VOLTAGE SAG MITIGATION USING SUPERCAPACITOR BASED DYNAMIC VOLTAGE RESTORER

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Abstract

One of the major issues in improving power quality in distribution network is the mitigation of voltage sags which is caused by the system faults and adversely affects the sensitive electrical equipments involved in the end user system. End user system includes industrial production processes and large commercial customers. System faults affect sensitive equipments and result in substantial financial losses. Thus need for introduction of custom power devices emerged. One of these devices is Dynamic Voltage Restorer (DVR) which has excellent dynamic capabilities, installed between supply and a critical load feeder; it compensates voltage sags and restores line voltage to its nominal value. The proposed system comprises of a supercapacitor and the power circuit of the DVR. Thus DVR avoids any power disruption to that load. This paper presents supercapacitor based DVR using Proportional Integral (PI) controller. The system is simulated using PSCAD/EMTDC software. The graphic facility available in this software helps to carry out various aspects of model implementation and simulation results.

Keywords: *Power Quality, Voltage sag, Dynamic Voltage Restorer, Custom Power devices, Voltage Source Inverter, PWM.*

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1. INTRODUCTION

Power quality is the most important aspects at transmission as well as distribution levels. Power quality is defined as the delivery of sufficiently high grade electrical services to the customer [1]. Power quality problems are because of the increased use of sensitive equipments used in process industries, communication system,.etc. This is the main factor for degradation of power quality. Power quality disturbances are transients, voltage sags, voltage swells, momentary interruptions, under voltage, overvoltage, electrical noise, flickers, harmonic distortion, and voltage imbalance [2]

Voltage sags are the phenomena of sudden voltage drops lasting for a short duration. Sag depends on two factors i.e. magnitude and duration of time it exist in the system. Voltage sags are caused mainly by the lightening in power distribution and transmission system [3]. Also it is caused by short circuit faults in power network [4] [5], during starting up of induction motors of very high rating [6]. Thus this reduces energy transfers of electric motors and disconnects sensitive equipment. A voltage sag description is found in the reference paper [7]. Harmonics are produced by nonlinear equipments such as variable speed drives, electric arc furnaces, loads which use power electronics, large concentrations of arc discharge lamps [8]. Harmonics currents generated by nonlinear device causes copper and iron losses in electrical equipments. Hence produce pulsating torques and overheating in rotating machinery. Voltage imbalances caused by unbalanced loads or short circuit faults produce overheating in synchronous machines and, in some extents leads to equipment failure or shutdown of loads.

Nowadays modern industrial applications are mostly based on electronic devices such as electronic drives and programmable logic controllers. Electronic devices are sensitive and less tolerant to power quality disturbances such as voltage sags, swells and harmonics [9]. Two approaches are involved to mitigate power quality problems. First approach which ensures equipment is less sensitive to power disturbances by storing “ride through” energy in the equipment or by intelligent control. Second approach is to install line conditioning device that suppress or counteracts the power system disturbances. They are based on PWM converters. So for longer power interruptions custom power devices are used [10].

Custom power technology is the low voltage counterpart of the Flexible AC Transmission System (FACTS) technology. Both custom power concepts and FACTS are directly credited to EPRI [11][12]. Among the custom power devices, the voltage source converter technology received great attention due to its features such as fast response, possibility of utilization together with energy storage devices thus allowing the active and reactive power compensation simultaneously.

Custom power devices are Distribution Static Synchronous Compensator (DSTATCOM), Active Power Filter (APF), Battery Energy Storage System (BESS), Dynamic Voltage Restorer (DVR), Static State Transfer Switches (SSTS), Uninterrupted Power Supplies (UPS), Thyristor Switched Capacitor (TSC). However custom power devices are mainly of three categories such as series connected compensator known as Dynamic Voltage Restorer (DVR), shunt connected compensators such as Distribution Static Compensator (DSTATCOM), and a combination of the two i.e. series and shunt connected compensators known as Unified Power Quality Condition (UPQC) [13-16]. DVR has higher energy capacity compared to the SMES, UPS devices. Also DVR has an ability to control active power flow in the system [17]. Owing to smaller size and lesser cost as compared to DSTATCOM and other custom power devices, DVR is an effective custom power device in mitigating voltage sags. Other features of DVR are power factor corrections and harmonics reduction thus it provide as economical solution for its size and capabilities [18].

