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Power Quality Improvement In Distribution System With Dynamic Voltage Restorer With Energy Storage Integration

Sudheer Bodapati, Karri Sarath, Yellamelli Siddhu Satya Manikanta, K. Gowthami

Department of Electrical Engineering, Godavari Institute of Engineering and Technology(A), Rajahmundry, A.P, India.

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ABSTRACT

Incorporating PEVs into a voltage-dependent control power grid is proposed in this study. As a result of the fuel gate scandal, a growing number of individuals, particularly in advanced technological communities, are opting for electric cars. PEVs have the benefit of being cutting-edge automobiles that can run on a variety of fuel cells and batteries. The suggested PEVs model was built for use as a static load model in balanced load power distribution systems. Enhanced voltage sag and swell correction may be achieved with the incorporation of energy storage, and one device that can do this is the dynamic voltage restorer (DVR). Ultracapacitors (UCAP) are well-suited for compensating voltage sags and swells, which demand high power for brief periods of time, due to their low-energy density and high-power density. This study makes a significant contribution by introducing DVR topology with rechargeable UCAP-based energy storage. The UCAP-DVR system will be able to autonomously adjust transient voltage sags and swells with active power capabilities after this integration, rather of having to rely on the grid to do so. The findings demonstrate the viability of the suggested concept and are the product of a MATLAB SIMULINK model of the complete system and Raspberry pi development board real-time controllers.

1. INTRODUCTION

Keeping the grid in excellent working order is critical, since electricity quality is a big issue for the sector. Because of this, devices that improve power quality, such as the dynamic voltage restorer (DVR) and the active power filter, have seen a resurgence in popularity (APF). After combining a DVR with an APF in a back-to-back inverter topology, the resulting architecture is known as a unified power quality conditioner (UPQC). When the load is nonlinear, DVR keeps the voltage from dropping too low or rising too high, while APF keeps the grid from providing nonsinusoidal currents. Unified power quality conditioner is the term given to the first implementation of the idea of combining the DVR and APF in a single device. This implementation uses a back-back inverter architecture (UPQC). Energy storage integration into the power conditioner topology is presented in this study to overcome the limiting design aim of the conventional UPQC and enable the integrated system to deliver extra functionality. Distributed energy resources (DERs) like wind, solar, and PHEVs are becoming more common, and this is leading to an increase in power quality issues and intermittencies on the distribution grid on a time scale of seconds to minutes. Integration of energy storage with DERs is an option that might improve the dependability of the DERs by decreasing their intermittencies and help address some of the distribution grid's power quality issues.

There is an ongoing attempt to make energy storage integration financially feasible on a wide scale by identifying applications where it will increase functioning. An example of an important application where energy storage integration and optimum control play a role is in the smoothing of DERs. The wind turbine generator is coupled with a super capacitor and flow battery hybrid energy storage system to smooth out the wind output, and the system is evaluated using a real-time simulator. A model-based controller is designed to provide optimum management when a super capacitor is employed as supplementary energy storage alongside a photovoltaic (PV) or fuel cell system. To smooth out the wind and PV output, a battery energy storage system based regulation is suggested. Battery storage integration for better photovoltaic (PV) integration into the distribution grid: a multi-objective optimization approach is given. In order to maximise battery discharge while dispatching intermittent renewable resources, a theoretical study is conducted to identify the upper and lower limits of the battery capacity for grid-connected PV systems based control rule. In order to integrate into cutting-edge power applications like DVR, different types of rechargeable energy storage technologies are compared. These technologies include superconducting magnet energy storage systems (SMES), flywheel energy storage systems (FESS), battery energy storage systems (BESS), and ultra capacitor energy storage systems (UCAPs). There has been work done to include energy storage into the DVR system, which will provide the system active power capabilities and make it grid-independent during voltage problems.

