Down Stream Fault Current Interruption by Dynamic Voltage Restorer

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ABSTRACT

This paper introduces and evaluates an control strategy for downstream fault current interruption in a radial distribution line by using a dynamic voltage restorer (DVR). The proposed controller can be able tocompensate the voltage-sag compensation control of the DVR. It independently controls the magnitude and phase angle of the injected voltage for each phase. Digital filters are used to estimate the magnitude and phase of the measured voltages and effectively reduce the impacts of noise, harmonics, and disturbances on the phasor parameters. The results of the simulation studies performed in the MATLAB SIMULATION. The control scheme: 1) can limit the fault current to less than the nominal load current and restore the point of common coupling voltage within 10 ms; 2) can interrupt the fault current in less than two cycles; 3) limits the dc-link voltage rise and,; 4) performs satisfactorily even under arcing fault conditions; and 5) can interrupt the fault current under low dc-link voltage conditions.

Key words: Digital filters, dynamic voltage restorer (DVR), fault current interrupting, multiloop control.

SECTION-1 INTRODUCTION

The Dynamic voltage restorer (DVR) is a custom power device utilized to counteract voltage sags. It injects controlled three-phase ac voltages in series with the supply voltage, subsequent to voltage sag, to enhance voltage quality by adjusting the voltagemagnitude,waveshape, and phase angle. Fig. 1 shows the main components of a DVR (i.e., a series transformer T_S, a voltage- source converter (VSC), a harmonic filter, a dc-side capacitor C_{DC}, and an energy storage device). The line-side harmonic filter consists of the leakage inductance of the series transformer $L_f$and the filter capacitor C_f.

The DVR is conventionally bypassed during a downstreamfault to prevent potential adverse impacts on the fault and toprotect the DVR components against the fault current.A technically elaborate approach to more efficient utilization ofthe DVR is to equip it with additional controls and enable it .

Also to limit or interrupt the downstream fault currents. A control approach to enable a DVR to serve as a fault current limiter is provided. The dc-link voltage increase can be mitigated at the cost of a slow-decaying dc fault current component using the methods introduced.

To overcome the aforementioned limitations, this paper proposes an augmented control strategy for the DVR that provides: 1) voltage-sag compensation under balanced and unbalanced conditions and 2) a fault current interruption (FCI) function. The former function has been presented and the latter is described in this paper.

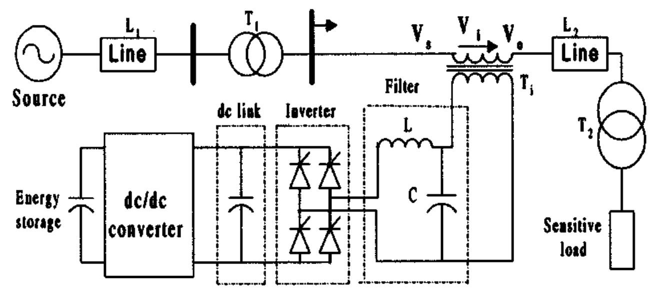


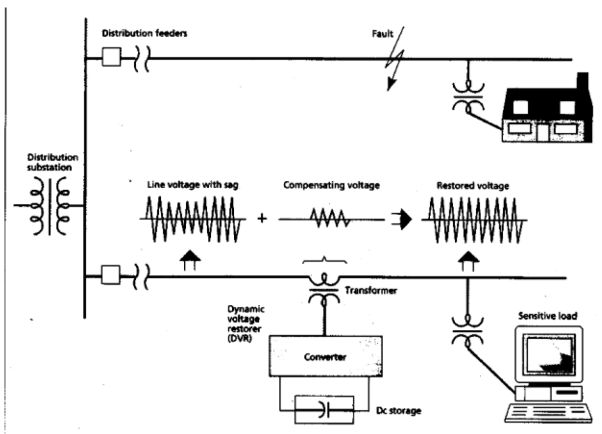
Fig.1 DVR with a line-side harmonic filter.

