A Fuzzy Logic Controller based dynamic voltage restorer-ultra capacitor for improving power quality of distribution grid

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Abstract

In this project, cost of various energy storage advancements is lessening rapidly and the combination of these developments into the power grid is transforming into a reality with the methodology of brilliant grid. Dynamic voltage restorer (DVR) is one thing that can give improved voltage rundown and swell pay with energy storage coordination. Ultra capacitors (UCAP) have low-energy thickness and high-control thickness flawless qualities for pay of voltage records and voltage swells, which are both events that require high power for constrained abilities to center time. The novel responsibility of this paper lies in the blend of rechargeable UCAP-based energy storage into the DVR topology.

Keywords: DC-DC converter; D-Q control; DSP; dynamic voltage restorer (DVR); energy storage integration

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Introduction

The idea of using inverter-based dynamic voltage restorers (DVRs) for keeping customers from transient voltage unsettling impacts on the utility side were shown curiously. The idea of Utilizing the DVR as a power quality thing has expanded critical fame since its first use. The makers propose the use of the DVR with rechargeable energy storage at the dc-terminal to meet the dynamic power prerequisites of the lattice during voltage unsettling impacts. With a particular true objective to keep up a key separation from and minimize the dynamic power mixture into the network, the makers also say an alternative game plan which is to compensate for the voltage list by embeddings a slacking voltage in quadrature with the line current. Due to the high cost of rechargeable energy storage, distinctive sorts of control methods have moreover been made in the composition to minimize the dynamic power mixture from the DVR. The high cost of the rechargeable essentialness storage keeps the passageway of the DVR as a power quality thing. Regardless, the cost of rechargeable energy storage has been reducing unquestionably in the later past in view of various creative headways and due to higher passageway in the business segment as aide energy storage for dispersed energy assets (DERs, for instance, wind, solar, half and half electric vehicles (HEVs), and module cross breed electric vehicle (PHEVs). Thus, there has been restored enthusiasm for the keeping in touch with
direction rechargeable energy storage again at the deterministic of power quality things, for instance, static compensator (STATCOM) and DVR. Diverse sorts of rechargeable energy storage developments in light of superconducting magnets (SMES), flywheels (FESS), batteries (BESS), and ultra capacitors (UCAPs) are searched for mix into cutting edge power applications for example, DVR.

Endeavors have been made to organize energy storage into the DVR system, which will give the system dynamic power limit that makes it free of the grid during voltage unsettling influences cascaded H-traverse based DVR with a thyristor-controlled inductor is proposed to minimize the energy storage prerequisites. Of all the rechargeable energy storage headways, UCAPs are ideally suited for applications which require dynamic power support in the milliseconds to second's timescale. In this way, UCAP-based consolidation into the DVR system is flawless, as the normal range of passing voltage sags and swells is in the milliseconds to second's extent. UCAPs have low-imperativeness thickness and high-control thickness impeccable characteristics for compensating voltage lists and voltage swells, which are both events that require high measure of power for constrained abilities to center of time. UCAPs in like manner have higher number of charge/discharge cycles when stood out from batteries and for the same module size, UCAPs have higher terminal voltage when appeared differently in relation to batteries, which makes the coordination more straightforward. With the prevalence of renewable energy sources on the circulation grid and the relating increment in power quality issues, the requirement for DVRs on the distribution grid is growing.

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

Energy storage coordination to a DVR into the distribution grid is proposed and the accompanying application regions are tended to. Integration of the UCAP with DVR system gives dynamic power ability to the system, which is key for autonomously remunerating voltage lists and swells. Experimental endorsement of the UCAP, DC-DC converter, besides, their interface and control. Development of inverter and dc–dc converter controls to give sag and swell remuneration to the circulation lattice. Hardware coordination and execution acknowledgment of the organized DVR-UCAP system.