To reduce the need for battery power, the authors suggest a cascaded H-bridge-based DVR that uses an inductor controlled by a thyristor. Of all the rechargeable energy storage technologies, UCAPs are most suited for applications that need active power sup-port in the milliseconds to second's timeframe; in, flywheel energy storage is incorporated into the DVR system to enhance its steady-state series and shunt adjustment. Since transient drops and spikes in voltage often last for milliseconds to seconds, DVR systems that make use of UCAP are optimal. UCAPs are well-suited for balancing voltage sags and swells, which demand a large amount of power for brief periods of time, thanks to their low-energy density and high-power density. UCAPs have a greater terminal voltage compared to batteries, which simplifies the integration; UCAPs can withstand more charge/discharge cycles for the same module size. DVRs are becoming more important on the distribution grid since the use of renewable energy sources brings with it an increase in power quality issues. The DVR for the distribution grid is planned to use supercapacitors as a form of energy storage. The notion is taught, but not the actual findings, and solely via simulation. In this study, we suggest adding DVRs with UCAP-based energy storage to the distribution grid and discuss many potential uses for this setup. Active power capability is added to the system by the integration of the UCAP with the DVR, which is required for autonomously adjusting voltage sags and swells. Hardware integration and performance validation of the integrated DVR-UCAP system, including experimental validation of the UCAP, dc-dc converter, and inverter's interface and control creation of inverter and dc-dc converter controls to offer sag and swell correction to the distribution grid.

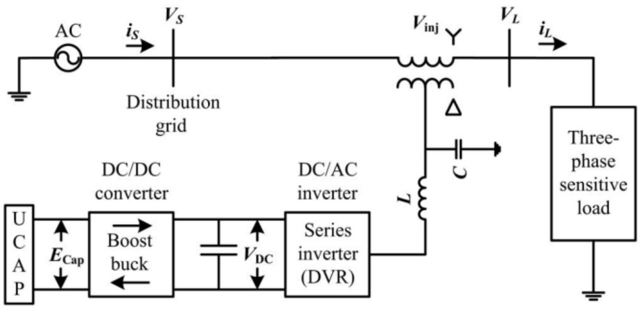

Fig.1. One-line diagram of DVR with UCAP energy storage

2. DC- AC CONVERTER (INVERTER)

Any desired voltage and frequency of alternating current (AC) may be produced by an inverter by using the right combination of transformers, switches, and control circuits to take DC and turn it into AC.

A. Strength of Current In this context, "power quality" refers to the practise of supplying electricity to and grounding electronic devices in a way that is optimal for the safe and effective functioning of such devices. This sudden surge of attention to power quality may be attributed to a number of factors. Here are a few of the more important ones:

- There has been a dramatic increase in the sensitivity of electrical and power electronic devices. Manufacturing processes are less tolerant of faulty equipment functioning, and businesses have less patience for production halts as a result of poor voltage quality. Voltage drops and interruptions are the primary causes, with the latter being more often discussed and cited in the literature.
- Equipment failure due to high-frequency transients is infrequently investigated. Compared to the past, machines now generate more frequent and severe electrical disruptions. Today, basic power electronic converters are used to provide electricity for a wide range of devices, from low to high power, and their output is accompanied by a wide spectrum of distortion. Despite mounting evidence that harmonic distortion in the power system is increasing, definitive conclusions remain elusive owing to a lack of comprehensive studies. There is now more demand for quality indicators due to deregulation in the electrical sector.
- More transparency about the expected voltage quality is being offered to customers. Power quality disruption is also significantly caused by energy-efficient devices. Energy-efficient lighting and variable-speed drives are two major devices that contribute to waveform distortion and are vulnerable to certain types of power quality disruptions. When these power quality difficulties prevent the widespread adoption of green energy sources and consumer technology, power quality transcends its existing economic and social implications to become a serious environmental hazard.
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3. THREE-PHASE SERIES INVERTER

A. Power Stage

The one-line diagram of the system is shown in Fig. 1. The power stage is a three-phase voltage source inverter, which is connected in series to the grid and is responsible for compensating the voltage sags and swells; the model of the series DVR and its controller is shown in Fig. 2. The inverter system consists of an insulated gate bipolar transistor (IGBT) module, its gate-driver, *LC* filter, and an isolation transformer. The dc-link voltage V_{dc} is regulated at 260 V for optimum performance of the converter and the line–line voltage V_{ab} is 208 V; based on these, the modulation index m of the inverter is given by

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

in which n is the isolation transformer's turns ratio. By plugging in n = 2.5 into (1), we get a modulation index of 0.52 as necessary. For precise voltage correction, the dc-dc converter's output must be controlled at 260 V. The purpose of an active power UCAPDVR system is to counteract voltage dips (0.1-0.9 p.u.) and spikes (1.1-1.2 p.u.) that persist for 3 seconds to one minute [15].

