A new process control method for compensation of voltage sags based on the multifunctional dynamic voltage restorer

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Abstract: Since the past decades, the dominance of the output power delivered as of the utilities has become a prime concern of the modern industries. Power Quality (PQ) problem arose in the power delivery system. The recent power systems are turning into sensitive to the quality of the power delivered by the utility firm. Voltage sags, swells, harmonic distortion (HD), interruptions, flicker, and other distortions in the sinusoidal waveform are some instances of the PQ problems. Many industries have met a huge loss on account of these problems. Several power electronic devices are used to avert the loss. This proposed methodology utilizes the Dynamic Voltage Restorer (DVR) controller for avoiding the voltage sags. But the general DVR is basically a small-sized one. For improving the performance of the power distribution, this paper proposed a new process control method for compensation of voltage sags based on multifunctional DVR. Also, the multi-loop controller utilizing the P+Resonant controller and Posicast controller is proposed for ameliorating the transient response as well as for eliminating the existing Steady-State Error (SSE) in the DVR, respectively. Lastly, the simulation outcomes evince the capability of the proposed multi-functional DVR in controlling the emergency scenarios of the distribution system.

Key words: *Multi Functional Dynamic Voltage Restorer, Posicast, P+Resonant controllers, and multiloop controller.*

1. INTRODUCTION

The simple and well-regulated form of energy termed Electrical energy could be transformed to other forms very easily [1]. Along with its quality, continuity has to be maintained for a better economy. PQ is a prime concern for today’s power firms and consumers [2]. PQ issues occur due to the rising demand for an electronic tool as well as nonlinear loads [3]. Normally, the electronic devices are highly sensitive to certain disturbances and are therefore less tolerant of PQ problems, namely, harmonics, voltage sags, and swells [4]. Voltage sags are regarded to be the utmost acute disturbances to the industrial equipment [5].

Short interruptions and Voltage sags are brief voltage reduction measures, which are followed by the reinstatement of the normal supply scenarios. They are the reason for the frequent causes of tripping of electrical devices in industrial installations, which leads to costly shutdowns [6]. There are ‘2’ approaches for controlling the PQ problems [7]. One solution is load conditioning which is done as of the utility end or customer side. The other is to install the line conditioning devices (system) that counteract or depress the PQ problems [8]. The DVR [9] stands as a solid-state power converter which infuses needed compensation voltages with the distribution feeder voltages on series. Those devices are installed at Medium Voltage (MV) or Low Voltage (LV) levels for compensating the voltage disturbances of the distribution system [10].

Here, Section 2 offers surveys of the associated works regarding the proposed work. In sections 3, a concise discussion about the proposed methodology is presented; section 4 analyzes the Investigational outcome and section 5 will convey the conclusion of this paper.

2. RELATED WORK

C.K. Sundarabalan and K. Selvi [11] proffered a utility of DVR in the form of a compensating tool and also introduced an inter-connecting device for the distributed generation structure. It was perceived that the real coded Genetic Algorithm (GA) optimized the Fuzzy Logic (FL) and Proportional Integral (PI) centered DVR that compensated voltage sag, harmonics and swell in the sensitive load voltage (VL). Under the disturbances, it was almost sustained to the reference value. The attained outcomes evinced the DVR’s effectual performance under disparate voltage variations. Lastly, the control strategies were contrasted to H^{∞} the controller in MV- DVR system with nonlinear load and balanced voltage sag. The VL THD transpired in FL centered MV level DVR was lower on considering the robust H^{∞}.

Bibhu Prasad Ganthia *et al* [12] endeavored to retain a proper voltage profile by mitigating the sag occurred during faults in power system like energizing of heavy loads, induction motors, transformers, insulation breakdown, bad weather, and closing or reclosing of circuit breakers. In this approach, the compensation of sag was also examined in disparate faults and diminishes the entire HD in a transmission line.

C.K. Sundarabalan and K. Selvi [13] designed the DVR for protecting the sensitive load as of voltage disturbances (source side) under the non-linear load scenarios. The real coded GA optimized FL controller was utilized for controlling q and d voltage components. Besides the compensation of HD in the VL, the system could compensate for the balanced and even unbalanced voltage sag or swell at the load end. The DVR's effectiveness under disparate sorts of fault scenarios were tested in MATLAB platform.

