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Role of Dynamic Voltage Restorer against Voltage Dip with Induction Motor as Load

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Abstract

A dynamic voltage restorer (DVR) is a custom power device used to correct the voltage dip by injecting voltage in series of the line in proper magnitude and phase. Voltage sag due to fault conditions, and starting dip are the major power quality problems which results in a failure or a mis-operation of induction motor. In this paper, these conditions of voltage dip are considered. Sensitive industrial loads and utility distribution networks all suffer from various types of outages and service interruptions which may result in a significant financial 1oss. This paper presents the role of Dynamic Voltage Restorer (DVR) with PI Controller to compensate balanced voltage sag and starting dip of induction motor. Simulation results show that this proposed method can compensate starting dip and balanced voltage sag conditions effectively.

Keywords*:* Power quality, voltage sag, voltage dip, custom power devices, DVR, Energy Storage System, pulse width modulation.

Introduction

The major concern in electricity industry today is power quality to sensitive loads. Power quality disturbances such as voltage sags, voltage dip and short duration outages on sensitive equipment can often lead to harmonic distortion, valuable data loss and long production downtimes [1],[3]. Motor starting and short circuit faults in power systems are the two major causes of voltage sags [2]. The former only produces shallow sags but for longer duration. The latter can cause deep voltage sags and has a direct impact on customer's power quality [11]. The prevailing voltage sag producing faults are shunt type faults such as single phase to ground fault, double line to ground fault and three phase to ground fault. For these abnormal conditions, dynamic voltage restorer (DVR) can provide the cost-effective solution to compensate the voltage sag problem by injecting the appropriate voltage in series of the line to maintain the required voltage quality level [4]. In our work, we have considered three phase to ground fault.

Dynamic Voltage Restorer

A DVR is a solid state power electronics switching device consisting of either GTO or IGBT, a capacitor bank and injection or booster transformers [5], [7]. It is connected in series between a distribution system and a load at the point of common coupling (PCC). It injects a controlled voltage generated by a forced commuted converter in a series to the bus voltage by means of an injecting transformer [6]. Fig. 1 gives an idea about the working of a DVR system when connected in a distribution system.

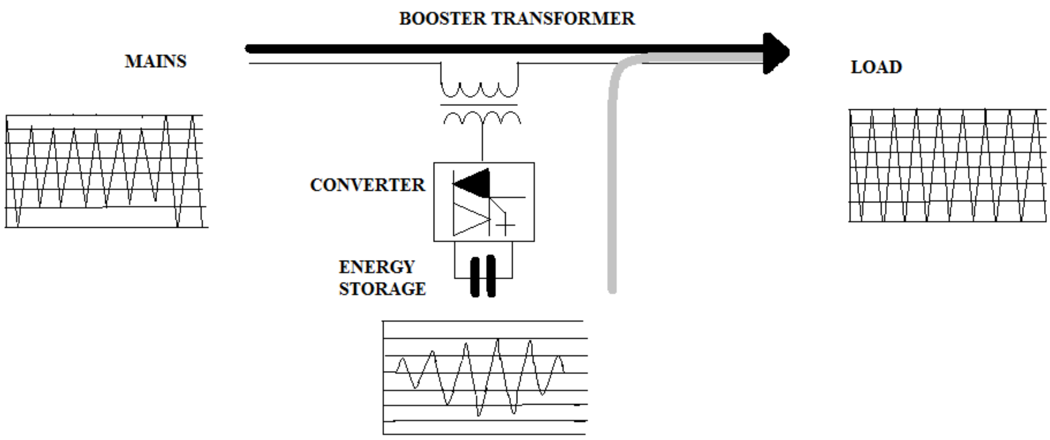

Figure 1: Concept of DVR system connected in distribution system.

The main parts of DVR system include the following:

- Booster transformer
- Voltage source converter
- DC charging unit
- Harmonic filters
- Energy storage unit

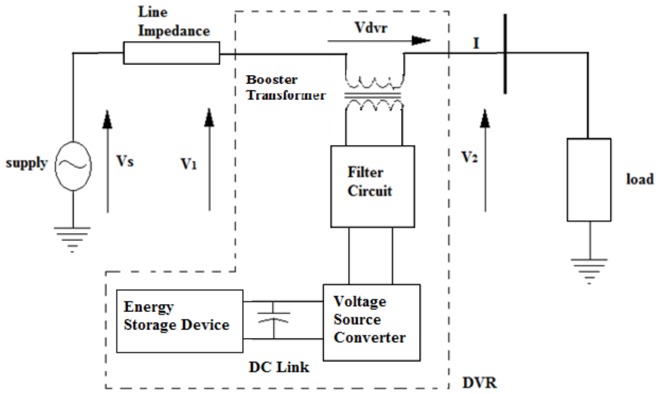

Figure 2: Dynamic voltage restorer.