The DVR is a voltage source converter connected in series with the ac network by an interfacing transformer. The basic principle of operation of DVR is the injection of an in phase series voltage with the incoming supply of load, sufficient enough to reestablish the voltage to its presag condition. Hence researches are more interested in DVR. There are three popular strategies to compensate voltage sags by using DVR. They are 1. Presage compensation method. In this the injected DVR voltage is calculated to compensate load voltage prior to presage state, 2. In phase compensation method. The DVR voltage is always in phase with the grid voltage or load voltage of the system and 3. Is the optimal energy compensation method. The compensation of voltage sags using DVR is done either by absorbing or injecting the reactive or real power into the system [19]. When injected voltage is in phase with the current, DVR injects a real power and hence a battery is required at the dc bus of VSC (Voltage Source Converter). In an application of DVR, the supercapacitor based energy storages provide very high power in a short duration of time also its efficiency with capacitor is more than that of conventional ones. Thus the limitation in the ability of delivering real power using battery is overcome by the supercapacitor help in storing sufficient energy and is able to release it in order to improve a high quality of distribution voltage.

2. DYNAMIC VOLTAGE RESTORER

Dynamic voltage restorer is a solid state device which injects three phase compensating voltages in series to the power lines through 3 single phase series transformer or a 3 phase series transformer system. The DVR dc side is connected to energy storage device. Its ac side is connected to the distribution feeder by injection transformer. The DVR compensates voltage difference between faulted and pre-faulted condition. Injecting voltage must be of required frequency, magnitude and phase angle as that required at load side. Energy required for compensation is taken from energy source element. There are two topologies regarding DVR i.e. system comprising with an energy source and without an energy source. Energy storage applied to DVR are a lead acid battery [20], capacitors [21][22], superconducting magnetic energy storage (SMES) [23],flywheel [24] etc. Energy storage system and injection transformer adds to its physical size, weight and cost to the system, is the main drawback of DVR. This inhibits DVR in spite of the superior performance in use at the wider aspect. Conventional DVR circuit topology is shown in fig.1

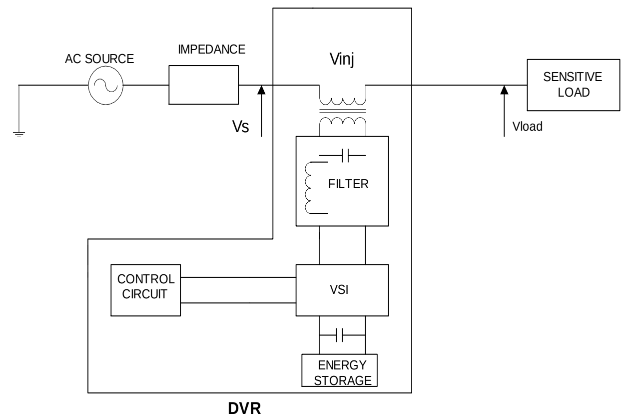


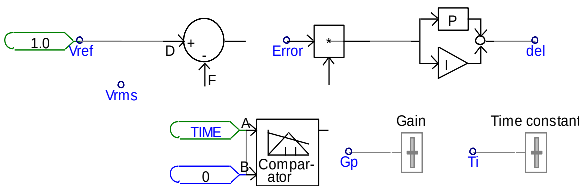
Fig.1 Conventional DVR Circuit Topology

The main components of DVR are voltage source inverter (VSI), energy storage system [25][26], injection transformer, harmonic filter,. The harmonic filter includes leakage inductance and filter capacitor of the series transformer. Energy storage device provide necessary real power for compensating voltage sag and voltage source converter generates sinusoidal voltage at required magnitude, phase and frequency. Also harmonic filter convert PWM inverted pulse waveform into the sinusoidal waveform, removing the unnecessary higher order harmonics components generated during conversion DC to AC in the VSI. Injection transformer increases the voltage which is supplied by VSI to a desired level and isolates the DVR from the distribution network. The VSC switching strategy is based on sinusoidal PWM technique since it is flexible, simple and provide better response.

