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Battery and Super Capacitor for Photovoltaic Energy Storage: a Fuzzy Logic Management

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Abstract:

This take a look at offers an approach of the voltage regulation of DC bus for the photovoltaic energy garage by way of the usage of amixture of batteries and super capacitors (SCs). The batteries are used to fulfill the power requirements for a distinctly long length, while the SCs are used to fulfill the immediately electricity demand. The power management strategy is developed to control the power flows among the storage gadgets by means of selecting the finest working mode, thereby to making sure the continuous supply of the load by way of retaining the country-of-fee (SoC) of SCs (SoCsc) and the SoC of the batteries (SoCbat) at applicable stages. This energy control method is executed by means of the usage of the bushy logic supervisor. The validation outcomes show the effectiveness of the proposed method**.**

Keywords **— Fuzzy logic, Super capacitors, PV cells.**

I. Introduction

The photovoltaic (PV) era has turned out to be a favoured form of the renewable strength era because it's miles seen as sustainable and easy [1]. The irradiance fluctuation of PV electricity may additionally reason immoderate versions of the output voltage, strength and frequency. However, storage systems have been used to design active mills, which might be capable of offer a strength reserve in much less fluctuating electricity [2–4]. The most commonplace sort of storage of hybrid structures is the chemical garage in the form of a battery. The present day batteries provide high discharging efficiency and higher power storage density, but they go through a especially low power density. Super capacitors (SCs) have low inner resistance. As a result, a mixture of battery and SC may additionally mitigate the charge ability impact of high pulsed discharge present day [5]. as a result, SCs are, presently, used as storage gadgets in indeed, this mixture is an exciting solution for enhancing system overall performance, in phrases of the dynamic behaviour of the batteries and their lengthy Life styles [9]. This mixture of batteries SCs became developed correctly in many applications like power storage machine and hybrid strength source for car packages [10, 11], energy garage gadget in independent micro grid [12] and hybrid strength assets for us packages [13]. A fuzzy common sense-primarily based algorithm is proposed to resolve. A fuzzy common sense-based algorithm is proposed to remedy the energy management problem and the strength distribution between the batteries and SCs. however, the fuzzy logic manager (FLS) does now not require complicated mathematical fashions as utilized in traditional control. The manage by way of FLS of the power control machine(EMS) is already used in many programs like, EMS for poly generation micro grids [14], overall performance evaluation of a grid independent hybrid renewable energy system [15] and EMS for DC micro grid systems [16]. but, on this work, it used to making sure the continuous deliver of the load by using keeping the nation-of charge(SoC) of the SCs (SoCsc) and the SoC of the batteries(SoCbat) at proper degrees to keep away from the dangerous of batteries and SCs. The final of this paper is organised as follows: phase 2 affords the description and modelling of the system beneath observe. The bushy logic EMS is addressed in section three to illustrate the effectiveness of the proposed EMS, a few simulation results are offered in section 4; and finally, in section five, conclusions are given.

II. Description and modelling of the system under study

A fuzzy logic-primarily based algorithm is proposed to clear up the power control problem and the energy distribution among the batteries and SCs. But, the bushy good judgment manager (FLS) does not require complex mathematical fashions as utilized in classic manage. The control by FLS of the energy management system (EMS) is already used in lots of programs like, EMS for poly generation micro grids [14], performance evaluation of a grid independent hybrid renewable power gadget [15] and EMS for DC micro grid systems [16]. However, on this paintings, it used to making sure the continuous deliver of the load by means of maintaining the state-of charge(SoC) of the SCs (SoCsc) and the SoC of the batteries(SoCbat) at applicable degrees to keep away from the damaging of batteries and SCs.

The remaining of this paper is organised as follows: phase2 affords the outline and modelling of the device under examine. The bushy common sense EMS is addressed in phase 3. To demonstrate the effectiveness of the proposed EMS, some simulation results are offered in phase 4; and sooner or later, in segment five, conclusions are given.