**Three-Phase Series Inverter**

**Power Phase**

The one-line layout of the system is showed up in figure 1. The power phase is a three-phase voltage source inverter, which is related in series to the system and is in charge of repaying the voltage lists and swells; the model of the series DVR likewise, its controller is showed up in figure 2. Inverter system contains a protected door bipolar transistor (IGBT)
module, its entryway driver, LC channel, and a withdrawal transformer. The DC-link voltage $V_{dc}$ is coordinated at 260 V for perfect execution of the converter and the line–line voltage $V_{ab}$ is 208 V; considering these, the tweak record $m$ of the inverter is given by

$$m = \frac{2\sqrt{2}}{\sqrt{3}V_{dc}^{*}}V_{dc(ma)}.$$  

(1)

Where, $n$ is the turn's extent of the separation transformer. Substituting $n$ as 2.5 in (Woodley et al., 1999), the required parity rundown is determined as 0.52. In like manner, the output of the DC-DC converter ought to be coordinated at 260 V for giving exact voltage pay. The objective of the consolidated UCAP-DVR system with dynamic power limit is to compensate for impermanent voltage sag (0.1-0.9 p.u.) and voltage swell (1.1-1.2 p.u.), which last from 3 s to 1 min.

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

**Controller Implementation**

There are distinctive techniques to control the series inverter to give dynamic voltage rebuilding and most of them rely on upon imbuing a voltage in quadrature with front line phase, so that responsive power is utilized as a part of voltage recovery. Phase propelled voltage reconstructing systems are boggling in usage, regardless, the key reason behind utilizing these techniques is to minimize the dynamic power support and along these lines the measure of energy storage prerequisite at the DC-connect in order to minimize the cost of energy storage. In any case, the cost of energy storage has been declining and with the accessibility of active power support at the DC-link, convoluted phase pushed methodology can be avoided and voltages can be infused in-phase with the system voltage during voltage sag or a swell event.

The control procedure requires the use of a PLL to find the pivoting point. As discussed already, the target of this foresees is to use the dynamic power capacity of the UCAP-DVR system and alter impermanent voltage sag and swells. The inverter controller execution relies on upon infused voltages in-phase with the supply-side line-neutral voltages.

This requires PLL for assessing $\theta$, which has been executed using the nonexistent power technique portrayed. Taking into account the surveyed $\theta$ and the line–line source voltages, $V_{ab}$, $V_{bc}$, and $V_{ca}$ (which are open for this delta-sourced system) are changed into the D-Q region and the line-fair fragments of the source voltage $V_{sa}$, $V_{sb}$, and $V_{sc}$, which are not available, can then be assessed utilizing

$$\begin{bmatrix} V_{ss} \\ V_{ss} \\ V_{ss} \end{bmatrix} = \begin{bmatrix} 1 & 0 & \cos(\theta - \frac{\pi}{3}) \\ \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{3}} & \sin(\theta - \frac{\pi}{3}) \\ \frac{1}{\sqrt{3}} & -\frac{1}{\sqrt{3}} & \cos(\theta - \frac{\pi}{3}) \end{bmatrix} \begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix},$$

(2)

$$\begin{bmatrix} V_{refb} \\ V_{refc} \end{bmatrix} = m \begin{bmatrix} \sin(\theta - \frac{\pi}{6}) & \cos(\theta - \frac{\pi}{6}) \\ \sin(\theta + \frac{\pi}{6}) & \cos(\theta + \frac{\pi}{6}) \end{bmatrix} \begin{bmatrix} \frac{V}{\sqrt{3}} \\ \frac{V}{\sqrt{3}} \end{bmatrix}$$

(3)

$$P_{line} = 3V_{dc}(rms)^{2}I_{dc}(rms)\cos\phi,$$

$$Q_{line} = 3V_{dc}(rms)^{2}I_{dc}(rms)\sin\phi.$$  

(4)