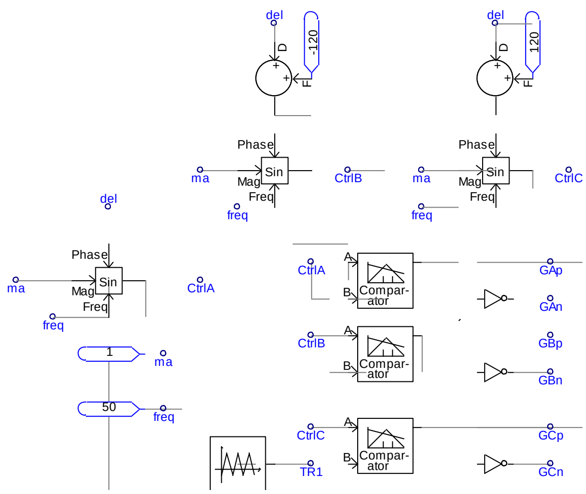
2.1 Sinusiodal PWM Based Control of the DVR

PWM control scheme is used, controls the magnitude and phase of the injected voltages by DVR and restores the rms voltage. The control system only measures rms voltage. No reactive power measurement is required [27]. VSC switching is based on sinusoidal PWM technique. Fig.2 shows the control scheme implemented in PSCAD/EMTDC to carry out DVR simulations.

The PI controller input is an error signal obtained by the difference between reference voltage and the three phase rms voltage at the load during fault condition. It generates the required angle δ (del) similar to that of the difference so as to drive the error signal to zero and thus brought back the voltage to the reference voltage. Voltages obtained from the three phases A, B, C is compared with triangular signal (carrier) generate switching signals for VSC valves.



Control system



Sinusoidal PWM based control[28]

Fig 2 Control scheme for test system implemented in PSCAD/EMTDC to carry out the DVR simulations

PWM Scheme has two main parameters namely amplitude modulation index ma, of the three phase voltage signal and is kept at 1, frequency modulation index mf of the triangular signal which is kept at 9 i.e the switching frequency of mf is set at 450 Hz. The angle δ is applied to the PWM generator in phase A and angles for phase B and C are shifted by 240° and 120° resp.

The structure of this paper is as follows. In Section III system modeling in PSCAD software, Section IV contains supercapacitor modeling, and finally, Section V concludes the paper.

3. SYSTEM MODELING IN PSCAD

Test system is implemented in PSCAD/EMTDC to carry out DVR simulations shown in fig 3 produced from the reference [28]. The DVR coupling transformer is connected in delta in the DVR side. Leakage reactance of coupling transformer is 10%. Transformer turn ratio is set as unity and the dc storage capacity is 5 kV.

Two simulations are carried out:

1. Three phase short circuit fault is applied on the critical load without DVR introduced into the system. Fault resistance is kept at 0.66Ω. Simulation period is