It should be noted that limiting the fault current by the DVRdisables the main and the backup protection (e.g., the distanceand the overcurrent relays). This can result in prolonging thefault duration. Thus, the DVR is preferred to reduce the faultcurrent to zero and interrupt it and send a trip signal to the upstreamrelay or the circuit breaker (CB).

It should be noted that the FCI function requires 100%voltage injection capability. Thus, the power ratings of theseries transformer and the VSC would be about three timesthose of a conventional DVR with about 30%–40% voltageinjection capability. This leads to a more expensive DVRsystem. Economic feasibility of such a DVR systemdependson the importance of the sensitive load protected by the DVRand the cost of the DVR itself.

The performance of the proposed control scheme is evaluatedthrough various simulation studies in the PSCAD/EMTDCplatform. The study results indicate that the proposed controlstrategy: 1) limits the fault current to less than the nominal loadcurrent and restores the PCC voltage within less than 10 ms, andinterrupts the fault current within two cycles; 2) it can be usedin four- and three-wired distribution systems, and single-phase configurations; 3) does not require phase-locked loops; 4)It is notsensitive to noise, harmonics, and disturbances and provides effectivefault current interruption even under arcing fault conditions;and 5) can interrupt the downstream fault current underlow dc-link voltage conditions.

SECTION-2
DYNAMIC VOLTAGE RESTORER



▲ A dynamic voltage restorer (DVR), in series with a sensitive load precisely compensates for distortion or disturbances or both on the distribution busbar by adding a voltage in series with the power distribution voltage. The device includes a dc storage, a converter, and a transformer with its primary connected in series with the distribution busbar.

Fig2.a. Schematic of a dynamic voltage restorer

Dynamic voltage restorer is a static vary device that has applications in a variety of transmission and radial line distribution systems. It is compensation device, which can protect sensitive electric load from power quality problems such as voltage sags, swells.
The principle of the dynamic voltage restorer is to inject a voltage of required magnitude and frequency, so it can restore the load side voltage to the desired amplitude and waveform even when the source voltage is unbalanced conditions.

The dynamic voltage restorer is just like a statcom, with a transformer, converter and storage, except that the transfomer is connected in series with the busbar feeding the sensitive load. The compensation occurs in both directions, making up for the voltage dips and reducing the overvoltage. The response is very fast, occurring within a few milliseconds. The cost would depend on the maximum level of compensating voltage and the magnitude of the load current. At about 30 percent maximum voltage [which means that the rating of the dynamic voltage restorer would be 30 percent of the rated load), compensation would eliminate over 95 percent ot the disturbing events. This becomes evident trom the statistics of voltage disturbances compiled by the Electric Power Research Institute, which show that the vast majority of voltage dips are within less than 40 percent of the nominal voltage and last less than 10 cycles.

The DVR consists of

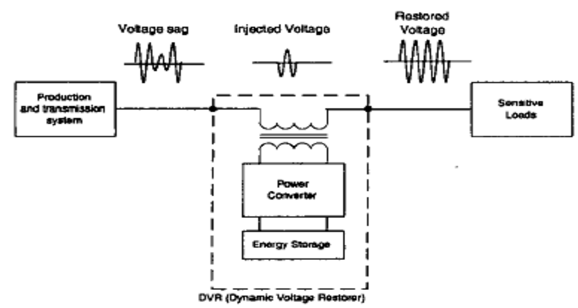


Fig 2.b. Components of Dynamic Voltage restorer.

A. Voltage Source Converter (VSC):

Voltage Source Converter converts the dc voltage from the energy storage unit to controllable three phase ac voltage. The inverter switches are normally using a sinusoidal Pulse Width
Modulation scheme.