Javier Roldan-P ´erez *et al* [14] propounded a control framework where reactive and active power used by series devices was controlled and analyzed. The method was centered on the synchronized reference frame and load current, which highly simplified the power computations and regarded the VL constraints to assure safe load operation. The method was validated on a 5kVA prototype of a Series Active Conditioner.

P.Suresh and B.Baskaran [15] handled the voltage sag compensation modeling and simulation utilizing Interline DVR (IDVR). Voltage sag was generated by linking an extra load with the prevailing load in parallel. The closed-loop PI, FL and also Proportional Integral Derivative (PID) controlled systems were simulated centered on Simulink and the outcomes were proffered. The Responses of PID, PI and FL controllers were contrasted. The outcomes evinced the improvement in dynamic response regarding settling time and SSE

3. PROPOSED METHODOLOGY

Amid the last decade, PQ problems turned into more-complex at all levels of a power system. Today, the Power electronics controllers are attaining concern to offer the PQ for the power suppliers as well as consumers. At the time of distribution, the PQ problem like, voltage sags, dips, swells, etc may arise. For compensating the voltage sags, this proposed work utilizes the multi-functional DVR. Here, the details of the general DVR and the proposed multi functional DVR are explained in separate sections.

3.1 Basic Operational Principle of DVR

The DVR device controls the VL through injecting a fantastic voltage phasor in collection with the machine the usage of the injection series transformer. In many sag compensation approaches, it is notable that in the compensation process, the DVR infuses some energy to the system. Therefore, the ability of the storage unit can be a limiting thing in compensation, specifically at some stages in long-term voltage sags. One of the blessings of this method over the in-phase method is that much less energetic power be transferred from the storage unit to the distribution system. It affects the compensation for sags of long durations or deeper sags. On account of the existence of semi-conductor switches in the DVR inverter, this equipment is non-linear. Nevertheless, the state equations could be linearized utilizing linearization approaches. The dynamic features of the DVR are influenced by the utilization of the filter and load. Though the modeling of the filter (an easy LC circuit) [8] is easy to do, the load modeling is not that easy because the load could fluctuate as of a linear time-invariant one to a non-linear time-variant one. Simulations are done with '2' sorts of loads: a) constant power load and b) motor load. The VL is regulated with the aid of the DVR through injecting V_{dvr} .

The DVR harmonic filter comprises a resistance Rf , an inductance Lf , and a capacitance Cf . The Posicast controller is employed for improving the transient response. On account of the fact in real scenarios, more than one feeders associated to a frequent bus, namely "the Point of Common Coupling (PCC)," are used. From now on, $V1$ and $V2$ would be replaced with V_{pcc} and $V1$, respectively to give a generalized sense. A simple approach is to feed the error signal onto the PWM inverter of the DVR. But the transient oscillations that are initiated at the time of voltage sag may no longer want to be damped. To ameliorate the damping, the Posicast could be utilized ahead of transferring the sign to the DVR's PWM inverter.

3.2 Proposed Multifunctional DVR

The groundwork of the proposed control strategy is that when the fault modern does no longer ignore the DVR, an outer feedback loop of the VL with the internal feedback loop of the filter capacitor contemporary will be used. Also, a feed-forward loop would be employed for enhancing the dynamic response of the VL. Moreover, the Posicast controller is employed to enhance the transient response, and the P+ Resonant controller is deployed to put off the SSE. But in case, the fault contemporary travels through the DVR, the usage of the flux-manipulate algorithm, the series voltage is injected on the contrary route and, thereby, the DVR stands as a sequence variable impedance.

