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Plug-in electric vehicles integrated into a power distribution system with a dynamic voltage regulator and energy storage

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ABSTRACT

Because it eliminates pollution caused by internal combustion engines (ICEs) and decreases reliance on fossil fuels, electric vehicle technology is rising in prominence. Since an electric vehicle's performance is heavily reliant on the limited amount of electricity supplied by a battery, optimising the power flow is crucial. Since electric vehicles may provide power backup to the grid and local loads, lowering the peak load and filling the valley point, their incorporation into the distribution grid is increasing at a quicker pace. Electric vehicles are popular among software professionals because of their commitment to green values. The car's batteries are connected to the grid monitoring facilities for the company's State of Charging (SOC) charging stations in the parking garage. Batteries will be charged to 100% SOC when renewable power is available, in the form of solar energy. In such case, the PV system's overflow power may be sent into the load and the grid. The vehicle's batteries will function as an uninterruptible power supply (UPS) and provide vital load support at a condition-based Allowable State of Charge (SOC). The number of automobiles available during a given shift determines the overall battery capacity for that day. This study recommends using the electric vehicle's battery backup as an uninterruptible power supply (UPS) for a software company, and also as a means of bolstering the Dynamic Voltage Restorer (DVR) in the event of a distribution system malfunction. Furthermore, the DVR designed for EVs automatically corrects for voltage harmonics, voltage sag-swell, and voltage interruptions introduced by the distribution system, hence improving the power quality of the whole EV system without the need for any extra compensation equipment. All aspects of the system are modelled in MATLAB/SIMULINK, and the results confirm the viability of the suggested goal.

1. INTRODUCTION

Because of its ability to reduce emissions and improve fuel economy, the hybrid electric vehicle (HEV) is a promising new development in the automotive industry. The ability to create sinusoidal voltages with just fundamental switching frequency and nearly little electromagnetic interference is how a multilevel inverter manages the electric drive of a high-power HEV and improves its performance. Hybrid electric vehicles (HEVs) are more fuel efficient than conventional cars because of the engine's optimised functioning and the vehicle's ability to collect kinetic energy while braking. The plug-in hybrid electric vehicle (PHEV) option allows the car to be driven entirely on electric power for up to 30-60 kilometres. Electricity produced from renewable sources like wind and solar, as well as nuclear power, is used to charge the PHEVs overnight. Using hydrogen as fuel to generate energy, fuel cell vehicles (FCV) are almost pollution free [1]. In the event of a blackout, the FCV may serve as a backup power source by supplying energy via its V2G connection to the electric power grid. FCVs are not yet accessible to the general population because of the difficulties associated with mass-producing and storing hydrogen and the technological constraints of fuel cells. There is a good chance that HEVs will become the standard in high-performance propulsion in the near future. Most fuels and power plants are suitable for hybrid systems. As a result, it cannot be considered a bridge technology. A wide variety of electric parts, including electric machines, power electronic converters, batteries, ultra capacitors, sensors, and microcontrollers, are used in HEVs and FCVs. Existence of conventional internal combustion engines (ICE), mechanical, and hydraulic systems does not precludes the presence of these electrified components or subsystems. There are new challenges in the design of advanced power train components such as power electronic converters, electric machines, and energy storage, as well as in power management, power train system modelling and simulation, hybrid control theory, vehicle control optimization, and power train component design. At the very least, a substantial increase in the number of plug-in electric vehicles (PEVs) would need a substantial increase in the amount of network power available for charging such a substantial increase in Overall, the present force structure cannot handle the added workload [2].. As more and more people take their electric vehicles out and about, there has been a corresponding increase in interest in charging infrastructure, such as the installation of charging stations in parking garages and covered parking lots.

Long-distance workers may need easy access to charging stations to make sure they can make it home at the end of the day. Even while plugging in isn't mandatory, many EV owners do so to reduce battery wear and shorten the charge release cycle. If there aren't enough places to plug in, people may be less likely to embrace EVs, and that might contribute to broader concerns about their safety.