B. Controller Implementation

Injecting a voltage in quadrature with advanced phase allows reactive power to be used in voltage restoration [3], and is one of several techniques for controlling the series inverter to offer dynamic voltage restoration. Although phase-advanced voltage restoration approaches have a high implementation complexity, their main purpose is to reduce the need for active power support and, in turn, the quantity of energy storage required at the dc-link. The availability of active power support at the dc-link and the falling cost of energy storage mean that voltages may be injected in phase with the system voltage during a voltage sag or swell event, eliminating the need for complex phase-advanced procedures. In order to determine the rotation angle, a PLL is used in the control approach. As previously mentioned, this project intends to use the UCAP-DVR system's active power capacity to offset transient voltage fluctuations.

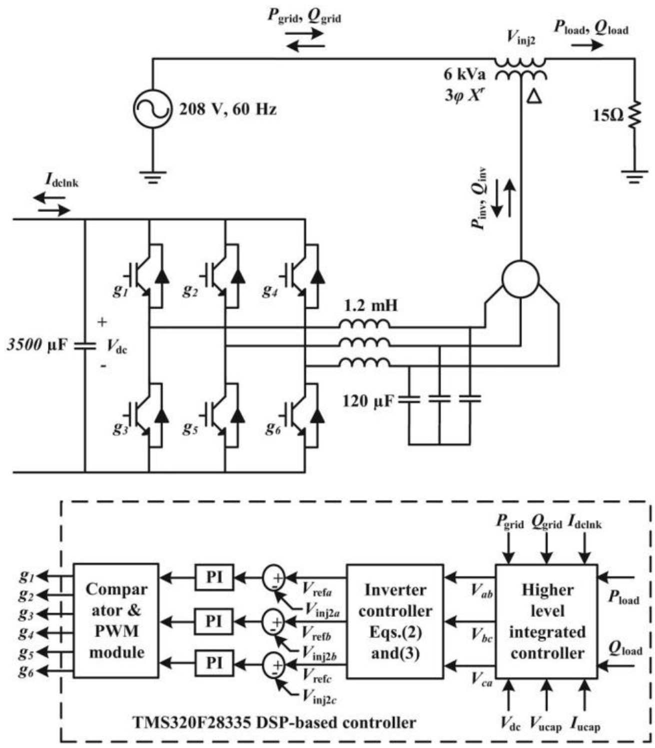


Fig. 2. Model of three-phase series inverter (DVR) and its controller with integrated higher order controller

Injecting voltages in phase with the supply-side line-neutral voltages is the foundation of the inverter controller implementation. Thus, PLL has been developed utilising the fictional power approach given in [18] to estimate. For this delta-sourced system, we have the line-line source voltages Vab, Vbc, and Vca; by transforming them into the d-q domain, we can estimate the line-neutral components of the source voltage Vsa, Vsb, and Vsc.

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

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

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

The injected voltage references Vref needed to keep the voltage constant at the load terminals, where m = 0.52 from (3), are transformed into unit sine waves based on the line-neutral system voltage of 120Vrms (1). The DVR and UCAP system injects an in-phase voltage Vinj2 to counteract any changes in voltage at the source end, keeping the voltage at the load end, VL, constant. The active and reactive power provided by the series inverter may be estimated from their root-mean-square values, which are derived

Bidirectional DC–DC Converter and Controller

Since UCAP's voltage profile fluctuates during energy dissipation, it can't be linked to the inverter's dc-link like a battery. Since the voltage of the UCAP changes during discharging and charging, a bidirectional dc-dc converter is required to integrate the UCAP system while keeping the dc-link voltage stable. Figure 3 shows a bidirectional dc-dc converter model and controller with three series-connected UCAPs as the input, an output with a nominal load of 213.5 that inhibits operation without a load, and a connection to the inverter's dc-link. When a dc-dc converter is operating in discharge mode, the amount of active power support needed from the grid is dependent on the magnitude and duration of the voltage drop. The dc-dc converter may either draw power from the grid or recharge itself using the grid's power. The bidirectional dc-dc converter used in this investigation may either boost or buck power, depending on whether it is being fed by the UCAP or the conventional power grid.

Since the UCAP's voltage changes depending on the energy it releases, a bidirectional dc-dc converter is needed as an interface between the UCAP and the dc-link. When the voltage of the UCAP bank is between 72 and 144 V and the output voltage is set at 260 V, the bidirectional dc-dc converter will begin operating in the boost mode. The bidirectional dc-dc converter switches to buck mode if the UCAP bank voltage drops below 72 V, drawing power from the grid to recharge the UCAPs and restoring the 260 V output regulation.