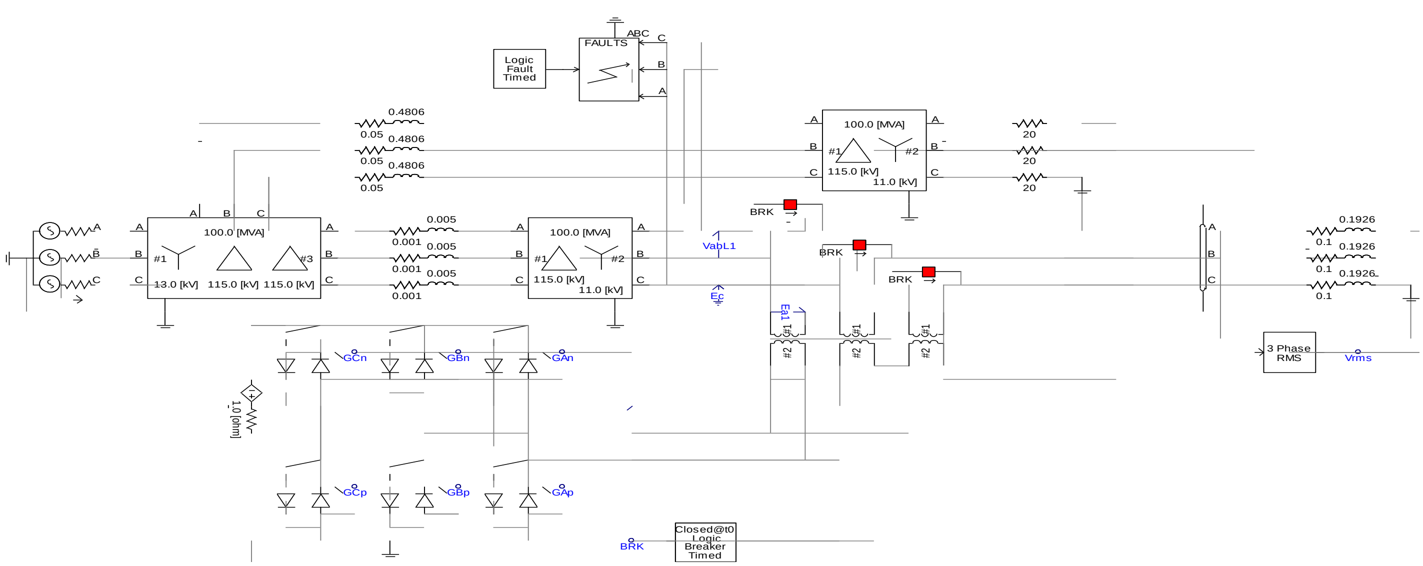
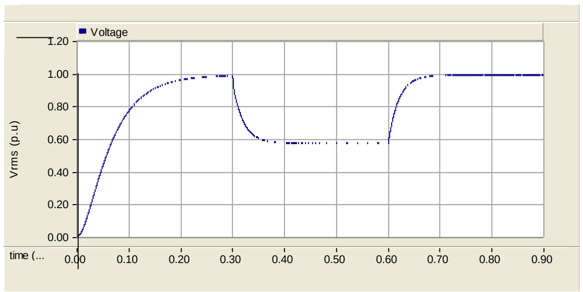
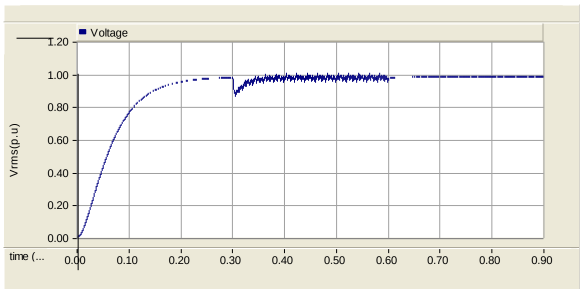


Fig.3 Test system implemented in PSCAD/EMTDC [28].

0.3 to 0.6 seconds. The voltage sag is 50% that of the reference voltage.



(a)



(b)

Fig. 4 Voltage obtained at the sensitive load point a) with no DVR and b) with DVR

2. The DVR is in operation. The test system scenario is same as previous case. Total simulation period is 0.9 seconds. The DVR is in operation only for the duration of fault. Results are shown in the fig.4. It is found that voltage sag is mitigated by DVR up to 90 to 95%.

4. SUPERCAPACITOR MODELLING

The unique property of Supercapacitors is they have high power densities that enable them to handle fast fluctuations in energy levels. The capacitance is related to the concentration of ions near the electrodes, thus when voltage increases, electric field attracts more ions. The highest capacitance is always found when low currents are used and vice versa

Supercapacitor model is produced from the reference [29] of this paper. Supercapacitor model is ESSP48 having value 42 V, 33F supplier is EPCOS, type is ACN (Acetonitrile), having normal current 500 A and 18 cells. The basic circuit model of supercapacitor is present in the datasheet of supercapacitor from EPCOS [30], and is shown below in fig 5. A supercapacitor is modeled using standard circuit components in the fig. 6.