Also, smaller batteries and hence more modest cars are necessary to meet consumer concerns [3] if a charging infrastructure is accessible at the workplace. To accommodate the growing demand for charging systems, it is necessary to meet a few prerequisites beyond the proximity of charging stations, such as as much as feasible and the electrical circuits that enable charging [3]. Charging stations that can manage many vehicles at once with the same technology are one possibility. If many cars are supposed to benefit from a charging station at the same time, then the station's various components need to be shared. Sharing the interface port means safely stopping to different vehicles immediately, sharing the circuit means apportioning the available energy to not over-load the circuit, and sharing as much as possible means acutely booking charging while keeping the end goal in mind to maintain a key distance from peak use. To meet this need, engineers devised a method for charging electric vehicles (EVs) that may safely expand the number of EVs connected to a circuit by dividing the available power among them in a more equitable manner [4].

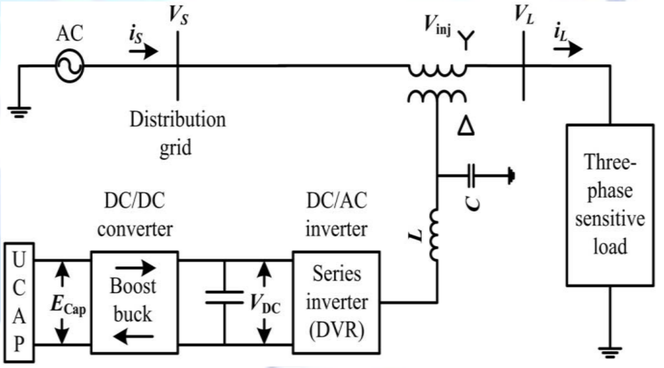


Fig.1. One-line diagram of DVR with UCAP energy storage

2. PLUG-IN ELECTRIC VEHICLE WITH PV

Sometimes, manufacturers will suggest having a DC/DC battery charger integrated into the dc connection of the PV structure's connection to the grid. The control estimate ensures the PEV battery is charged from the most efficient source by evaluating the power produced by the PV and the power consumption of the PEV. Different scenarios are shown in light of the discrepancy between PV control and the store's demand. The flow of electricity in a PV halting area is managed in the case of by a system of computer-controlled swaps [10]. PEV chargers and the electrical grid are connected through computer-controlled data exchanges, with PV panels of varying ratings serving as the interconnecting medium. The exchanges route all of the power generated by the PV systems to the PEVs, the grid, or both, depending on the available light. Through a series of DC/DC converters, a few PV sheets are connected to the dc transport system.

The DC/DC converter does an excellent job of regulating the power going to the PEVs in light of a few fixed locations of voltage suppression for the dc transport system. In a move that defies common sense, the energy conversion unit powers a three-way flow of vitality between the power system, PV modules, and PEVs. A few manufacturers have presented the idea of DC transport hailing as a means to construct energy to dc stacks for a micro grid. They have likely used this strategy to charge PEVs in a micro grid region more than once.

This magnificent charging station has two modes of operation: independent and system-related. The fluctuation in DC interface voltage levels prompted by the shift in sun-positioned protection fuels the switching between modes. The controller shifts the charging of PEVs to a non-peak time of day during the months with less solar protection and a higher stack on the course transformer.

Since the suggested control figure uses only one parameter—the DC associate voltage—to negotiate the charging station's energy flow, it is easy to understand and implement. It enables plug-in electric vehicle charging with little grid imperativeness and no detrimental effects on the distribution transformer. The next sections explain the feasibility of DC interface voltage recognition and its potential use in the management and administration of PV-controlled charging stations. Several PV string modules connected to independent DC/DC converters that all connect to the same DC bus. In order to power the PV board's operations, the DC/DC converter will track the maximum power point until it is reached. The DC transport is connected to the ESU, or essentiality Energy Storage Unit, through a bidirectional DC/DC buck-help converter. When there is no energy available from the cross section or the PV, the ESU will be used to charge PEVs [11].

After all the PEVs have been charged at the charging office, the ESU's battery pack may be charged from the PV or the lattice. Power for the PEV is supplied by a DC/DC buck converter connected to the dc transport. The control representation shown while charging is dependent on PEV requirements. Each charging station may accommodate a different kind of PEV by providing its own buck converter. A DC-to-AC bidirectional system-tied converter connects the charging office to the power allocation unit. The PEV's power flow from the source is monitored and managed by the control unit. Using the results from the voltage and current identification units, the control unit generates the shifting signals used to regulate the various power converters during charging. In order to implement MPPT, incremental conductance estimate methods are employed to measure the voltage across the PV display and the current leaking from the PV array.