Booster transformer: It connects the DVR to the distribution network via the HV-windings and transforms and couples the injected compensating voltages generated by the voltage source converters to the incoming supply voltage [7].

Voltage source converter: A VSC consists of a storage device and switching devices, which can generate a sinusoidal voltage at any required frequency, magnitude and phase angle. In the DVR application, the VSC is used to temporarily replace the supply voltage or to generate the part of the supply voltage which is absent [9]. In our work, we have used IGBT as the switching device.

DC charging unit: The dc charging circuit perform the following tasks:

- Firstly, it charges the energy source after a sag compensation event.
- Secondly, it maintains the dc link voltage at the nominal value.

Harmonic filters: The main function of harmonic filter is to filter the unwanted harmonic content generated by the VSC and hence, keep the harmonic voltage content within the permissible limit.

Energy storage unit: It is responsible for energy storage in DC form. Flywheels, batteries, superconducting magnetic energy storage (SMES) and super capacitors can be used as energy storage devices [8], [10]. It is supplies the real power requirements of the system when DVR is used for compensation.

Control Philosophy

Voltage sag is created at load terminals by a three-phase fault as shown in Fig.3. Load voltage is sensed and passed through a sequence analyzer. The magnitude of load voltage is compared with reference voltage. Pulse width modulated (PWM) control technique is applied for inverter switching so as to produce a three phase 50 Hz sinusoidal voltage at the load terminals [1], [4]. Chopping frequency is kept in the range of a few KHz. PI controller is used with the IGBT inverter to maintain 1 p.u. voltage at the load terminals.

PI controller input is an actuating signal which is the difference between the *Vref* and *Vin.* An advantage of a proportional plus integral controller is that its integral term causes the steady-state error to be zero for a step input [12]. Output from the controller block is in the form of an angle δ that is used to introduce an additional phase-lag/lead in the three-phase voltages.

Parameters of DVR Test System

Simulation model of DVR test system is shown in Fig.3. System parameters of DVR test system are listed in Table 1. Voltage sag is created at load terminals via a three-phase fault as shown in Fig.3. Load voltage is sensed and passed through a sequence analyzer. The magnitude is compared with reference voltage (*Vref*). The controller used is PI.

Table 1: System Parameters.

S.No	System Quantities	Standards
1	Source	3-phase, 13kv, 50Hz
2	Inverter parameters	IGBT based,3 arms ,6Pulse, Carrier Frequency=1080 Hz , Sample Time= 5 μs
3	PI controller	Kp=0.5,Ki=30, Sample time=50 μs
4	RL load	Active power = 1Kw Inductive Reactive Power=500 Var
5	Motor load	Voltage Vrms=460v Frequency 50hz
6	Transformer1	Y/Δ/Δ 13/115/115kv
7	Transformer2	Δ/Y 115/11kv

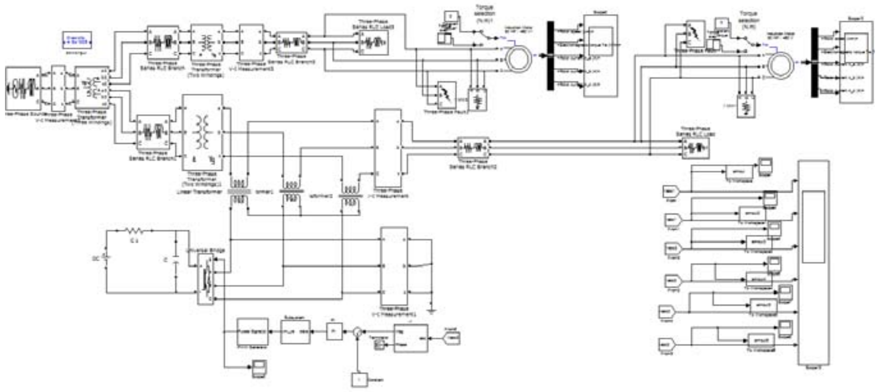

Figure 3: Simulation diagram of the test system.

