verify them.
under actual traffic conditions. Computation and observational investigation have shown that it functions like expected were developed by the EMS. Eventually, it has been shown that the battery life range of about 55% can be reached related on a model of life cycle of battery and performance in experiments. Because of the PV HESS/battery. It is evident that these acquisitions improve the battery life and ensure the hybrid system’s feasibility considering the converter’s specified input voltage range.

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