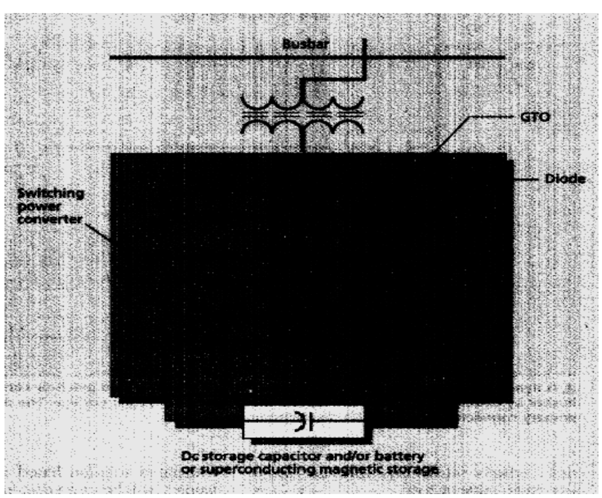
B. Injection Transformer:

Injection transformers used in the DVR plays a crucial role in ensuring the maximum reliability. It is connected in series with the radial distribution line.

C. Passive Filters:

Passive Filters are placed at the high voltage side of the DVR to filter the harmonics of content. These filters are placed at the high voltage side.

D. Energy storage device:



Energy storage devices are dc capacitors, batteries and super-capacitors,. The capacity energy storage device has a big impact on the compensation capability of the system. The capacity of the dc

storage capacitor, in both the statcom and the dynamic voltage restorer, determines the duration of the correction provided for individual voltage dips. It can be a few cycles or seconds long. To enhance the load support capability, a storage battery with a booster electronic circuit can be connected in parallel with the capacitor.

Superconducting magnetic energy storage (so-called micro-SMES) can be very effective if what is needed is high power tor short periods. When the storage is not supporting the load, the converter will automatically charge the storage from the utility system. to be ready tor the next event. Also, since the converter is a threephase unit, power from each phase can be made to mutually support correction of other phases, thus leaving the customersusceptible to only the events of long three- phase outages, beyond the capabi li**ty** of the storage system.

SECTION-3

TYPICAL POWER DISTRIBUTION SYSTEM

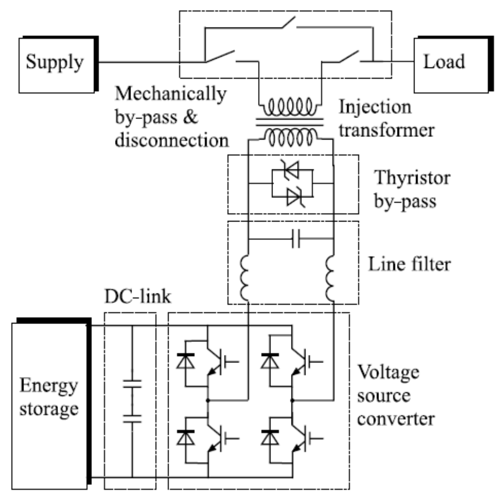


Fig. 3. Typical power distribution system compensated by a DVR

The basic elements of a DVR

• Converter; The converter is most likely a Voltage Source Converter (VSC),which Pulse Width modulates (PWM) the DC from the DC-link/storage toAC-voltages injected into the system.
• Line-filter; The line-filter is inserted to reduce the switching harmonics generatedby the PWM VSC.
• Injection transformer; In most DVR applications the DVR is equipped withinjection transformers to ensure galvanic isolation and to simplify the convertertopology and protection equipment.
• DC-link and energy storage; A DC-link voltage is used by the VSC to synthesizean AC voltage into the grid and during

a majority of voltage dips activepower injection is necessary to restore the supply voltages.

• By-pass equipment; During faults, overload and service a bypass path for theload current has to be ensured

SECTION-4
EXISTING METHOD

A.THREE PHASE DOWNSTREAM FAULT WHEN DVR IS INACTIVE:

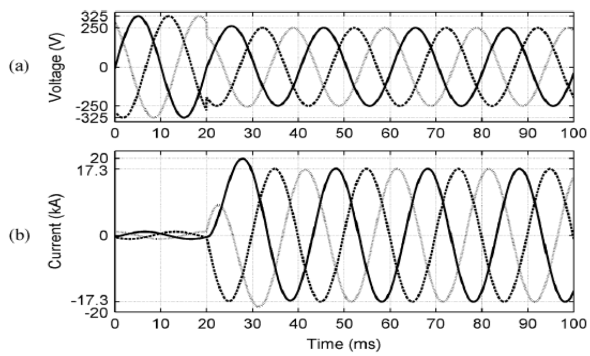


Fig.4 (a) Voltages at Bus_3. (b) Fault currents, during downstream three-phasefault when the DVR is inactive (bypassed).

