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UCAP based Dynamic Voltage Restorer using Impedance Source Inverter

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Abstract— Penetration of various renewable energy sources in to the distribution grid in recent years is high due to increase in energy demand. This leads to deterioration of power quality in the grid. The challenge is to design efficient Dynamic Voltage Restorer (DVR) to mitigate the power quality issues. The potential solution is to integrate energy storage based DVR in to the distribution grid. Impedance source inverters combine dc-dc converter and dc-ac inverter into a single topology thereby reduces the cost of the system. UCAP based energy storage has high power density compared to conventional energy storage system. In this paper, UCAP based DVR using impedance source inverter is proposed. The advantage of proposed system is that it has high compensation capability with improved active power capability and reduced cost. Modeling and Simulation of the proposed system has been carried out using MATLAB.

Keywords— UCAP, DVR, impedance source inverter

I. INTRODUCTION

The improvement of power quality is an important objective for electrical utilities and industrial and commercial consumers. Highly intermittent distributed generation, rapidly changing loads, and direct-off-line power electronic systems all contribute to reduced power quality leading to revenue loss.

Among the Custom Power devices, DVR is considered to be the most effective device than Static Var Compensator (SVC), DSTATCOM and UPS.The concept of using the DVR as a power quality product has gained significant popularity since its first use(1).

According to IEEE standard 1159-1995, a voltage sag is defined as a decrease to between 0.1 and 0.9 p.u. in root mean square (rms) voltage at the power frequency for durations of 0.5 cycle to 1 min.

Energy storage topology can compensate deep voltage sags independent of Grid than storage less DVR (2) even then it ranks second because of the size of energy storage system. The size and cost of energy storage element and inverter are the major drawback of energy storage topology.

Various types of rechargeable energy storage technologies based on Superconducting Magnetic Energy Storage (SMES), Flywheels Energy Storage System (FESS), Batteries Energy Storage System (BESS) and Ultra capacitors (UCAPs) are compared in (3) for integration into advanced power applications like DVR to mitigate the voltage sags. Of all the rechargeable energy storage technologies UCAPs are ideally suited for applications which need active power support in the milliseconds to seconds timescale (8).

UCAP [8] is promising candidate for the next generation energy storage device. UCAPs have low energy density and high power density ideal characteristics for compensating voltage sags and voltage swells which are both events which require high amount of power for short spans of time.

The impedance source inverter(7) is more promising in renewable energy system mainly for three reasons:

- The traditional PWM inverter has only one control freedom to control the output AC voltage whereas the Z-source inverter has two independent control freedoms as shoot-through duty cycle and modulation index that can produce any desired output AC voltage.
- The Z-source inverter provides the same features of a DC-DC boost inverter in a single-stage and hence less complex and more cost effective.
- The Z-source inverter has the benefit of enhanced reliability because the shoot-through state can never destroy the inverter.

Proper implementation of the impedance-source network with appropriate switching configurations and topologies reduces the number of power

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conversion stages in the system power chain improve the reliability and performance of the power systems.

II. Storage Device Propoerties

Batteries vary in weight, cost, technical maturity, degradation proprieties and speed of discharge and charge, these distinctions affect the decision of using a BSS or HBSSS per application.

In BESS system (6), rapid deep discharges of battery may lead to early replacement of the battery, since heating resulting in this kind of operation reduces battery lifetime and is toxic.

UCAPs have low energy density and high power density ideal characteristics for compensating voltage sags and voltage swells which are both events which require high amount of power for short spans of time(8). UCAPs also have higher number of charge/discharge cycles when compared to batteries and for the same module size; UCAPs have higher terminal voltage when compared to batteries, which makes the integration easier.

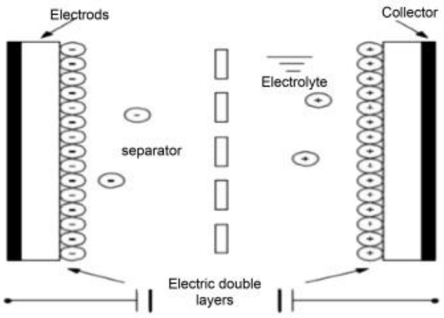

Fig.1. Ultra-capacitor Structure

Ultra-capacitors are electrochemical double layer capacitors. Due to their material composition and design structure they have a high power density and low equivalent series resistance (ESR). These characteristics lead to higher efficiency, larger current charge and/or discharge capacity, and low heating losses.

III. Proposed System

Proposed system UCAP based DVR system with impedance source inverter is shown in Figure 2. In this paper, Ultra capacitors are used as energy storage element with porous electrode material and high power density. Conventional bi directional converter is replaced with impedance source inverter to reduce the cost and size of energy storage element.

