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MITIGATION OF VOLTAGE SAG WITH TRANSFORMER LESS DVR BASED ON REDUCED SWITCH COUNT MULTILEVEL INVERTER

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ABSTRACT:

Voltage sag is widely regarded as one of the most critical power quality issues in power systems. Dynamic Voltage Restorers (DVRs) offer a cost-effective solution to protect sensitive loads from such disturbances. Further reductions in cost, as well as improvements in reliability and efficiency, can be achieved by removing the injection transformer. This paper presents a transformer less DVR design based on a T-type multilevel inverter. Without an injection transformer, the proposed DVR is more economical, lighter, and more compact. The DVR controller uses d- q transformation, and MATLAB/SIMULINK is employed to generate the simulation results.

INTRODUCTION

Power stations are designed to produce high-quality

Mitigation devices	Sags	Interruptions	Swells	Transients	Overvoltage	Undervoltage	Harmonics
SA				✓			
BESS	✓	✓	✓	✓	✓	✓	
DSTATCOM				✓	✓	✓	
DSC						✓	
DVR	✓		✓	✓			✓
PFCC					✓	✓	
SMES	✓	✓	✓	✓	✓	✓	
SETC	✓		✓		✓	✓	
SSTS	✓	✓	✓				
SSCB		✓					
SVC	✓		✓		✓	✓	
TSC				✓		✓	
UPS	✓	✓	✓		✓	✓	
APF(TF)				✓			✓

APF(TF) = Active power filter or tuned filter
BESS = Battery energy storage system
DSTATCOM = Distribution static synchronous compensator
DSC = Distribution series capacitor
DVR = Dynamic voltage restorer
PFCC = Power factor correction capacitor
SA = Surge arrester
SMES = Superconducting magnetic
SETC = Static electronic tap chang
SSTS = Solid-state transfer switch
SSCB = Solid-state circuit-breaker
SVC = Static var compensator
TSC = Thyristor switched capacit
UPS = Uninterruptible power supp

Sinusoidal waveforms. However, the wide spread use of nonlinear, power electronic-based devices, as well as system faults, can lead to deviations from these ideal waveforms. Customers require stable sine wave shapes, consistent frequency, and symmetrical voltages with constant root mean square (RMS) values to maintain continuous operations. Consequently, system disturbances such as voltage sags, swells, interruptions, phase shifts, harmonics, and transients must be mitigated.

The extensive use of nonlinear loads—including personal computers, variable speed drives, UPS systems, and other electronic equipment—generates harmonics, posing a significant problem in industrial and commercial power systems. Harmonic currents interact with system impedances, causing voltage harmonics that can interfere with sensitive loads.

Electronic equipment, in particular, is susceptible to harmonic distortion, as these devices depend on the peak value or zero-crossing points of the voltage supply, both of which can be disrupted by harmonic interference. These issues create challenges for both power providers and customers, making power quality a prominent concern across the electricity industry.

Voltage sags and swells can severely impact sensitive equipment, such as those in semiconductor and chemical manufacturing, causing shutdown so failures and creating large current imbalances that can blow fuses or trip breakers. These disruptions can lead to significant financial losses for customers, including minor quality inconsistencies, downtime, and potential equipment damage. While there are various methods to mitigate voltage sags and swells, the use of custom power devices remains the most effective solution.

REDUCTION OF HARMONICS USING FACTS DEVICES

a. **Power Quality (PQ) Problems**
b. **Power quality concerns**
c. **Power quality categories**

The Dynamic Voltage Restorer

The Dynamic Voltage Restorer (DVR) is a power electronic converter-based device designed to protect sensitive loads from various power supply disturbances, excluding outages. It operates in series with a distribution feeder and can injector absorb both real and reactive power at its terminals. By injecting a voltage with the required magnitude and frequency, the DVR restores the load voltage to its pre-sag state, primarily consisting of power and control circuits.
DVR Power Circuit

The power circuit of the DVR comprises four key components: a Voltage Source Inverter (VSI), a voltage injection transformer, a DC energy storage device, and a low-pass filter, as shown in Fig.3.1.

Common devices used to mitigate voltage sags and swells include Uninterruptible Power Supplies (UPS) and DVRs, which offer voltage sag compensation. While UPS systems are widely known and used, DVRs are still in the development phase. However, DVRsarehighlyefficientandcost-effectivecompared to UPS systems. With ongoing advancements inpower electronics and declining costs of power devices, the popularity of DVRs in industrial applications is expected to increase.

Both UPS and DVR devices arecapableof injecting a voltage waveform into the distribution line. However, a significant difference is that UPS systems continuously supply the full voltage to the load, whether the waveform is distorted or not, resulting in the UPS operating at full power at all times.