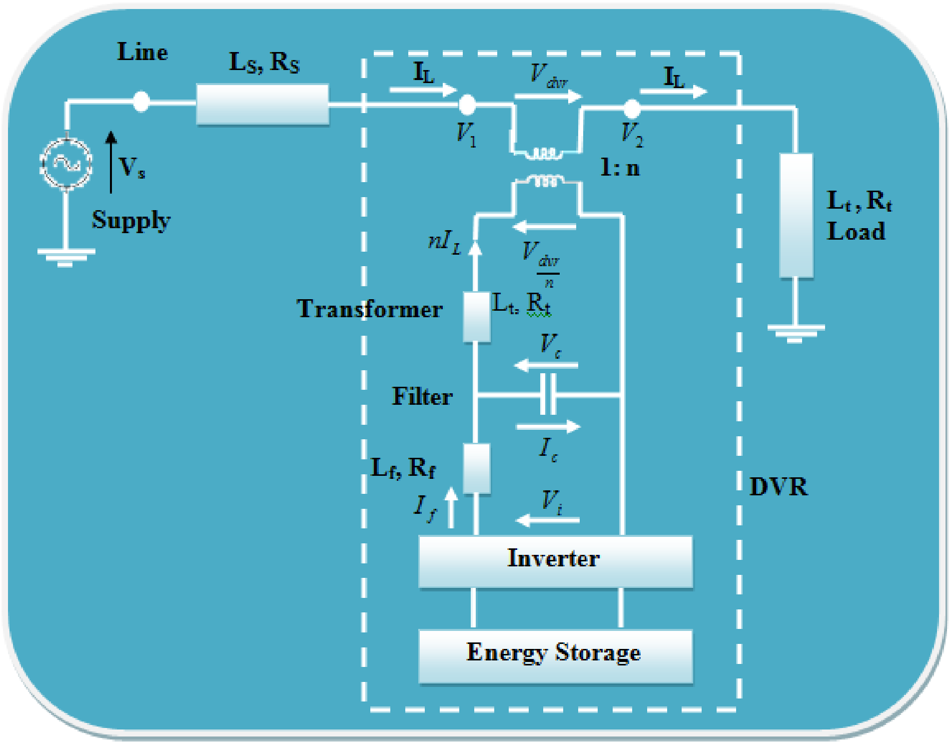


Figure 1: Distribution gadget with the DVR

As Figure 1 evinces, the VL is regulated with the aid of the DVR through injecting. This will be separated from the circuit, and the battery will be connected in sequence with a diode simply when the downstream fault occurs in order that the energy no longer enters the battery and dc-link capacitor. It should be stated right here that the inductance is used in the main to stop massive oscillations in the current. The active energy stated is, therefore, absorbed with the aid of the impedance.

In this work, the PCC voltage is applied as the major reference signal, whereas, the DVR acts as variable impedance. Consequently, the absorption of real electricity is destructive for the dc-link capacitor and battery. To resolve this problem, impedance inclusive of resistance and inductance would be linked in parallel with the dc-link capacitor. This capacitor will be separated from the circuit, and the battery will be connected in collection with a diode simply when the downstream fault takes place so that the power never enters the battery and the dc-link capacitor. The active power cited is, therefore, absorbed with the aid of the Impedance.

3.3 Proposed Method used in Flux-Charge Model Three-Phase Short

In this part, an algorithm is proposed for the DVR to repair the PCC voltage, restrict the fault current and also to shield the DVR components. The flux -charge mannequin right here is used in a way so that the DVR acts as a virtual inductance with a variable value in series with the distribution feeder. To do this, the DVR needs to be controlled in a way to inject a desirable voltage having the contrary polarity in respect of the typical cases. It is stated that over current tripping two is now not feasible in this case, until extra verbal exchange between the DVR and the downstream facet over modern circuit breaker (CB) is available. If it is essential to function over modern CB at PCC, a verbal exchange between the DVR and the PCC breaker may have to be made and this can be without difficulty carried out by means of sending a sign to the CB when the DVR placed after PCC is in the fault-current limiting mode. It is cited that the reference flux is attained via integrating with the subtraction of the PCC reference and DVR load-side voltages. The DVR join in an MV level electricity system is evinced in Fig 2,