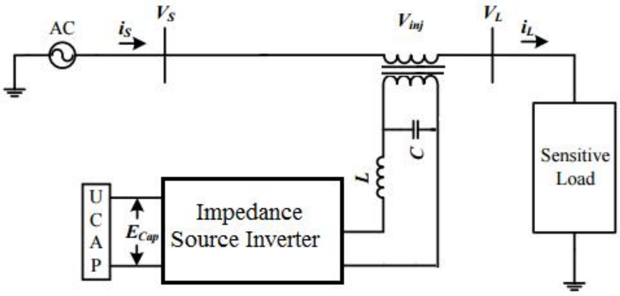

Fig.2.Proposed System

A. DVR Model

The Single phase series DVR model consists of the Insulated gate bipolar transistor (IGBT), its gate driver; filter circuit and an isolation transformer. The key purpose of a DVR is the protection of sensitive loads from power quality problems such as voltage sag and swell. If a fault arises on the transmission lines, DVR injects a series voltage and compensates the missing voltage. The equivalent voltage generated by the inverter will compensate any discrepancy of voltages produced by transient disturbances in the ac feeder.

B. Modeling of UCAP

The choice of selecting the number of UCAPs depends on the factors such as a terminal voltage of UCAP, dc-link voltage and voltage of the distribution grid. The value of capacitance and Equivalent series resistance (ESR) depends on the formula given by,

$$C_{sy} = \frac{C_{cell}}{n} \quad (1)$$

$$ESR_{sy} = ESR_{cell} * n \quad (2)$$

The capacitance of the UCAP varies directly with the parallel plate area A and inversely with the distance a between the plates and is given by,

$$C = \frac{£_0 £_r A}{d} \quad (3)$$

The design parameters are shown in Table 1. In this paper, two UCAP, each of 48 V with 165 F capacitance, are connected in series to obtain the output voltage of 96 V. This model is simulated in Matlab is shown in Figure 3.

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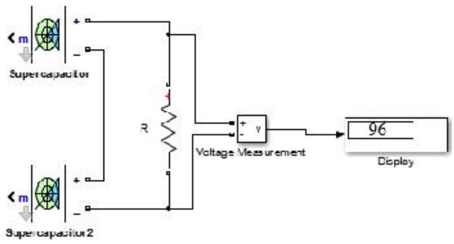

Fig.3.UCAP design using MATLAB

The design parameter of UCAP is shown in the table.

Parameters	Values
Rated Voltage	48V
Rated Capacitance	165 F
ESR	7 mΩ
Operating temperature	25^o C

C. Impedance Source Inverter

The impedance source inverter is a cascaded buck boost inverter that can process the power in single stage. It has the benefit of high reliability, as shoot-through state can never destroy the inverter. General topology of ZSI is shown in Fig 3.

In the conventional VSI and CSI, ac output voltage is limited below dc voltage and additional converters are required to meet desired ac output above dc input. ZSI can buck or boost voltage to a desired output voltage that is greater than available dc bus voltage. The presence of two inductors and two capacitors in the Z-Source network allows shoot through of switches in same leg.

In Fig. 4, a two-port network that consists of a split-inductor L_1 and L_2 and capacitors $C_1$and C_2 connected in X shape is employed to provide an impedance source (Z-source) coupling the converter (or inverter) to the dc source (UCAP).

When the UCAP voltage is more than 48V, Impedance inverter will boost and inject missing voltage into the Grid. If the UCAP voltage is less than 48V, UCAP will be charged from Grid.

V_0 is the output of DC source (UCAP) and $\hat{V}_i$ is the peak dc link voltage and expressed as

$$\hat{V}_i = BV_0 \qquad (4)$$

where $B = \frac{T}{T_1 - T_0} = \frac{1}{1 - 2\frac{T_0}{T}} \geq 1,$ (5)

B is the boost factor resulting from the shoot-through zero state.

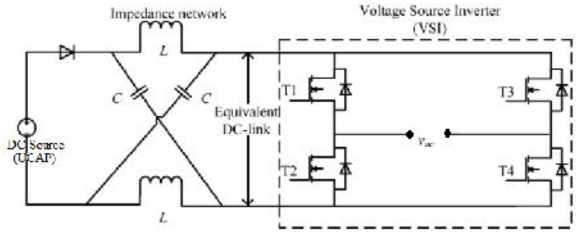

Fig.4.Z source Inverter

The output peak voltage of inverter is given as

$$\hat{V}_{ac} = M.B.V_0 \qquad (6)$$

where M is the modulation index.