DVRCompensationStrategiesandControl

Compensation Strategies of the DVR

The compensation control technique of the DVR tracks the supply voltage and synchronizes it with the pre-sag supply voltage during voltage sags or swells in the upstream distribution line. Voltage sags typically involve both a phase angle shift and a magnitude change. The chosen control technique depends on the load's sensitivity to changes in magnitude, phase shift, or waveform shape. Additionally, the voltage injection capability (i.e., inverter and transformer ratings) and the size of the energy storage device must be considered when selecting a control method.

Under normal conditions, the supply voltage (Vs) is designated as the pre-sag voltage, denoted as Vpre-sag. In this scenario, since the DVR is not injectinganyvoltage, theloadvoltage(Vload) andthe supply voltage are identical. During a voltage sag,both the magnitude and phase angle of the supply voltage change, represented as Vsag. The DVR activates in this situation, injecting voltage (Vdvr). If the DVR fully compensates for the voltage sag, the load voltage during the sag will match Vpre-sag. Severalcontroltechniques havebeenproposedfor this compensation.

Pre-sagCompensation

This techniquecompensates for thedifference between the sagged and pre-sag voltages by restoring the instantaneous voltage magnitude and phase to the nominal pre-sag voltage. This method is particularly suitablefornon-linearloads,suchasthyristor- controlled loads, that are sensitive to phase shifts. However, it requires higher-rated energy storage devices and voltage injection transformers due to the lack of active power control.

In-phaseCompensation

Inthis method, thecompensated voltage is in-phase with the sagged voltage and compensates only for the voltage magnitude. This technique minimizes the amount of voltage injected by the DVR and isideal for linear loads, which do not require phaseangle compensation. Both real and reactive power are needed for compensation, with the DVR supported by an energy storage device.

CombiningPre-sagandIn-phaseCompensation

To enhance efficiency and control, different compensation techniques can be combined. One approach involves initially restoring the load voltageto the pre-sag phase and magnitude (pre-sag compensation) and gradually shifting the injected voltage towards the sagged voltage phasor.Ultimately, thecompensated voltage matches both the magnitude and phase angle of the pre-sag voltage,with the phase angle slowly transitioning to thesagged voltage.

EnergyOptimizationTechnique

This method minimizes energy consumption by reducing or eliminating the use of real power, injecting the required voltage at a 90° phase angle to the load current. While this technique requires a higher-ratedtransformer andinverter duetothehigher injected voltage, it results in compensation with a phaseshift, ensuringthecompensatedvoltagematches the pre-sag voltage in magnitude.

ReferenceSignalGeneratorsoftheDVRControl

Simulation Results of the DVR

Simulation is a powerful tool for testing and verifying practical results through software. MATLAB, particularly its Simulink component, isone of the most effective tools available. In this project, a transformerless DVR based on a T-type multilevel inverter is proposed. This DVR topology offers fewer switches, higher efficiency, and better Total Harmonic Distortion (THD) than other designs. The DVR is controlled using a d-q rotating reference frame. The DVR model, switching strategy, and controltechniquesaredetailed,andloadvoltage compensation during sag conditions is performed to maintain the desired voltage level, with results validated using MATLAB/SIMULINK software.