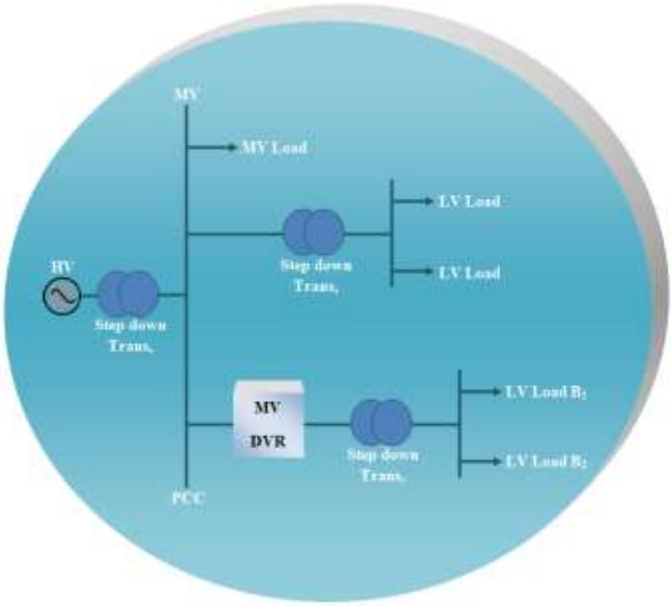


Figure 2: DVR join in a medium-voltage level electricity system

The 3-phase short circuit is utilized on bus “26: FDR G," and the functionality of the DVR in protecting the voltage on a bus "05: FDR F” is studied. At 206 ms, the fault is utilized at 286 ms, and the breaker works and separates the line between buses “03: MILL-1” and “26:FDR G” from the system. At 306ms, the fault is recovered and, lastly, at 311ms, the separated line is rejoined to the device by the CB. The DVR begins the compensation after detecting the sag. As in the figure, the DVR has restored the voltage to everyday structure with the attenuation of the oscillations at the beginning of the compensation in much less than half of a cycle. It is not worth that the quantity and structure of the oscillations depend also on the time of making use of the fault. As in the figure, the voltage fee of segment B is nearly ‘0’; this section has minimal oscillation when the fault begins.

3.3.1 Starting the Induction Motor

The induction motor is started out on bus “03:MILL-1.” The long, the motor starting, the low the PCC voltage (voltage of bus “03:MILL-1”) will be. The PCC rms voltage will drop up to 0.8p.u. The motor velocity reaches the nominal price in about 1s. During this period, the PCC bus is below voltage sag. From 1.4 s, as the pace tactics nominal, the voltage also approaches the regular condition. However, during those events, the DVR continues the load bus voltage (bus 05:FDR F voltage) at the usual condition.

4. SIMULATION RESULTS

Here, the performance of the proposed voltage sag compensation using multifunctional DVR is analyzed and the proposed system is employed in the working platform of Simulink. The performance is proffered in ‘3’ cases such as, case 1: proposed method, case 2: DVR system with induction motor and case 3: DVR system under fault current limiting.

4.1 Case 1: Proposed Method

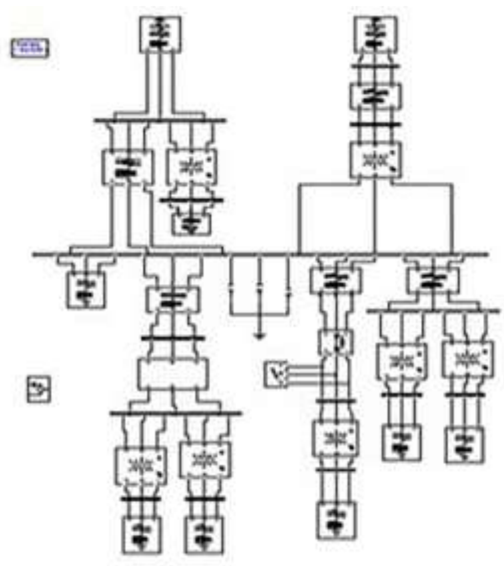


Figure 3: Shows the simulation circuit of the proposed system with short circuit fault applied