3. DYNAMIC VOLTAGE RESTORER

Dynamic voltage regulators, series-connected pulse width modulation (PWM) regulators, and static series regulators are all common names for the devices used to regulate the main supply voltage in a circuit. If the device just adds reactive power, then it is a series var compensator. Using the same inverted concept of the supply and load, but this time including a series controller to handle the load. A 0.5pu DVR can restore voltage after a 0.5pu drop thanks to a series device, with the DVR providing just half of the power needed to sustain the load. Similar to a shunt-connected converter, the supply remains connected and no resynchronization is required. The protected load is wired in series with the series voltage controller. While transformers are often used to make the connection, there are some systems that use power electronics to make a coordinated connection. The sum of the grid voltage and the DVR injection voltage equals the voltage at the load bus bar. Reactive power is produced by the converter, while active power is drawn from the energy storage. Each situation calls for a different approach to energy storage to meet the various compensatory needs. Limitations in the depth and length of the voltage sag that can be adjusted by the DVR are a common issue. In order to get the desired certainty, it is necessary to use accurate estimates. Power may be stored in normal capacitors for short periods but at great depth, batteries for longer but smaller voltage dips, or super capacitors that fall somewhere in between. Numerous permutations and configurations are also feasible.

Protection against voltage fluctuations is provided by a dynamic voltage restorer (DVR). DVR maintains the load voltage at a fixed level regardless of the source voltage's irregular characteristics, such as voltage sags/swells or distortion. Figure 1 illustrates the DVR's operating principle. Let Va1, Vb1, and Vc1 be the phasors of the three-phase voltage under normal operating circumstances. During unusual situations, it is possible to change the phase voltage vectors to Va2, Vb2, and Vc2. Unfortunately, DVR does not provide any meaningful power in this unrelenting environment. This implies that in the steady state, the phase angle difference between the voltage and current phasors in a DVR must be 90 degrees. The necessary compensating voltage is introduced by the DVR via transformer. A series connection between the transformer and the load is used. DVR is only active during rare events and does nothing during normal operations. When in use, DVR may both generate and consume active and reactive power.

In the case of a minor failure, a dynamic voltage restorer corrects the load voltage by injecting reactive power generated elsewhere. Active power is produced by DVR when it is needed to correct larger problems. For the active power to be generated, a DC energy device is needed. While conventional systems rely on DC capacitor banks as the dc storage device, the proposed setup makes use of a PV array.

4. PROPOSED SYSTEM

A. Power Stage

In Fig. 1 we see a simplified schematic representation of the whole setup. Figure 2 depicts the model of the series DVR and its controller, which is used to smooth out the voltage fluctuations that occur when the power stage, a three-phase voltage source inverter, is linked in series with the grid. Isolation transformer, LC filter, and insulated gate bipolar transistor (IGBT) module make up the inverter system. The modulation index m of the inverter is determined by the line-line voltage Vab being 208 V and the dc-link voltage Vdc being 260 V for maximum converter performance.

$$m = \frac{2\sqrt{2}}{\sqrt{3}V_{dc*n}} V_{ab(\mathrm{rms})}. \qquad (1)$$

where n is the isolation transformer's turns ratio. Using (1), we see that the necessary modulation index is 0.52 if we set n equal to 2.5. For precise voltage correction, the dc-dc converter's output must be controlled at 260 V. The purpose of the active power capacity of the integrated UCAPDVR system is to counteract voltage drops (0.1-0.9 p.u.) and surges (1.1-1.2 p.u.) that continue for 3 seconds to one minute [15].

B. Controller Implementation

Most methods for regulating the series inverter to provide dynamic voltage restoration [3] include injecting a voltage in quadrature with advanced phase. Phase-advanced voltage restoration methods are used primarily to lessen the necessity for active power support and, by extension, the amount of energy storage required at the dc-link, despite the fact that they are difficult to implement. While phase-advanced procedures were once necessary to maintain system voltage during a voltage sag or swell event, the declining cost of energy storage has made them unnecessary. A PLL is employed in the controller to calculate the rotational angle. One of the key goals of the UCAP-DVR system is to compensate for transient voltage drops and spikes using the system's active power capabilities.