The system is subjected to a three-phase short circuit with anegligible fault resistance at t = 20 ms at Bus_5. Prior to thefault inception, the DVR is inactive (in standby mode) (i.e., theprimary windings of the series transformers are shorted by theDVR). During the fault if the DVR is bypassed, the voltageat Bus3 drops to 0.77 p.u. and the fault current increases toabout 17 times the rated load current (Fig. 4).

B. PHASE-TO-PHASE DOWNSTREAM FAULTS WHEN DVR IS INACTIVE:

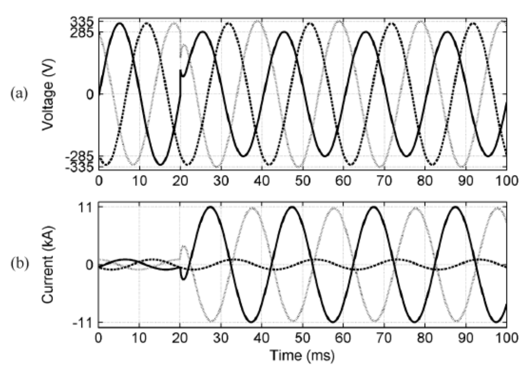


Fig.5. (a) Voltages at Bus_3, (b) Fault currents, during downstream phase-to phasefault when the DVR is inactive (bypassed).

The system of Fig. 5 is subjected to a phase-A to phase-Cfault with the resistance of 0.05Ω at 10% of the cable lengthconnecting $Bus_4$to Bus_5, at t = 20 ms. When the DVR isinactive (bypassed) during the fault (Fig. 5), the PCC voltagedrops to 0.88 p.u., and the fault current increases to about 11times the rated load current.

C. SINGLE-PHASE-TO-GROUND DOWNSTREAM FAULT WHEN DVR IS INACTIVE

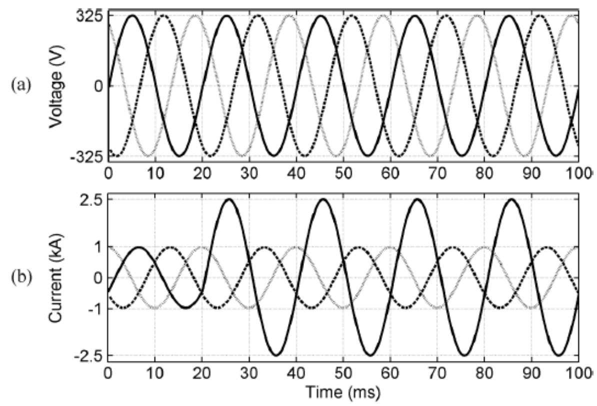


Fig.6.(a)Voltages at Bus_3. (b) Fault currents, during the downstream singlephase-to-ground fault when the DVR is inactive (bypassed).

Phase-A of the system of Fig. 4 is subjected to a fault withthe resistance of 0.2Ω at 10% length of the cable connecting $Bus_4$to Bus_5, at t = 20 ms. If the DVR is inactive (Fig. 6), thePCC voltage does not considerably drop and the fault current isabout 2.5 p.u. It must be noted that although the PCC voltagedrop is not considerable, the fault current must be interruptedby the DVR to prevent possible damages to the VSC before thefault is interrupted by the relays. The reason is that the operationtime of the overcurrent relays is considerable for a fault currentof about 2.5 p.u.