$C_1 = C0 + CV \cdot v_1$ (1)

By neglecting the leakage current, the equivalent circuit of the SC is given by the following equation:

$U_{SC} = NSsc/vSC = NSscv_1 + R_1 I_{SC} NPsc$ (2)

Where U_{SC} and I_{SC} are the SCs pack voltage and current, respectively; v_{sc} is the elementary SC voltage. NP_{sc} and NS_{sc} are the number of parallel and series branches of the SCs connections, respectively. The voltage V_2 is given by

$V_2 = 1/C_2 \int i_2\, dt = 1/C_2 \int 1/R_2 (V_1 - V_2)\, dt$ (3)

The current i_1 in the main capacitor C_1 is expressed in terms of the instantaneous charge Q_1 and C_1 as:

$i_1 = C_1 dv_1/dt = dQ_1/dt = C_0 + C_v \cdot V_1 dv_1/dt$ (4)

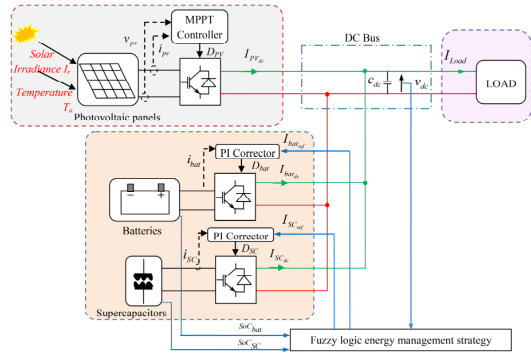


Fig. 1 Configuration of the proposed hybrid system by using a combination of batteries and SCs

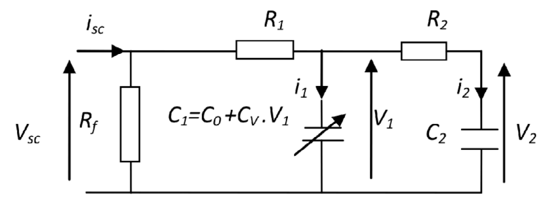


Fig. 2 SC simplified circuit: two-branch model

Table 1 Units for magnetic properties

Parameter	BCAP3000
Normal Capacitor	3000 V
Rated Voltage	2.7 V DC
Maximum Operating Voltage	2.85 V DC
Maximum ESR, DC initial	0.29 mΩ

Table 2 Parameters of two-branch model of SC

Parameter	Value
R	0.8 mΩ
C	2170 F
Cv	520 F/V

where−40+70°Cwhere the charge Q_1 is given by

$Q_1 = C_0 \cdot v_1 + 1_2/Cv$ (5)

Then the voltage V_1 is defined as follows:

$V_1 = -C_0 + C0_2 + 2CvQ_1$ (6)

The parameter specifications of SCs are listed in Table 1. The parameters of the two-branch model are given in Table 2.

CIEMAT battery model

The battery version used on this work is the CIEMAT model it's far based on the electrical diagram provided in Fig.2 three, according to which the battery is defined through simply factors: an inner resistance R_i and a voltage source E_b. It has two operation modes: the fee and the discharge the following equation represents the relation among the voltage V bat and the modern I bat of battery with n_b cells in collection:

$$V_{bat} = n_b \cdot E_b + n_b \cdot R_i \cdot I_{bat} \quad (7)$$

The capacity of the battery delivers the quantity of energy C_{bat} that the battery can restore according to the average discharge Current I_{bat}. This last is established with respect to discharge current I10 corresponding to the rated capacity

$$C_{bat}/C_{10} = 1.67/1 + 0.67 \cdot (I_{bat}/I_{10})0.9 \cdot 1 + 0.005 \cdot \Delta T \quad (8)$$

III. Fuzzy logic EMS

3.1 Control and management of DC bus

The PI corrector calculates the reference current of DC bus Idcref to maintain the bus voltage at the reference voltage Vref = 400 V. are delivered by the EMS. These reference currents will allow to keep the DC bus voltage constant regardless of the load behaviour and the variation of the power extracted from PVgenerator. The batteries and/or SCs make certain the law of the DC bus voltage whilst a hassle happens on a detail which include SoC, energy failure, and variant of sun irradiation. At any time, the sum of the reference currents, I_{sc}ref and I $_{bat}$ref, should be identical to Idcref

$$Idcref = I_{sc}ref + I_{bat}ref \quad (9)$$

The behaviour of the DC bus can be modelled by the following equation:

$$Cdc/dvdcdt = i_{sc}dc + i_{bat}dc + i_{p}vdc - i_{Load} \quad (10)$$

whereI_{SC}dc, I_{bat}dcand$I_p$vdc, represent the DC currents of SCs, batteries and PV panels, respectively. I_{Load} is the load current. C_{dcis} the central bus capacity that will allow imposing a common DC bus voltage to the load and all other sources. These capacitors filter the power fluctuations from the adopted static converters.

3.2 Energy management system

The reference current of batteries I_{bat}refand reference current of SCs I_{SC}refare. A low-pass filter is applied to the DC bus current to divert sudden power variation into the SCs. The reference current of the DC bus *I*dcrefpasses in this filter to construct the batteries current reference *I*batref′.