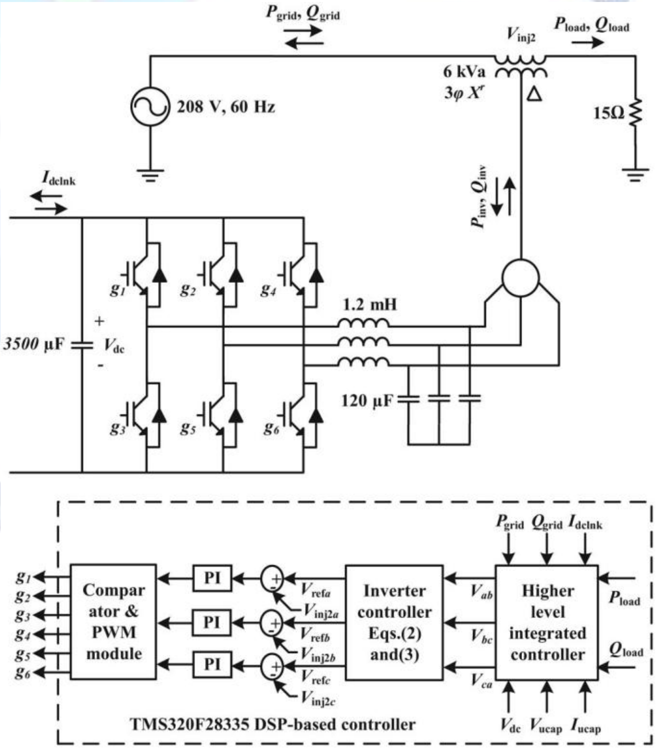


Fig. 2. Three-phase series inverter (DVR) model and controller with integrated HOC

$$\begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ \frac{-1}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} \cos\left(\theta - \frac{\pi}{6}\right) & \sin\left(\theta - \frac{\pi}{6}\right) \\ -\sin\left(\theta - \frac{\pi}{6}\right) & \cos\left(\theta - \frac{\pi}{6}\right) \end{bmatrix} \begin{bmatrix} \frac{V_d}{\sqrt{3}} \\ \frac{V_q}{\sqrt{3}} \end{bmatrix} \tag{2}$$

$$\begin{bmatrix} V_{\mathrm{ref}a} \\ V_{\mathrm{ref}b} \\ V_{\mathrm{ref}c} \end{bmatrix} = m* \begin{bmatrix} \left(\sin\theta - \frac{V_{sa}}{169.7}\right) \\ \left(\sin\left(\theta - \frac{2\pi}{3}\right) - \frac{V_{sb}}{169.7}\right) \\ \left(\sin\left(\theta + \frac{2\pi}{3}\right) - \frac{V_{sc}}{169.7}\right) \end{bmatrix} \tag{3}$$

$$P_{\mathrm{inv}} = 3V_{\mathrm{inj}2a(\mathrm{rms})} I_{La(\mathrm{rms})} \cos\varphi$$
$$Q_{\mathrm{inv}} = 3V_{\mathrm{inj}2a(\mathrm{rms})} I_{La(\mathrm{rms})} \sin\varphi. \tag{4}$$

DVR and UCAP inject an in-phase voltage Vinj2 whenever the source voltage drops or rises, keeping VL from oscillating. If we know the injected voltage Vinj2a, the load current ILa, and the phase difference, we can compute the series inverter's active and reactive power (4).

5. SIMULATION RESULTS:

These are the findings of a simulation run on the DVR while it is operating in a voltage-sag state, with compensation provided by a Solar-PV/BESS using a VSI topology in the distribution system. There are a number of voltage-related PQ difficulties that might arise when the source voltage is obtained from the grid system at 415V, 50Hz. Specifically, the load voltage effect manifests as a voltage drop between t-0.2 sec and t-0.3 sec. As seen in Fig.4, the DVR's series-VSI kicks on at this point, compensating voltage through injection transformers to keep the load voltage stable.