It has been extensively studied [19] that the output voltage of the bidirectional dc-dc converter may be adjusted using average current mode control while the UCAP bank is being charged or discharged. When compared to other methods like voltage mode control or peak current mode control, this one tends to be more reliable. The voltage compensator C1(s) in Fig. 3 determines the average reference current Iucref from the difference between nominal and observed output voltages Vout and Vref. If the grid's reference voltage Vref is lower than the inverter's output voltage Vout, the error grows and the dc-dc converter switches to boost mode (Iucref > 0). Vout will rise above Vref and the error will be negative if the inverter is receiving power from the grid during a voltage swell event or when charging the UCAP. Since Iucref is also negative, the dc-dc converter runs in buck mode. It follows that the working direction of the bidirectional dc-dc converter is determined by the sign of the error between Vout and Vref (Iucref). Variations in UCAP current (including inductor current) Iuc from the reference current Iucref are cancelled out by the current inductor C2 (s). The steady response is provided by the transfer functions of the compensator, which are specified as.

$$C_1(s) = 1.67 + \frac{23.81}{s}$$

$$C_2(s) = 3.15 + \frac{1000}{s}.$$

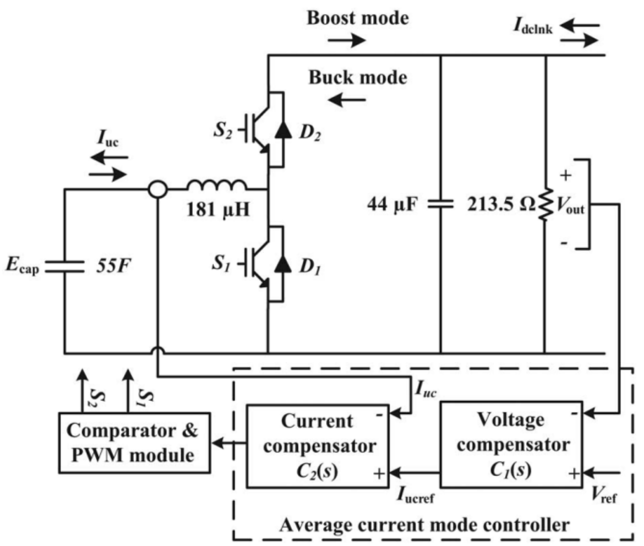


Fig. 3. Model of the bidirectional dc–dc converter and its controller.