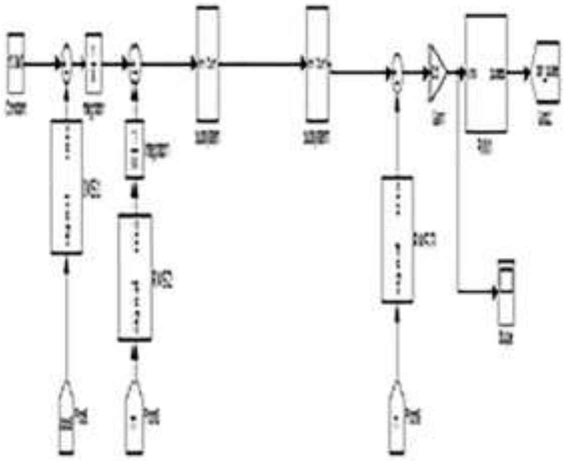
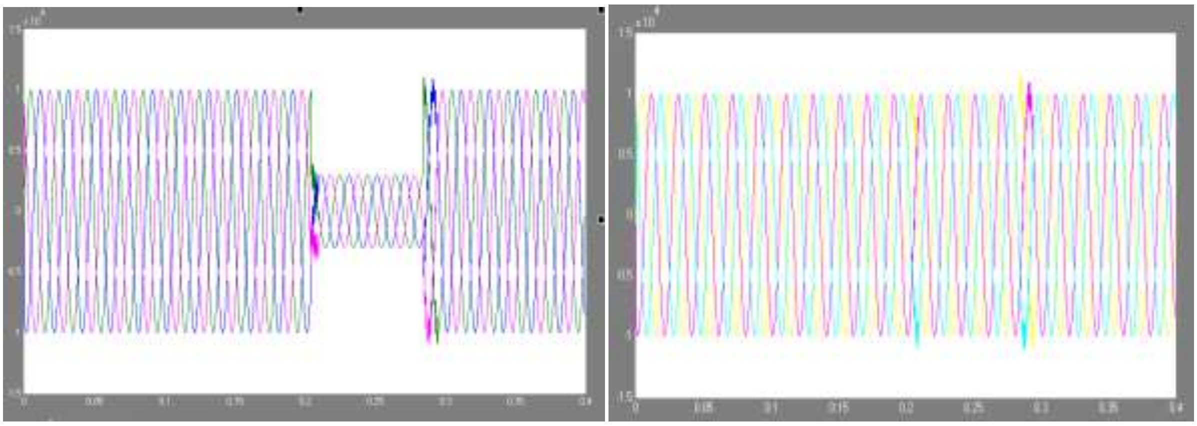


Figure 4: DVR subckt



(a) **(b)**

Figure 5: (a) the rms voltage of PCC drops to about 0.25 p.u. during the fault, (b) shows the PCC voltages of the proposed system