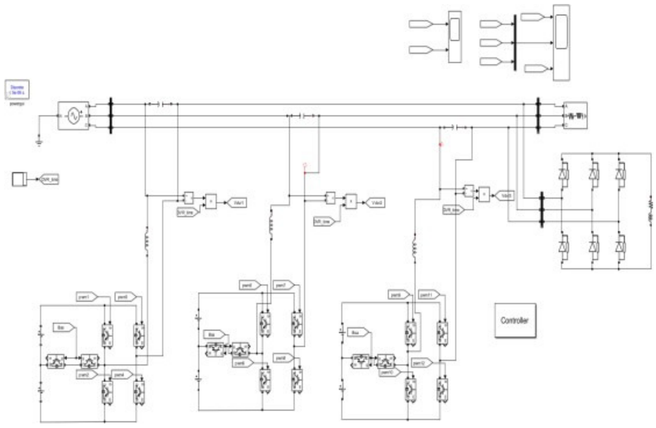

Fig:6.1ThemodulationcircuitwithoutDVR

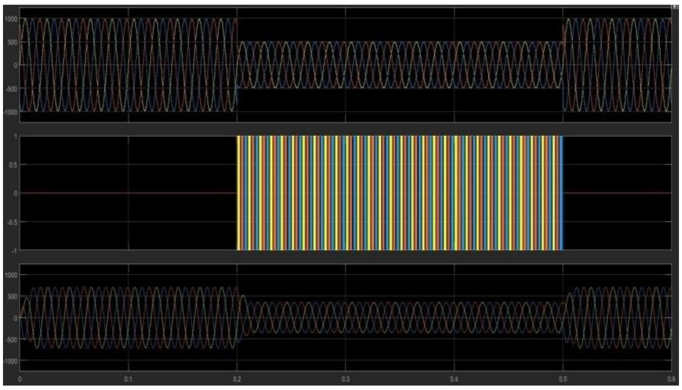

Fig:6.2SwitchingpulsesgeneratedbyreducedcarrierPW M technique method

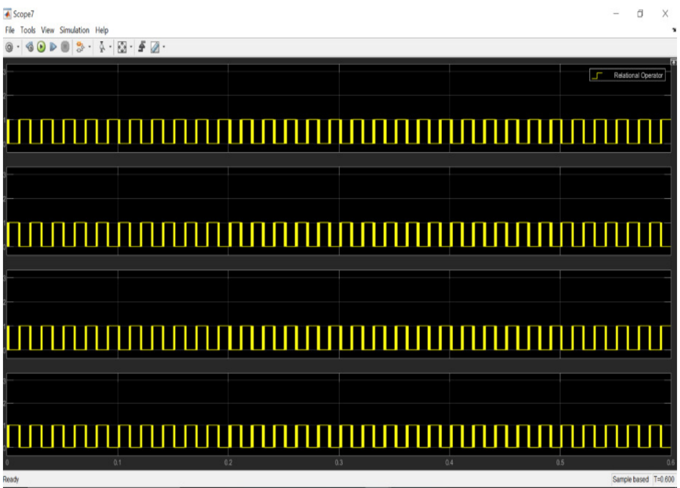

Fig:6.3Output voltage without DVR at0.2sec sag is createdthenthedifferenceintheswitchingcanbe observed.

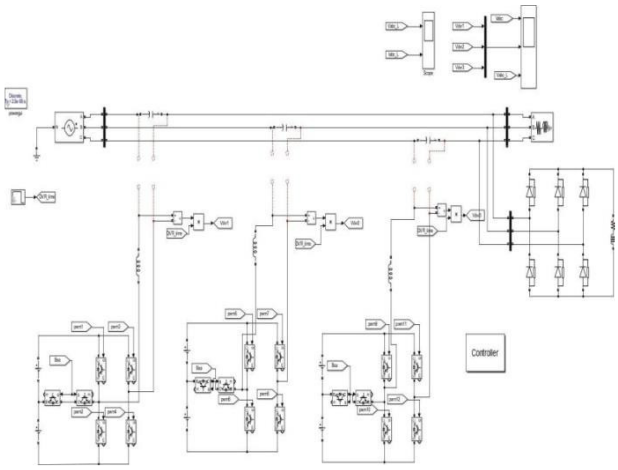

Fig:6.4SimulationofT-TypeMultilevelinverterasDVR

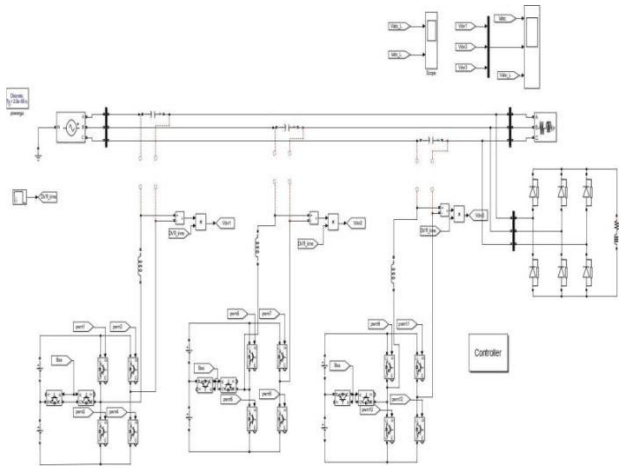

Fig:6.5ThecircuitofPIcontrollerbyusingPWMtechnique

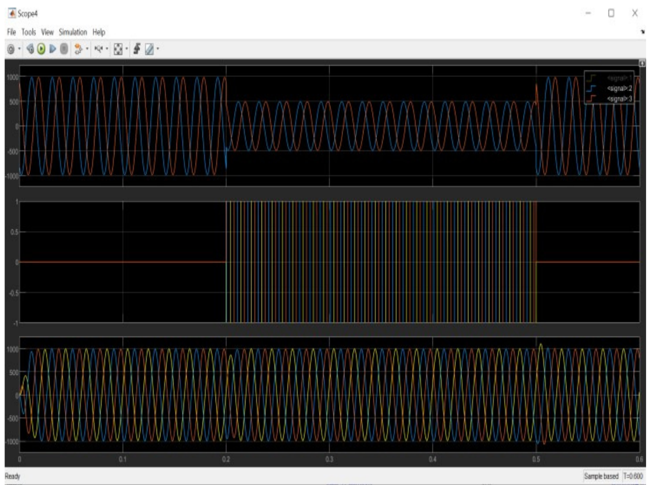

Fig:6.6CompensatedOutputvoltagewithDVRat 0.2sec sag is created then the difference in the switchingcanbe observed.