These voltages are institutionalized to unit sine waves using line-nonpartisan system voltage of 120 Vrms as reference and took a gander at to unit sine waves in-
phase with real framework voltages $V_s$ from (Vilathgamuwa et al., 2003) to find the implanted voltage references $V_{\text{ref}}$ essential to keep up a predictable voltage at the heap terminals, where $m$ is 0.52 from (Woodley et al., 1999). Along these lines, at whatever point there is a voltage sag on the other droop swell on the source side, a looking at voltage $V_{\text{inj2}}$ is infused in-phase by the DVR and UCAP system to ruin the effect and hold a predictable voltage $V_L$ at the heaps end. The real dynamic and responsive power supplied by the course of action inverter can be prepared using (Li et al., 2007) from the rms estimations of the mixed voltage $V_{\text{inj2a}}$ and burden current $I_{\text{La}}$, and $\phi$ is the phase qualification between the two waveforms.

**UCAP and Bidirectional DC-DC Converter**

**UCAP Bank Hardware Setup**

The choice of the amount of UCAPs key for giving grid support depends on upon the measure of bolster required, terminal voltage of the UCAP, DC-link voltage, and course lattice voltages. In this paper, the trial setup includes three 48 V, 165F UCAPs (BMOD0165P048) created by Maxwell Technologies, which are connected in series. In this way, the terminal voltage of the UCAP bank is 144 V and the DC-link voltage is adjusted to 260 V. This would give the DC-DC converter a commonsense working obligation proportion of 0.44-0.72 in the help mode while the UCAP is discharging and 0.27-0.55 in the buck mode while the UCAP is charging from the grid through the dc-link and the DC-DC converter. It is sensible likewise; financially savvy to use three modules in the UCAP bank. Tolerating that the UCAP bank can be discharged to half of its hidden voltage ($V_{\text{uc, ini}}$) to distinct voltage ($V_{\text{uc, fin}}$) from 144 to 72 V, which implies significance of arrival of 75%, the energy in the UCAP bank available for

$$E_{\text{UCAP}} = \frac{1}{2} \times C \times \left(\frac{(V_{\text{uc, ini}}^2 - V_{\text{uc, fin}}^2)}{60}\right) W \text{ min}$$

$$E_{\text{UCAP}} = \frac{1}{2} \times 165 \times \frac{1}{3} \times \frac{\left((144^2 - 72^2)\right)}{60} = 7128 W \text{ min.}$$

**Bidirectional DC-DC Converter and Controller**

A UCAP can't be direct connected with the DC-connection of the inverter like a battery, as the voltage profile of the UCAP changes as it discharges energy. Thusly, there is a need to link the UCAP system through a bidirectional DC-DC converter, which keeps up a firm dc-link voltage, as the UCAP voltage reduces while discharging and augments while charging. The model of the bidirectional DC-DC converter and its controller are showed up in figure 3, where the data involves three UCAPs connected in series and the output includes an apparent heap of 213.5 $\Omega$ to balance operation at no-pile, and the output is connected with the DC-connection of the inverter. The measure of element power support required by the system in the midst of a voltage sag event is dependent on the significance and length of the voltage droop, and the DC-DC converter should have the ability to withstand this power during the discharge mode. The DC-DC converter should moreover be compensator.

To work in bidirectional mode to have the ability to charge or retain additional power from the lattice during voltage swell event. In this paper, the bidirectional DC-DC converter goes about as a bolster converter while discharging power from the UCAP and goes about as a buck converter while
charging the UCAP from the grid. A bidirectional DC-DC converter is required as an interface between the UCAP and the dc-link taking after the UCAP voltage changes with the measure of energy discharged while the dc-link voltage must be firm. Thusly, the bidirectional DC-DC converter is planned to work in bolster mode when the UCAP bank voltage is some place around 72 and 144 V and the output voltage are coordinated at 260 V. Right when the UCAP bank voltage is underneath 72 V, the bidirectional dc–dc converter is worked in buck mode and draws energy from the grid to charge the UCAPs and the output voltage is again controlled at 260 V.