SECTION-5
SIMULATION RESULTS

A.THREE PHASE DOWN STREAM FAULT WITH DVR:

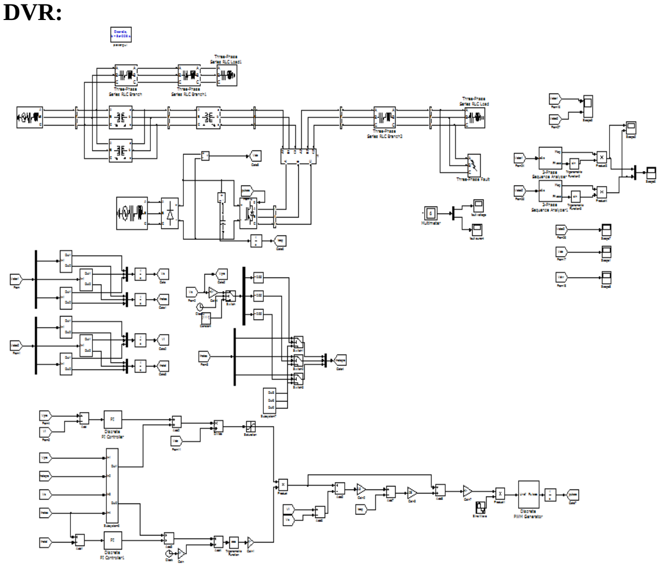


Fig.7.Simulation block diagram of three phases downstream fault interruptionwith DVR.