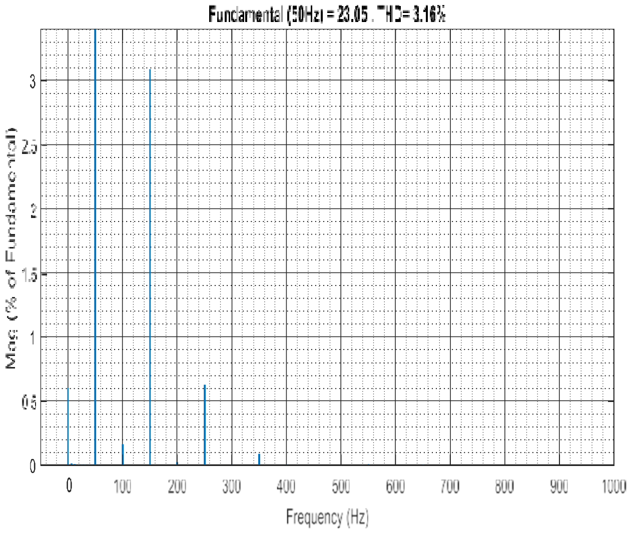

Fig:Harmonicanalysisofoutputvolage without DVR

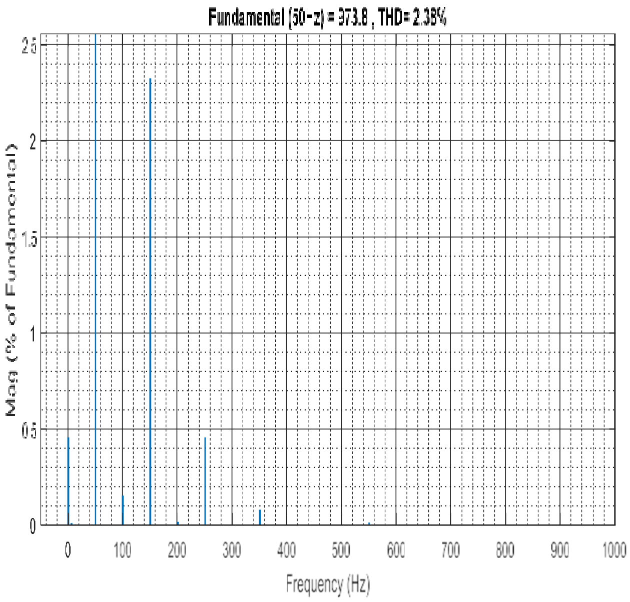

Fig: Harmonic analysis of output current without DVR

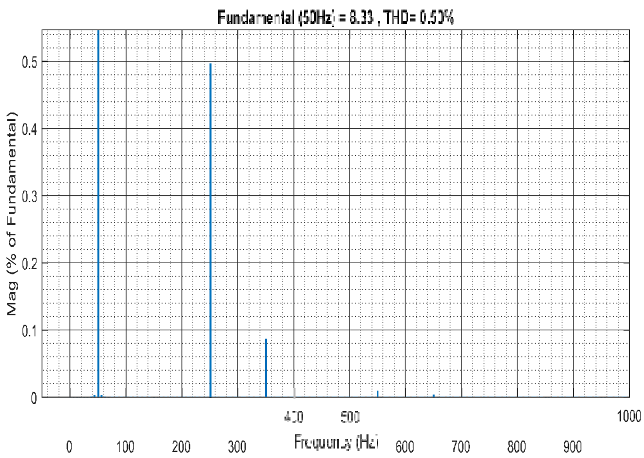

Fig: Harmonic analysis of output Voltage with DVRThis paper introduces a transformer-

CONCULSION

less Dynamic Voltage Restorer (DVR) based on a T-type multilevel inverter, which offers a design with fewer switches, higher efficiency, and improved Total Harmonic Distortion (THD) compared to other configurations. It operates using a d-q rotating reference frame for control. The paper details the DVR model, switching strategy, and control techniques. Load voltage compensation is conducted under sag conditions to stabilize and maintain the required load voltage, with performance validation achieved through MATLAB/SIMULINK software. Additionally, the proposed DVR model will undergo verification usinga hardware prototype.

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