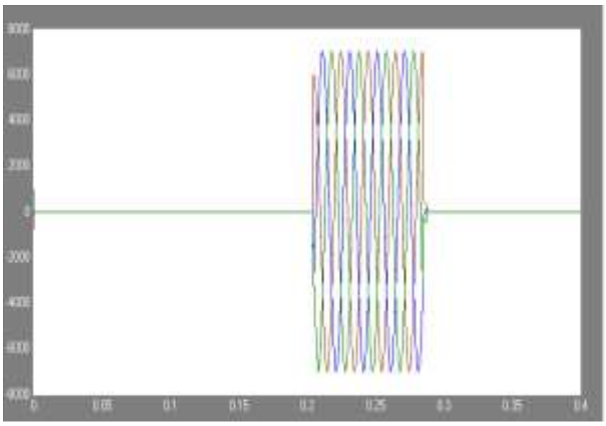


Figure 6: shows the injected voltage of DVR

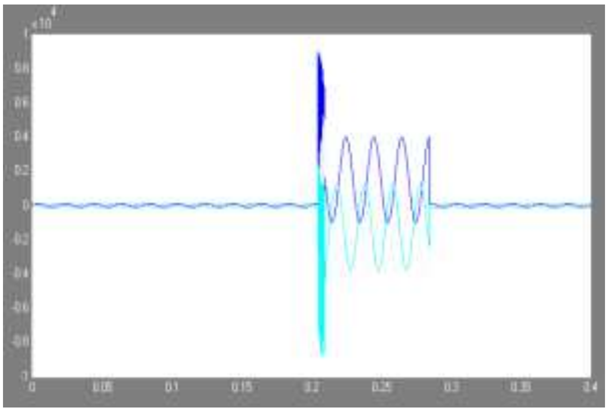


Figure 7: shows the three-phase currents

Figures 3 and 4 evinces the Matlab/Simulink circuit of the proposed voltage sag compensation centered on a multifunctional DVR system with a short circuit applied and the DVR subckt. Figure 5(a) elucidates the rms voltage of PCC which drops to about 0.25p.u. during the fault and Figure 5(b) delineates the PCC voltages of the proposed system. Next, Figures 6 and 7 evince the injected voltage of DVR and the 3-phase currents.

4.2 Case 2: DVR System with Induction Motor

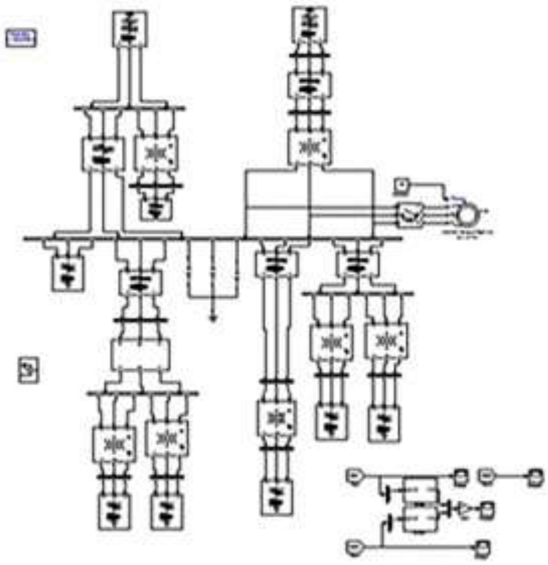
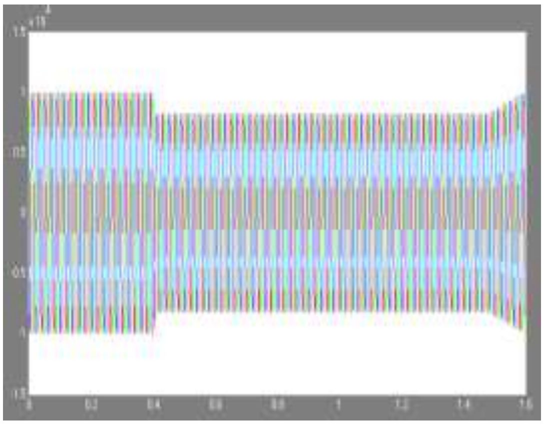
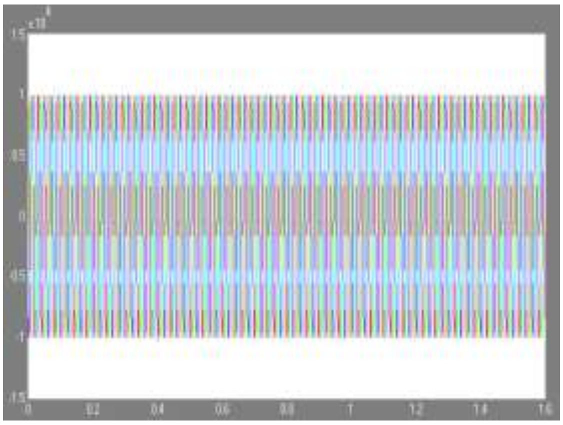


Figure 8: shows the Simulation circuit of the multifunctional DVR system with Induction Motor





(a) **(b)**

Figure 9: (a) PCC voltages with Induction Motor and (b) Output VLs

Figure 8 gives the Simulation circuit of the multifunctional DVR system with Induction Motor, Figure 9(a) elucidates the PCC voltages with induction motor and Figure 9(b) proffers the output VLs.