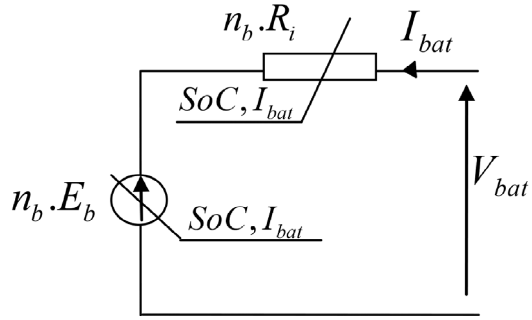


Fig. 3 Equivalent electrical diagram of N_b battery elements in series

The SCs current reference I_{SC}ref ′ is determined by the difference between Idcrefand I_{bat}ref ′ .To elaborate the reference currents, the SoC of batteries and the SCs must be taken into account. Three switches are used to select the exact reference current, they are controlled by fuzzy logic in function of I_{bat}ref.

IV. Simulation results and validation

The studied gadget has been applied with specific operating situations inside the MATLAB/SIMULINK environment. To make sure the continuous deliver of the weight and to do not harm the batteries and the SCs we have to maintain the SoCof the SCs (SoCsc)and the SoC of the batteries (SoCbat) at acceptable ranges. The low price of rate of batteries and SCs are 25% and the excessive price of rate of batteries and SCs are ninety five%. All simulation assessments are performed by using a time time constant of the low pass filter at τ = 6 s. The structure of simulation setup diagram is represented in Fig. 4.The first simulation test, as shown in Fig. 5, was carried out with a constant solar irradiance of 1000 W/m2 and with different values of load currents [120, 200, 120, 90 A]. The initial SoC of batteries is considered at 50% and the initial SoC of SCs is considered at 29.5%. This simulation test is executed with a classic control in MATLAB/SIMULINK and without FLS. Fig. *5a* represents the PV current I pv and load current Iload. The variation the batteries current and the SCs current are shown in Fig. 5b and *c*, respectively. The SoC of SCs (SoCsc) is represented in Fig. 5d. In the case where SCs are fully discharged, when the SoC sc reaches 25%, SCs must stop to discharge and the batteries give all the currents demanded by the load, but is not the case, SCs continues to give current fluctuations (between 15 and25 s) and the batteries also. In the follow results, we propose to use the management of energy distribution by the FLS. The second simulation test is executed with the same condition sof the first one (solar irradiance, load current, the initial SoCof SCs and initial SoCof battery).Fig. 6*a* represents the batteries and the SCs currents, the batteries react more slowly to the needs while the SCs provide the transient currents. Fig. 6b shows the variation of the PV current Ipv and the load current Iload. The SoC of SCs (SoCsc) isrepresented in Fig. 6d. The DC bus voltage is shown in Fig. 6c, it's considered constant 400 V with small variations. In the case where SCs are fully discharged, the SoCsc reaches 25%, SCs stop to discharge and the batteries give all the currents demanded by the load.via evaluating the primary and the second simulation take a look at, we note that the energy control method by means of the usage of FLS gives exceptional consequences. but, SC stops to discharge and the batteries deliver all the currents demanded with the aid of the load. The 1/3 simulation check changed into carried out with a regular sun irradiance of 1000 W/m2 and with different values of load currents irradiance of 1000 W/m2 and with different values of load currents [120, 90, 135, 80 A] as shown in Fig. 11.The initial SoCbat is considered at 50% and the initial SoCsc is considered at 94%. The PV current Ipv and load current I Load re represented in Fig. 11a where the weight cutting-edge is considered constant at 120 A and the PV modern-day is considered variable. Fig. 7b illustrates the batteries current and the SCs modern-day, the batteries react extra slowly to the desires whilst the SCs offer the transient currents. The DC bus voltage is shown in Fig. 7c. The SoCsc is represented in Fig. 7d.We be aware that inside the case in which SCs are absolutely charged, the SoCsc reaches ninety five%, SCs prevent to price. Therefore, the batteries absorb all of the difference currents between the load and the PV modern-day. We demonstrate for the duration of simulations of PV strength garage by means of the use of a aggregate of batteries–SCs that the SCs reply immediately to the need of the load. The batteries react more slowly to the needs while SCs provide the transient currents as demanded by the Ibatrefand ISCrefdue to the use of the low pass filter. The SC current compensates the difference between the batteries current and load current. Consequently, the proposed of the EMS supervisor, based on fuzzy logic, represents a reliable and efficient energy management. However, the simulation results prove the effectiveness of the proposed strategy by keeping a DC bus voltage at 400V and allow maintaining the SoCsc and SoCbat at acceptable levels.