Simulation Results

Here simulations are performed on the DVR test system using MATLAB SIMULINK. The system performance is analyzed for compensating voltage dip and fault conditions with DC storage capacity. Two cases of different load condition are considered to study the impact of DVR system in distribution system. Here induction motor is taken as load. Different cases are discussed below:

Case I: A three-phase induction motor is taken as load. While starting of an induction motor, it causes a starting dip in the voltage for few seconds. Here DVR is used to compensate the starting dip. Under this condition the simulation results of voltage wave shapes without DVR and with DVR compensation technique are shown in Fig.4 and Fig.5 on p.u basis. in presence of capacitor rating of 750×10-6 F with energy storage devices viz. 5kv.

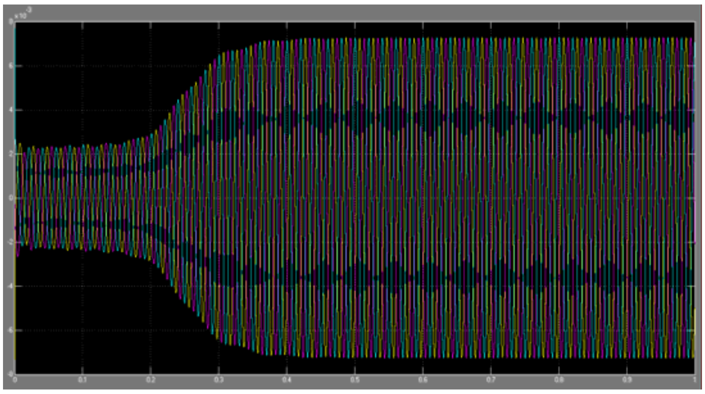

Figure 4: Motor load without DVR.

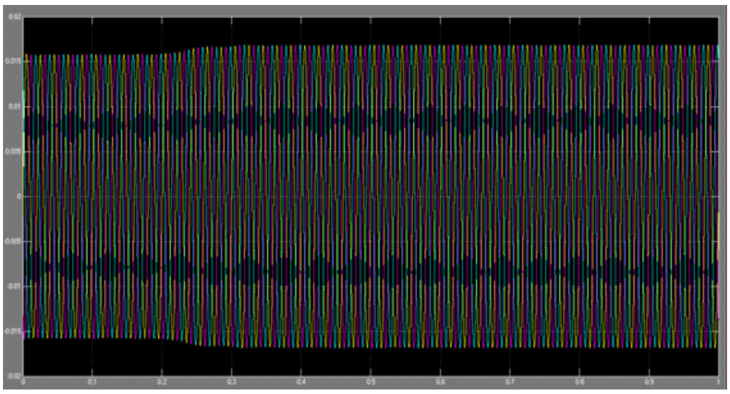

Figure 5: Motor load with DVR.

Now fig.4 represents the wave shape of load voltage of that feeder in which DVR is not connected. Here induction motor is taken as load. The fig.5 shows the wave shape of load voltage of that feeder in which DVR is connected for same loading condition. Here we can see that the starting dip in the voltage is compensated to a large extent where DVR is connected in the system.

Case II: Under same loading condition a three-phase line to ground fault is created at point X via a resistance of 0.66 Ω. Transition time for the fault is considered from 0.4 sec to 0.5 sec. This three phase line to ground fault produces a voltage sag for that duration. The simulation results of voltage wave shapes without DVR and with DVR compensation technique are shown in Fig. 6 and Fig. 7 on p.u basis.

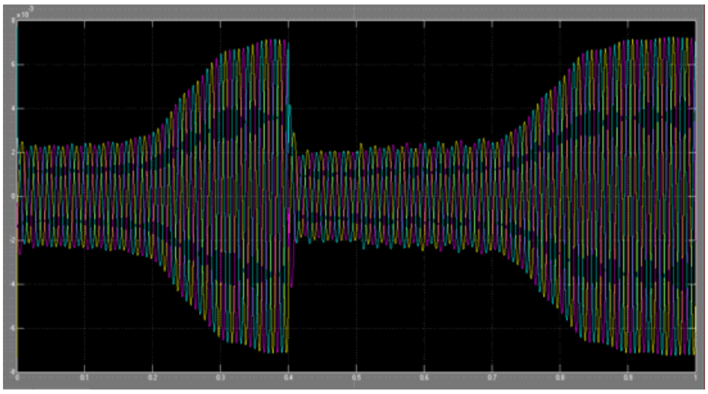

Figure 6: Fault condition without DVR.

In the above case a three phase line to ground fault is created in both the feeders for the duration of.4 to.5 sec. Now fig.6 represents the voltage wave shape when DVR is not connected in the feeder. It shows a voltage dip in the duration.4 to.5 sec.