D.Simple Boost Control

Simple boost control is the basic method which is simple and easy to be implemented. The simple boost control method is illustrated in Fig. 5. Two straight lines are employed to realize the shoot through duty ratio.

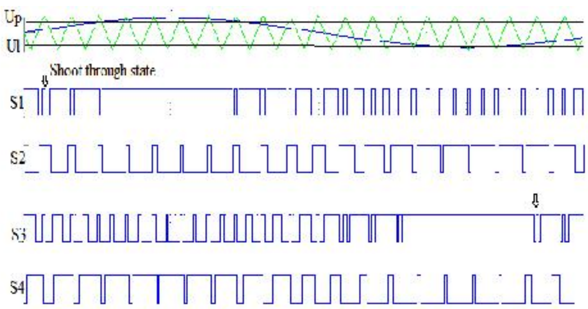

Fig.5.Boost Control

Whenever the triangular carrier signals is higher than the positive straight line or lower than the negative straight line, the inverter will be operated in shoot-through, otherwise, it works as a traditional PWM inverter. The Pulse Width Modulation (PWM) signals are generated and part of output is inverted through logic gates to perform the control process of active and zero states. The OR gates are used to perform addition of active and shoot-through states.

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IV. SIMULATION RESULTS

The Simulation of UCAP based DVR with impedance source inverter is carried out with R = 25 Ω. Z source network parameters $L_1=L_2= 160\ \mu H$ and $C_1=C_2=1000\mu F$. The purpose of the system is to boost UCAP voltage 96V to 230V rms at the output at modulation index M=0.85 at switching frequency of 1KHZ.

$$B=\frac{1}{1-2\frac{T_0}{T}}=3.92$$

$$\hat{V}_{ac}=M.B.V_0 = 0.85*3.92*92 =320V$$

V_{rms} = 230V

UCAP model is designed and integrated with DVR through the impedance inverter and is connected to distribution system for the compensation of voltage sag and swell. The power quality problems voltage sags are simulated in Matlab for the time interval of 0.1 s to 0.2 s is shown in Figure 6.

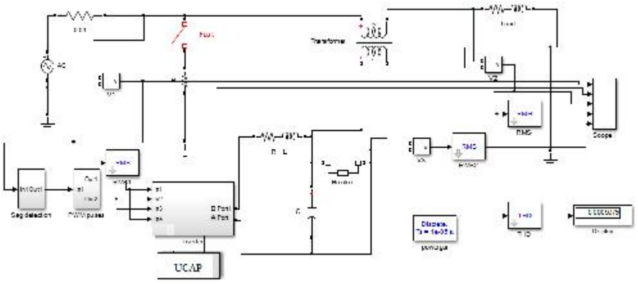
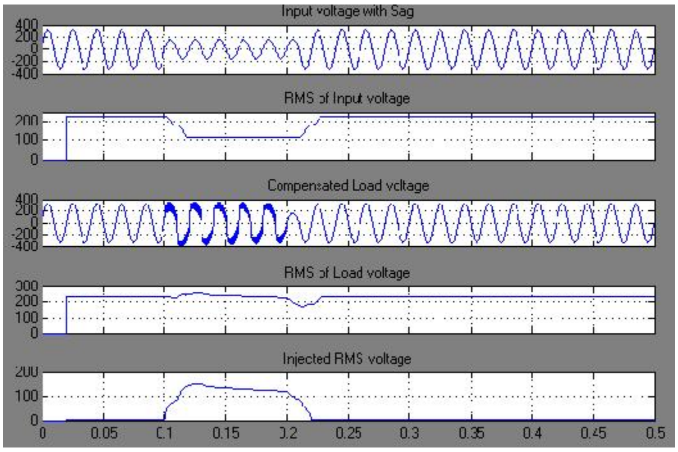


Fig.6.Simulink Model of the Proposed System

The Simulated waveform of proposed system is shown in Figure 7.



The requirement of UCAP size is less as only two modules of ultra-capacitors are used. UCAP is integrated into dc-link of the DVR through a Z-source converter and the integration helps in compensating deeper voltage sags, voltage swells for longer durations.

TABLE I. COMPARISION

Converter	**Parameter**		
	UCAP Module	***Voltage Requirement***	***Boost factor***
Traditional	3	144	2
Z-source	2	96	5

V. CONCLUSION

UCAP based DVR using impedance source inverter is proposed in this paper. The proposed system has high compensation capability with improved active power capability and reduced cost. Modeling and Simulation of the proposed system has been carried out using MATLAB. The size of energy storage element is reduced by using impedance source inverter and boosting capability also improved.

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