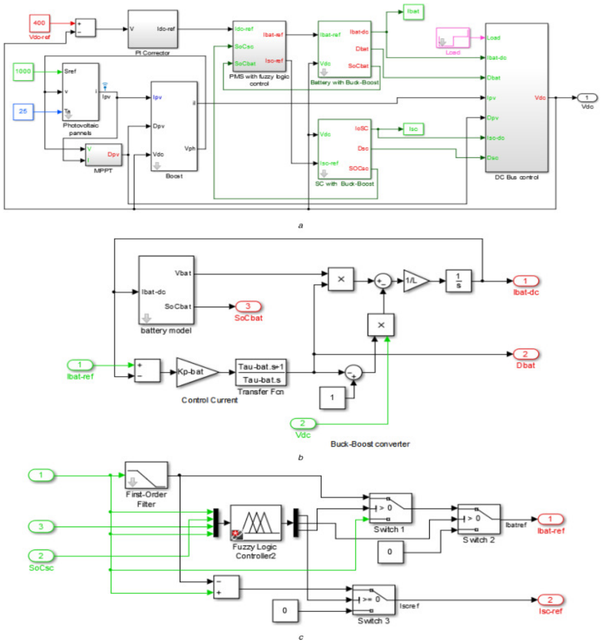
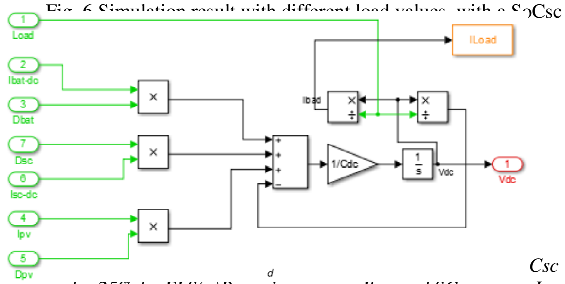
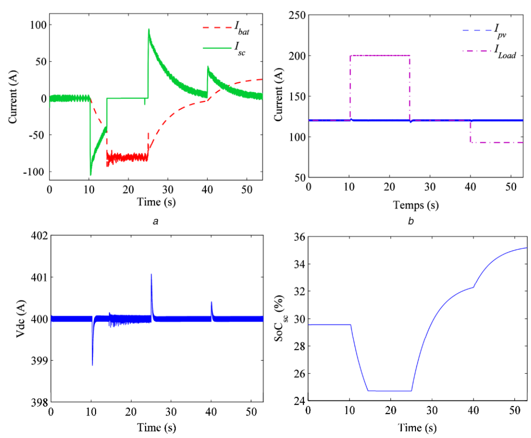


Fig. 6 Simulation result with different load values, with a SoCsc

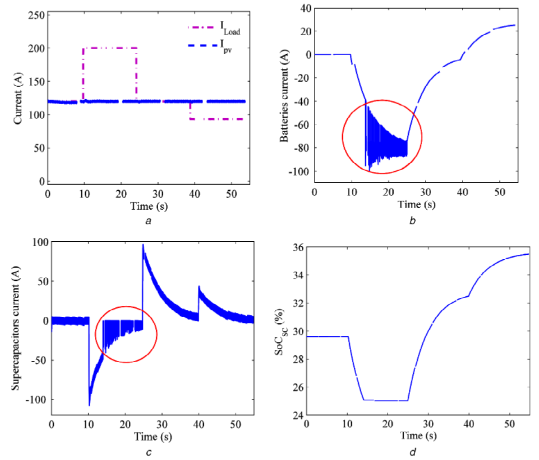


Csc under 25% by FLS(a)Batteries current Ibat and SCs current Isc, (b) PV current Ipv and load current ILoad, (c) DC bus voltage, (d) SoC of SCs (SoCsc)

Conclusion



On this project, a management strategy of PV power garage, using battery–SC combination, has been evolved. To this stop, a manage technique and regulation of the DC bus voltage become proposed that allows you to cope with the variation of the weight and the fluctuation of the solar irradiation. The diagram of EMS used turned into primarily based on FLS to hold the batteries and SCs atad missible intervals of their SoC. Simulation consequences with special values of load and different values of sun irradiation prove the effectiveness of the proposed approach electricity management.



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