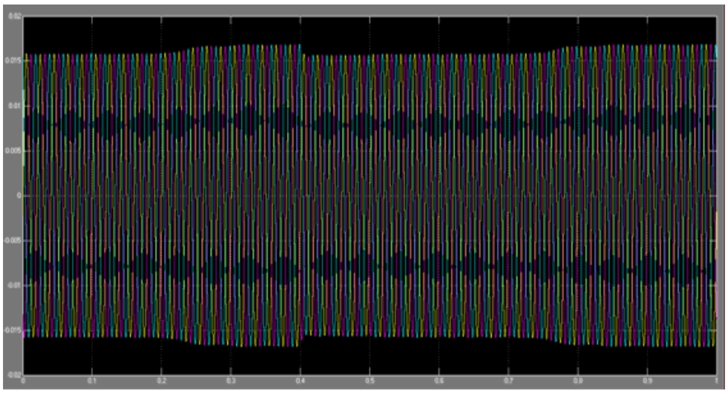

Figure 7: Fault condition with DVR.

Here Fig.7 represents the voltage wave shape when DVR is connected in the system. Now we can see that the distortion in the feeder where DVR is connected is less as compared to the other feeder.

Now in above case it is also clear from the THD graph that the harmonics in the system is reduced up to large extent in which DVR is connected. Total harmonic distortions in both conditions are given in fig.8 and fig.9.

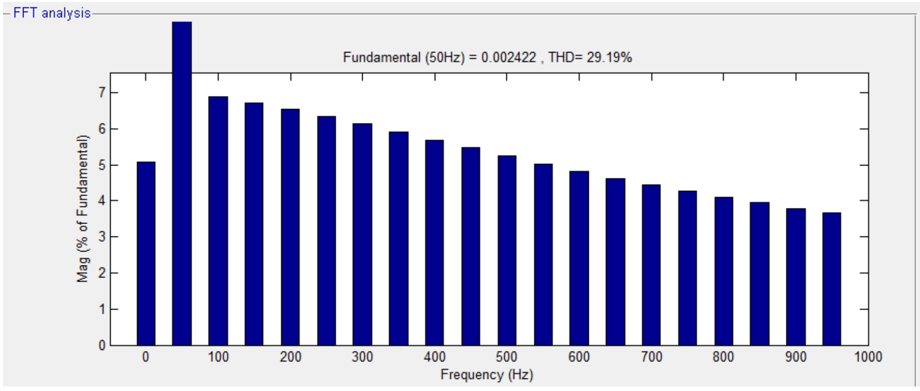

Figure 8: Total harmonic distortion without DVR.

Here Fig.8 represents the total harmonic distortion in the system where DVR is not connected. Here the total harmonic distortion is 29.19% , system frequency 50Hz

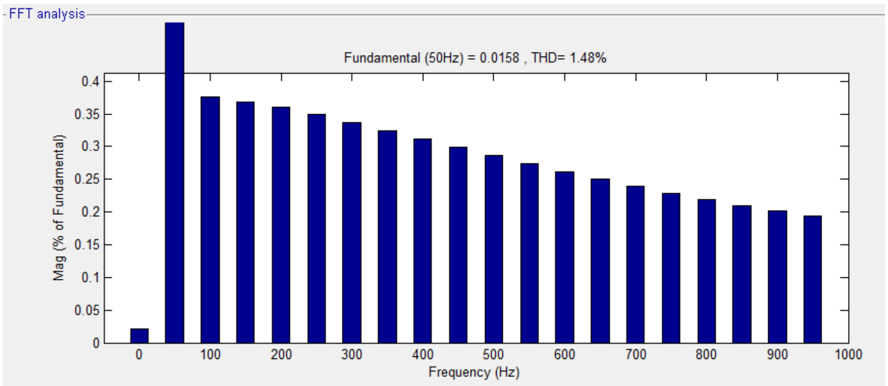

Figure 9: Total harmonic distortion with DVR.

Here Fig.9 represents the total harmonic distortion in the system where DVR is connected. In this case the total harmonics distortion is very less as compare to the feeder where DVR is not connected. Here the total harmonic distortion is 1.49% for system frequency 50Hz.

Conclusion

In this paper, a fast and cost effective Dynamic Voltage Restorer (DVR) is proposed for mitigating the problem of voltage sags or dip in industrial distribution systems, specially consisting for the induction motor load. A controller which is based on feed foreword technique is used which utilizes the error signal which is the difference between the reference voltage and actual measured load voltage to trigger the switches of an inverter using a Pulse Width Modulation (PWM) scheme. Calculation of the compensating voltage is done with reference to voltage only. Here investigations were carried out for various cases of load at 11kv feeder.

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