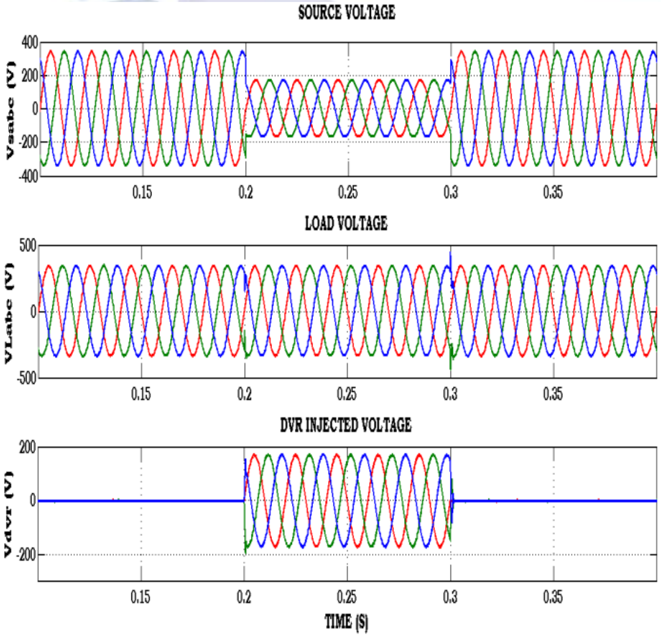


Fig.4 Simulation Results of DVR during Voltage-Sag Condition

We present the results of a simulation of the DVR under a voltage-swell condition, with compensation provided by a Solar-PV/BESS using a VSI topology in the distribution system. There are a number of voltage-related PQ difficulties that might arise when the source voltage is obtained from the grid system at 415V, 50Hz. Load voltage causes a voltage spike at around t-0.4 sec to t-0.5 sec. This triggers the DVR's series VSI, which, as shown in Fig. 5, compensates the voltage via injection transformers and keeps the load voltage stable.

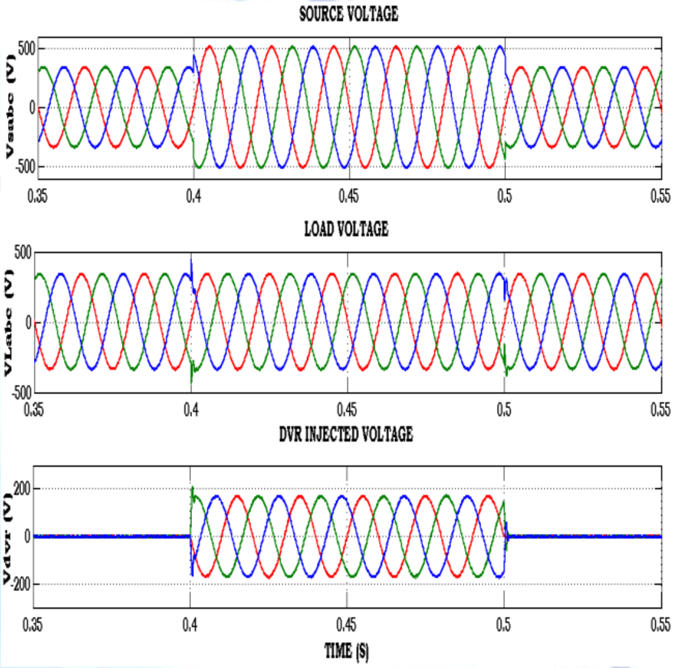


Fig.5 Simulation Results of DVR during Voltage-Swell Condition

Distribution voltage regulator (DVR) simulation results under voltage-harmonics situation, with compensation provided by Solar-PV/BESS using a VSI architecture. Since the grid system's 415V, 50Hz RMS amounts are subject to a wide range of voltage-related PQ concerns, this is where the source voltage originates. High harmonic distortions in the load voltage are caused by voltage harmonics that develop between t-0.1 sec and t-0.3 sec.

The DVR's series voltage source inductor (VSI) kicks in at this point, correcting the load voltage through injection transformers to keep it sinusoidal, balanced, and constant (as seen in Fig. 6).