4.3 Case 3: DVR System under Fault Current Limiting

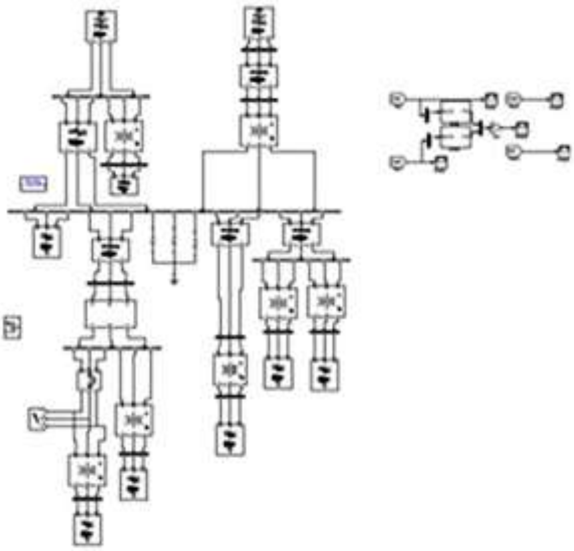
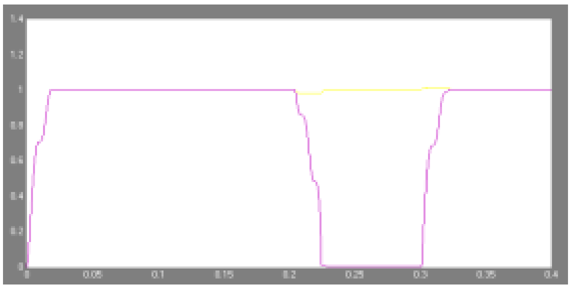
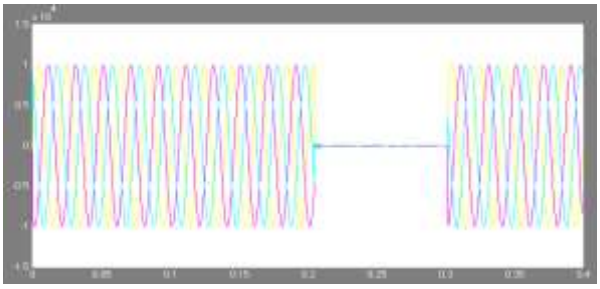
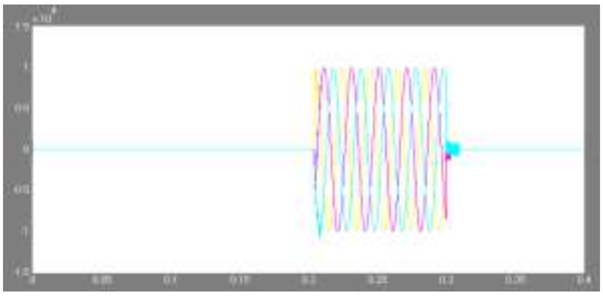


Figure 10: shows the MATLAB/SIMULINK circuit of the proposed DVR system under fault current limiting with DVR.

(a) **(b)**



(c)

Figure 11: shows (a) the RMS voltages of load and PCC, (b) the load voltages, and (c) the injected voltages

Figure 10 elucidates the circuit of the proposed DVR system under fault-current limiting with DVR. Next, Figure 11 (a) evinces the RMS voltages of load and PCC, 11(b) delineates the VLs and 11(c) proffers the injected voltages.

5. CONCLUSION

PQ problem is becoming an important issue for electricity users at all levels of usage. The deregulation of electric power energy has elevated the awareness toward PQ amongst all sorts of users. This proposed methodology utilizes the DVR controller for avoiding the voltage sags. But the general DVR is smaller in size. For augmenting the power distribution performance, this paper proposed a new process control approach for the compensation of voltage sags centered on multi functional DVR. Also, the multiloop controller utilizing the P+Resonant and Posicast controllers is proposed for improving the transient response and eliminating the SSE response in DVR, respectively. As the 2nd function of this DVR, utilizing the flux-charge model, the device is controlled in order that it limits the downstream fault currents and shields the PCC voltage at the time of those faults by acting as variable impedance. The simulation results were also elucidated in detail in this work.

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