**Fig. 3.** Model of the bidirectional DC-DC converter and its controller

Ordinary current mode control, which is comprehensively examined in composing, is used to deal with the output voltage of the bidirectional DC-DC converter in both buck and help modes while charging and discharging the UCAP bank. This procedure has a tendency to be steadier when diverged from various methodologies, for instance, voltage mode control and peak current mode control. Typical current mode controller is showed up in figure 3, where the DC-connection furthermore, real output voltage \( V_{out} \) is differentiated and the reference voltage \( V_{ref} \) and the blunder is experienced the voltage compensator \( C_1(s) \), which makes the ordinary reference current \( I_{ucref} \). When the inverter is discharging power into the network during voltage list event, the DC-link voltage \( V_{out} \) tends to go underneath the reference \( V_{ref} \) and the mix-up is sure; \( I_{ucref} \) is certain and the DC-DC converter works in bolster mode. Exactly when the inverter is holding power from the network during voltage swell event on the other hand charging the UCAP, \( V_{out} \) tends to increase over the reference \( V_{ref} \) and the blunder tends to increase over the reference \( V_{ref} \) and the blunder is negative; \( I_{ucref} \) is negative and the DC-DC converter works in buck mode. Along these lines, the sign of the blunder amongst \( V_{out} \) what's more, \( V_{ref} \) chooses the sign of \( I_{ucref} \) additionally, thusly the heading of operation of the bidirectional DC-DC converter. The reference current \( I_{ucref} \) is then appeared differently in relation to the real UCAP current the compensator exchange capacities, which give a steady reaction, are given by

\[
C_1(s) = 1.67 + \frac{23.81}{\sigma} \\
C_2(s) = 3.15 + \frac{1000}{\sigma}
\]

**Extension**

**Fuzzy Logic Controller**

Fuzzy logic is a complex mathematical method that allows solving difficult simulated problems with many inputs and output variables. Fuzzy logic is able to give results in the form of recommendation for a specific interval of output state, so it is essential that this mathematical method is strictly distinguished from the more familiar logics, such as Boolean algebra.

**Advantages of Fuzzy Controller over PI Controller**

Usage of conventional control PI, its reaction is not all that great for non-linear systems. The change is striking when controls with Fuzzy logic are
utilized, acquiring a superior dynamic reaction from the system. The PI controller requires exact direct numerical models, which are hard to get and may not give tasteful execution under parameter varieties, load unsettling influences, and so forth. As of late, Fuzzy Logic Controllers (FLC’s) have been presented in different applications and have been utilized as a part of the power devices field. The benefits of fuzzy logic controllers over ordinary PI controllers are that they needn't bother with a precise scientific model, can work with uncertain information sources and can deal with non-linearities and are more powerful than traditional PI controllers.

**Results**

*THD Analysis of the proposed and extension Methods*

**Fig. 4.** Load Voltage THD in the case of Sag (proposed method)

**Fig. 5.** Load Voltage THD in the case of Sag (Extension method)

**Conclusion**

In this project incorporating UCAP-based rechargeable energy storage to the DVR system to upgrade its voltage recovery limits is explored. With this linking, the DVR will have the ability to uninhibitedly reimburse voltage droops and swells without relying upon the cross section to make up for weaknesses on the system. The UCAP coordination through a bidirectional DC-DC converter at the DC-connection of the DVR is proposed. The power phase and control procedure of the series inverter, which goes about as the DVR, are discussed. The control system is direct in addition, relies on upon injecting voltages in-phase with the system voltage in addition, is less requesting to realize when the DVR system has the ability to give dynamic power. Series of real parts in the power period of the bidirectional DC-DC converter are discussed. Ordinary current mode control is used to coordinate the output voltage of the DC-DC converter as a result of its inherently unfaltering trademark. The entertainment of the UCAP-DVR system, which includes the UCAP, DC-DC converter, and the network tied inverter, is finished using PSCAD. Hardware trial setup of the fused system is shown and the ability to give impermanent voltage sags and swells.

**References**


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