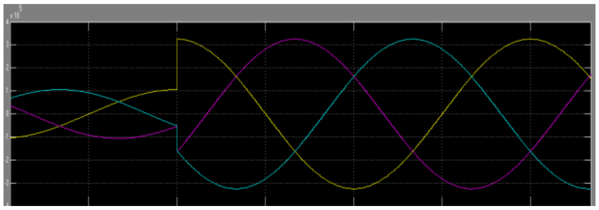


Fig.7 (a).Injected voltage with time on x-axis and voltage on y-axis

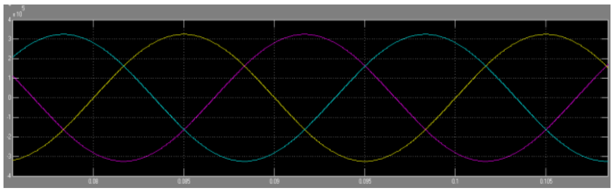


Fig.7 (b).Supply voltage with time on x-axis and voltage on y-axis

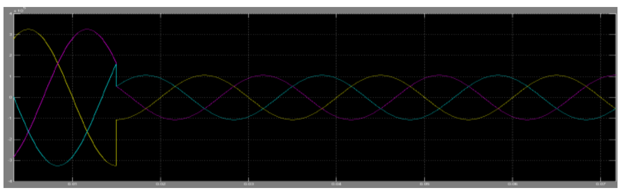


Fig.7(c).Load voltage with time on x-axis and voltage on y-axis

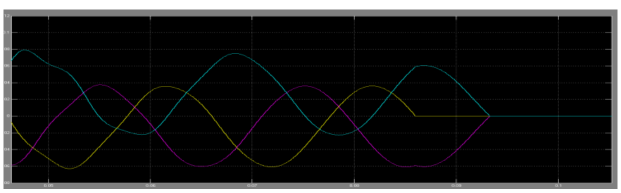


Fig.7 (d).Line current with time on x-axis and current on y-axis

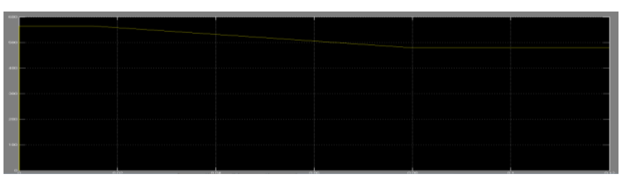


Fig.7 (e).Dc link voltage with time on x-axis and voltage on y-axis

B. PHASE TO PHASE DOWNSTREAM FAULT CURRENT INTERRUPTION WITH DVR

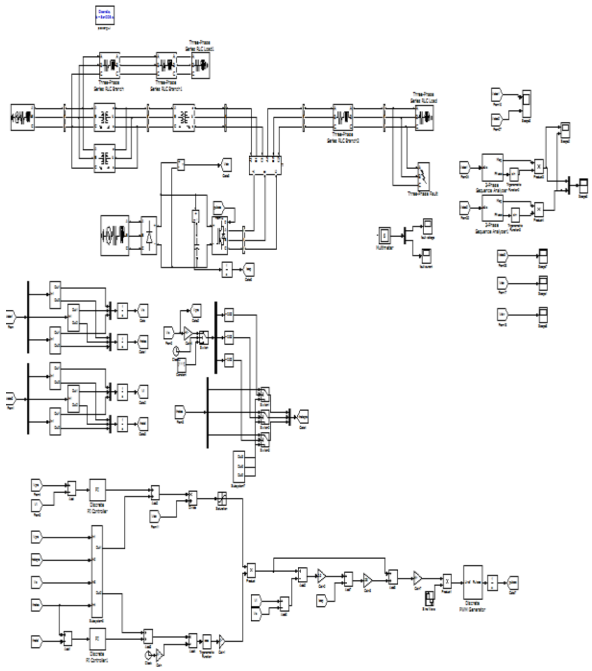


Fig.8.Simulation block diagram of phase to phase downstream fault interruptionwith DVR.