4. SIMULATION RESULTS:

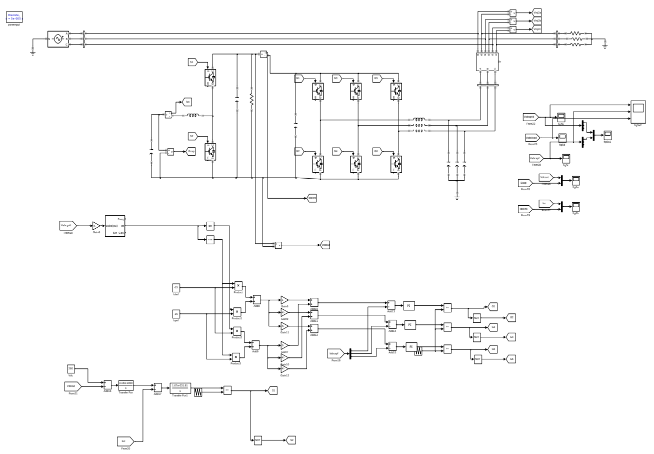


Fig 4: Simulation Circuit

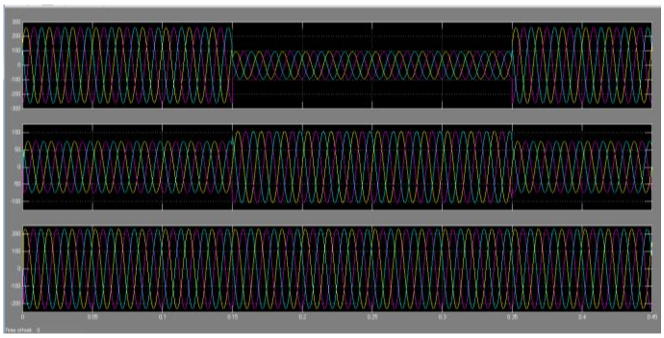
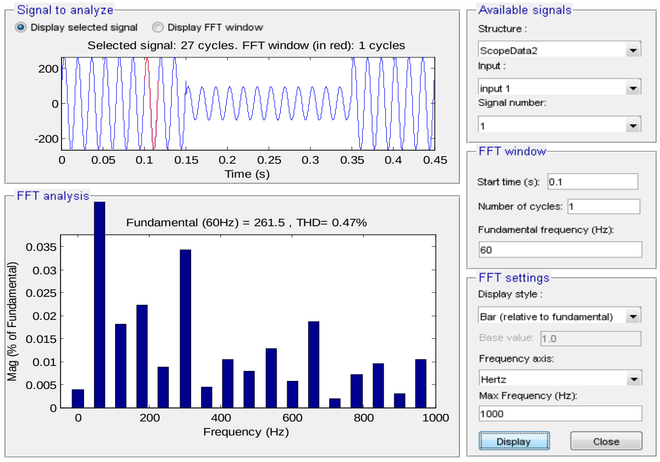
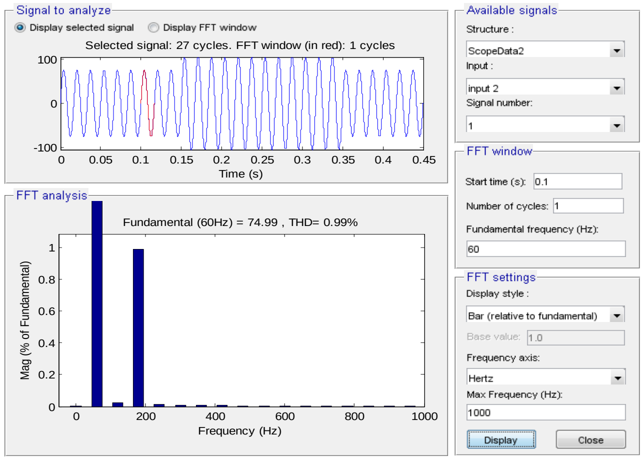


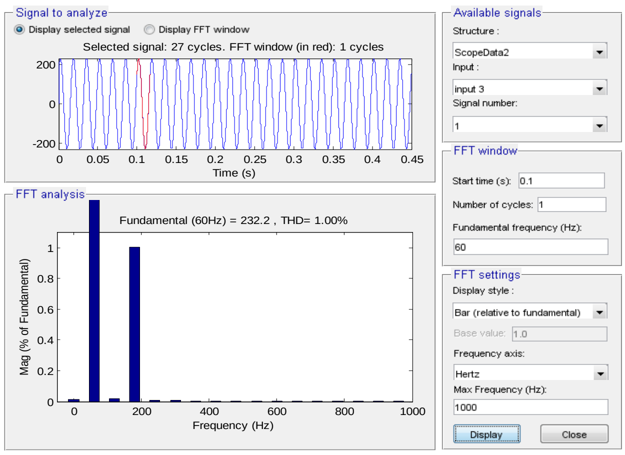
Fig.5. Insert Ultracapacitor Voltage for load maintained



Input THD



DVR THD



Load THD

Comparison Table:

	EV fed DVR with battery	DVR with UC
THD Values	10.31%	0.99%

CONCLUSION

In order to enhance the power quality of the distribution grid, this study introduces the idea of incorporating UCAP-based rechargeable energy storage into a power conditioner system. The APF part of the power conditioner will be able to offer active/reactive power assistance and renewable intermittency smoothing to the distribution grid, while the DVR part of the power conditioner can independently adjust voltage sags and swells. A bidirectional dc-dc converter is suggested for UCAP integration at the dc-link of the power conditioner. The shunt inverter (APF) uses the idiq approach for its control strategy, whereas the series inverter (DVR) relies on in-phase compensation. The power stage of the bidirectional dc-dc converter is dissected, and the designs of the key components are explained. Given its inherent stability, the dc-dc converter's output voltage is controlled using average current mode control. Inverter and dc-dc converter controllers get inputs from a higher-level integrated controller that makes choices based on system characteristics. The UCAP, bidirectional dc-dc converter, series, and shunt inverters make up the integrated UCAP-PC system, which is simulated in MATLAB. The UCAP-PC system is simulated using PSCAD. The integrated system is given, together with the experimental hardware configuration used to evaluate its ability to temporarily compensate for voltage sags, offer active/reactive power assistance, and smooth out renewable intermittency in the distribution grid. The principles presented in this study are supported by both simulation and experimental results, which show good agreement with one another. The distribution grid's voltage and power profiles are subject to dynamic changes; in the future, similar UCAP-based energy storages may be placed in a microgrid or low-voltage distribution grid to adapt to these changes.

Conflict of interest statement

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

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