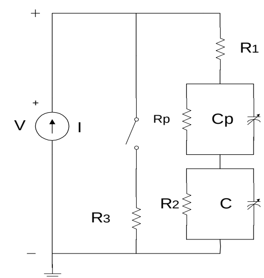


Fig 5 The basic circuit model of supercapacitor

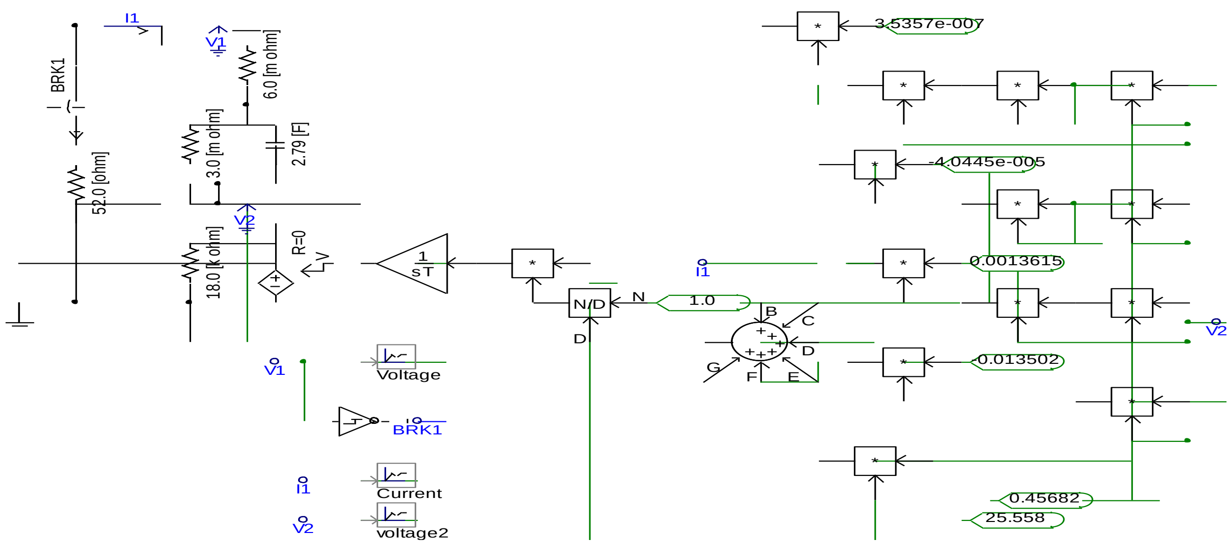


Fig.6 Model made in PSCAD, using controlled voltage source [29].

Values are : R1 = 6 mΩ, R2 = 18 kΩ, R3 = 52Ω, Rp = 3mΩ, C = 35 F, Cp = 2.79Ω.

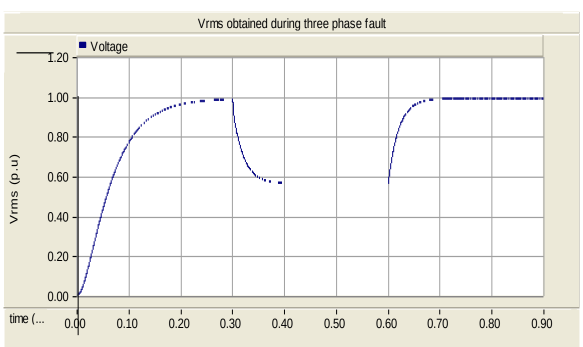
R1 represents the losses during charge and discharge . Losses occur due to resistance of conducting element of supercapacitor, not ideal. R2 represent self discharge of capacitor C as discharge is very slow hence its value is high. R3 is called as balancing resistor and it provides overvoltage protection. Capacitance C determines amount of energy stored and Cp is taken as one thirteenth of C, as its impact is very small. The resistance Rp and capacitance Cp shows fast dynamic behavior of the supercapacitor. Switch is connected with balancing resistor R3 and is set to be connected when the voltage goes above 42.84 V and disconnected when voltage goes below 42.83 V. This keeps the voltage from rising too high value over the supercapacitor. The switching voltage levels are set in the hysteresis block located on the left of label BRK1.