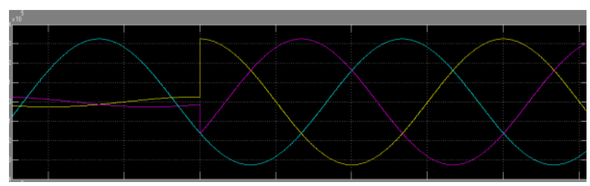


Fig.8 (a).Injected voltage with time on x-axis and voltage on y-axis

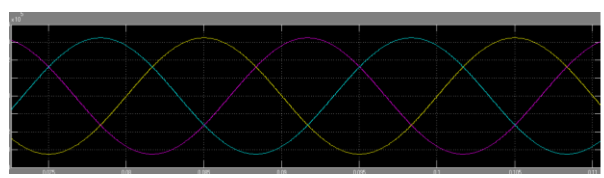


Fig.8 (b).Supply voltage with time on x-axis and voltage on y-axis

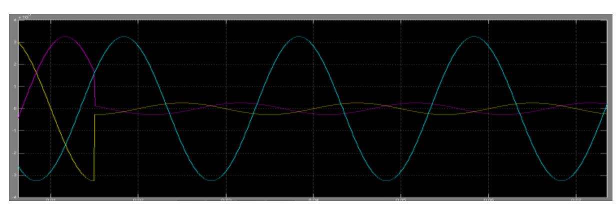


Fig.8(c).Load voltage with time on x-axis and voltage on y-axis

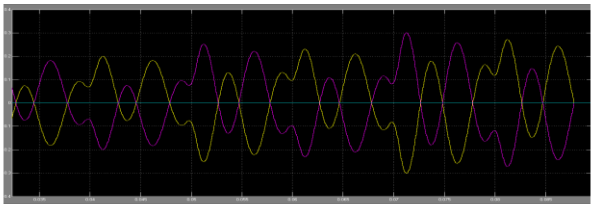


Fig.8 (d).Line current with time on x-axis and current on y-axis

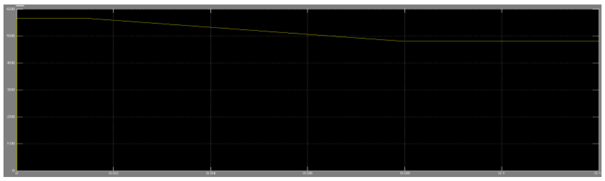


Fig.8 (e).Dc link voltage with time on x-axis and voltage on y-axis

C. SINGLE PHASE TO GROUND DOWNSTREAM FAULT INTERRUPTION WITH DVR

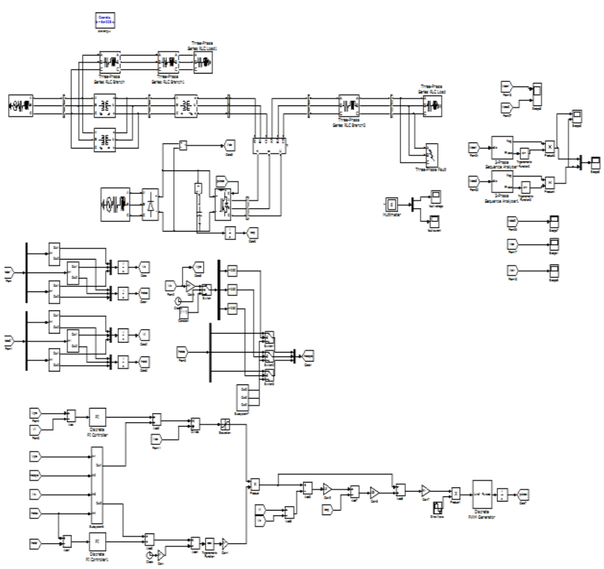


Fig.9.Simulation block diagram of phase to phase downstream fault interruptionwith dvr

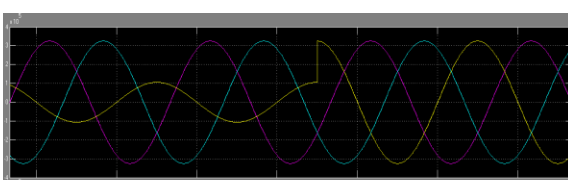


Fig.9 (a) Injected voltage with time on x-axis and voltage on y-axis

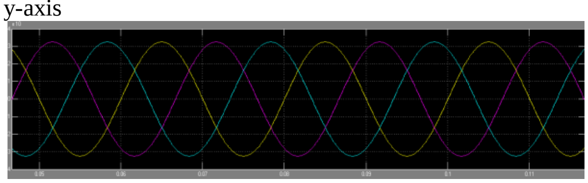


Fig.9 (b) Supply voltage with time on x-axis and voltage on y-axis

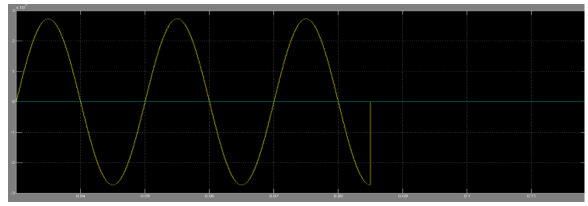


Fig.9(c) Load voltage with time on x-axis and voltage on y-axis

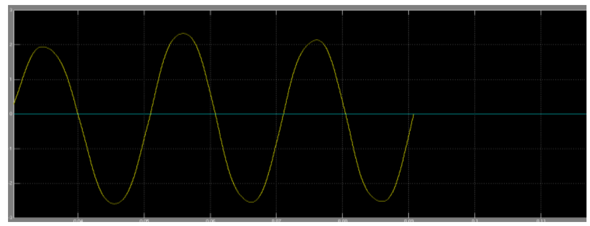


Fig.9 (d) Line current with time on x-axis and current on y-axis

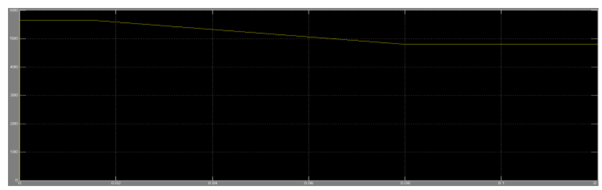


Fig.9 (e) Dc link voltage with time on x-axis and voltage on y-axis

CONCLUSION

The proposed multiloop control system provides a desirable transient response and steady-state performance and effectively damps the potential resonant oscillations caused by the DVR LC harmonic filter.The proposed control system detects and effectively interrupts the various downstream fault currents within two cycles (of 50 Hz). In future enhancement simultaneous operation of Fault current interruption and voltage sag compensation can be obtained by Dynamic voltage restorer.

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