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Development of an off-grid solar PV system with battery-supercapacitor hybrid energy storage

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In off-grid photovoltaic (PV) systems, the charge controller is a significant device since the system's end-to-end efficiency depends on its efficiency. Currently, the commercially available MPPT charge controllers have an average efficiency of 90%. Supercapacitors' (SCs') high energy density compared to traditional capacitors makes them used as energy storage devices. But theoretically, 50% of energy loss will occur in the capacitor charging loop if we charge it directly connecting to a power supply. According to the supercapacitor-assisted loss management (SCALoM) theory, inserting a useful resistive load into the capacitor charging loop, a portion of the above wasted 50% of energy can be utilised for beneficial work. This paper proposes a novel off-grid PV system with a battery-SC hybrid energy storage. This system utilises the SCALoM theory using the combination of a charge controller and battery as the useful load in the capacitor charging loop, while PV panels are used as the external power source. To achieve maximum use of the SCALoM theory, the SC must be kept under partially charged condition. An electronic switching network consisting of nine electronic switches was designed to realise this. Two SC banks, SC-1 and SC-2 were embedded in the prototype system. The proposed system operates in four different modes: SC-1 charging mode, SC-2 charging mode, SC bypass mode, and night mode. These modes are defined by the state of each switch in the switching network and the voltage of both SC banks. In SC-1 and SC-2 charging modes, the relevant SC bank is connected in series with the PV panels and charge controller while a DC load is connected in parallel to the SC bank. In this mode, the remaining SC bank is discharged through another DC load. In SC bypass mode, the operation of the system is the same as the typical off-grid PV system because both SC-1 and SC-2 are disconnected from the system so that the PV panels are connected in parallel with the charge controller. In this mode, DC loads are connected to the battery. In night mode, an SC bank is connected in series to the PV array and the charge controller and DC loads are connected to the battery again. For maximum utilisation, this system must be operated in SC-1 and SC-2 charging modes as much as possible throughout the day. The overall operation of the system is controlled by microcontroller-based control circuitry. This system achieved end-to-end efficiencies of 87.36%, 87.50%, 75.68%, and 93.28%, respectively, for SC-1 charging, SC-2 charging, SC bypass, and night modes, respectively. Therefore, it can be concluded that the end-to-end efficiency of an off-grid PV system can be increased by implementing a supercapacitor in a series configuration to the solar panel and to the charge controller.

Keywords: Charge controller, Energy efficiency, PV systems, SCALoM theory, Supercapacitors

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