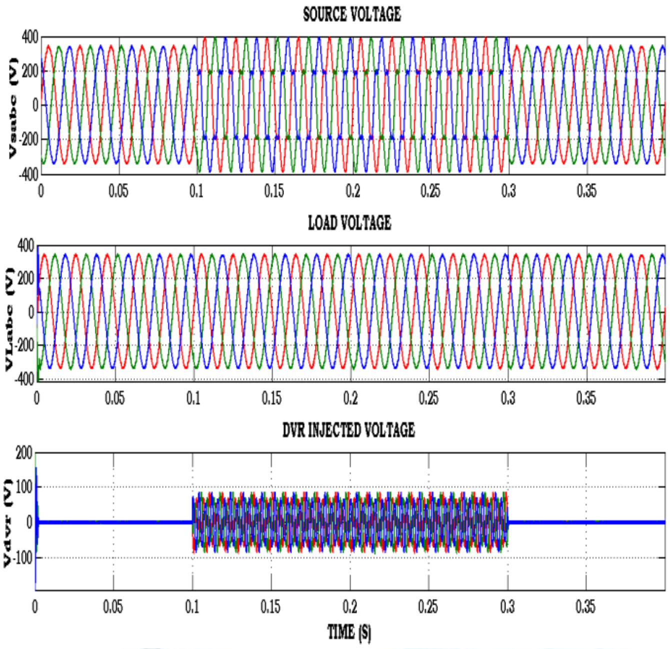
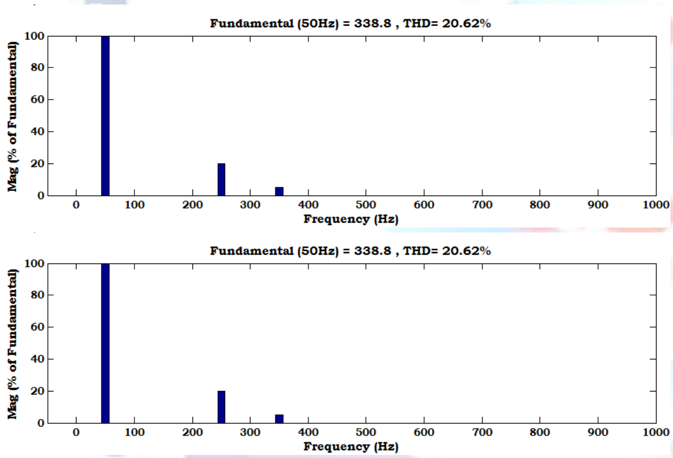


Fig.6 Simulation Results of DVR during Voltage-Harmonics Condition



Results from a simulation of the DVR under fault conditions that are mitigated by the Solar-PV/BESS and VSI topology in the distribution system. Since the grid system's 415V, 50Hz RMS amounts are subject to a wide range of voltage-related PQ concerns, this is where the source voltage originates. At some point between t0.65 seconds and t0.75 seconds, a fault condition manifested itself, causing the load voltage to drop. As illustrated in Fig.7, the DVR's series-VSI kicks in at this point to keep the load voltage stable by injecting a voltage-reducing current into the load. Based on a THD study of the source voltage at 20.62% without compensation and 0.03% with compensation through DVR, the system complies with IEEE-519/1992 requirements (Fig.8)..

6. CONCLUSION

This research proposes the use of a power conditioner system that incorporates UCAP-based rechargeable energy storage in order to improve the power quality of the distribution grid. The power conditioner's DVR component can independently manage voltage sags and swells, while the APF component can help the distribution system with active/reactive power assistance and renewable intermittency smoothing. For UCAP integration, it is proposed to use a bidirectional dc-dc converter at the power conditioner's dc-link. The shunt inverter (APF) depends on in-phase compensation for its control technique, whereas the series inverter (DVR) employs the idiq approach. The component designs and operation of the power stage of the bidirectional dc-dc converter are discussed. Since a dc-dc converter's output voltage is often relatively stable, average current mode control is typically used to fine-tune the converter's output. An integrated controller at a higher level makes decisions depending on the parameters of the system and feeds those decisions down to the controllers of the inverter and dc-dc converter. Each component of the UCAP-PC system, including the bidirectional dc-dc converter, series and shunt inverters, and the integrated system itself, are modelled in MATLAB. The UCAP-PC system may be simulated using PSCAD. Experimental hardware setup of the integrated system is detailed, and its ability to temporarily adjust for voltage sags, give active/reactive power assistance, and smooth out renewable intermittency in the distribution grid is assessed. The hypotheses described here are supported by both simulation and experimental evidence. UCAP-based energy storages might one day be used by microgrids and low-voltage distribution networks to dynamically respond to variations in voltage and power demand.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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