To model the nonlinear capacitance C using a controlled voltage source a controlling signal is required. As the voltage value of capacitor is given by equation $u(t) = \int\frac{i(t)}{C}\,dt$ therefore integration is to be performed to reach the correct voltage value of the controlled voltage source. This leads to initial value of the voltage source over the capacitance. A polynomial is adapted to the original function that describes the relation between voltage and capacitance. The resulting polynomial is:

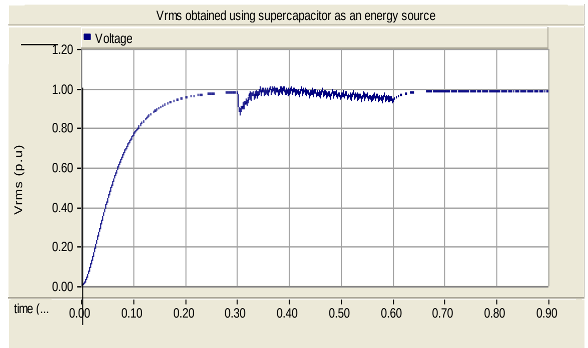
$$C = p1.u5+p2.u4+p3.u3+p4.u2+p5.u+p6$$

Where,
p1 = 3.5357e-7, p2 = -4.0445e-5, p3 = 1.3615e-3, p4 = 1.3502e-2, p5 = 4.5682e-1, p6 = 25.558.

The simulation results of DVR using supercapacitor as an energy source are shown in fig 7.



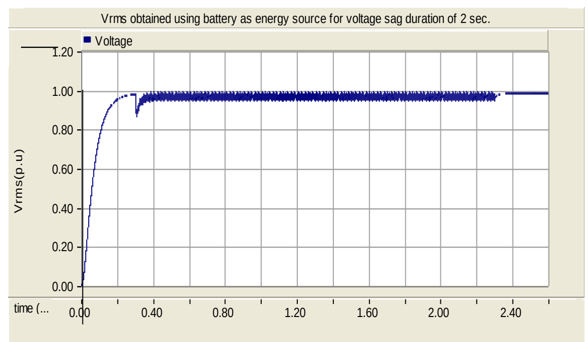
(a)



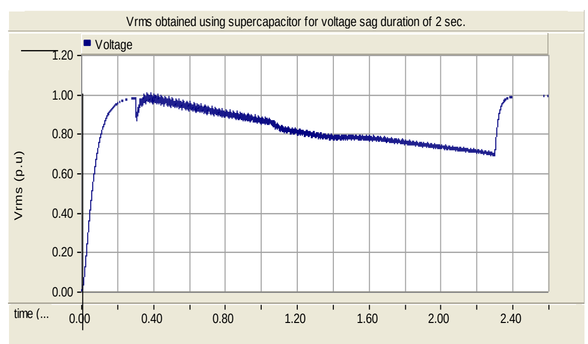
(b)

Fig.7 Voltage obtained at the sensitive load point a) with no supercapacitor and b) with supercapacitor.

So as to find out the impact of battery and supercapacitor in long duration sag, fault duration is increased to 2 sec. The simulation results are obtained as:



(a)



(b)

Fig.8 Vrms at the sensitive load point a) with battery and b) with supercapacitor.

Results show that supercapacitor can not stand for long duration voltage sag it starts discharging. But as battery is a continuous source of supply it supports the system.

5. CONCLUSIONS

In this paper, model of DVR and supercapacitor is done using PSCAD/EMTDC software. Results show that for short duration disturbances supercapacitor can replace battery. Problems associated with battery can be avoided by using supercapacitor however for longer duration disturbances battery must be used.

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