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Simulation and Analysis of Dynamic Voltage Restorer with PI Controller under Different Fault Condition

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***Abstract:** This document gives formatting instructions for authors preparing papers for publication in the Proceedings of an IEEE conference. The authors must follow the instructions given in the document for the papers to be published. You can use this document as both an instruction set and as a template into which you can type your own text.*
The demand for quality power has become a challenging issue for industrial area and consumers. Among them voltage unbalance is considered as the major affecting problem leads to degradation in performance of electrical equipments. FACTS devices used for compensation are the best method to overcome such problem. Among them DVR considered the most efficient and cost effective. In a control system of the DVR main consideration includes: detection of the start and finish of the sag, voltage reference generation, transient and steady-state control of the injected voltage, and protection of the system. In this work, the simulation model of nonlinear load connected power distribution system with Dynamic voltage Restorer controlled by PI Controller has been developed using Matlab/Simulink. In this case we simulate three fault likewise: Three-line to ground fault, Double-line to ground fault and Single-line to ground fault with two different PI controller to study the THD.
***Keywords:** PI Controller, DVR, FACTS devices, Power Quality, THD*

I. INTRODUCTION

With thousands of load centres and hundreds of producing stations connected by extensive power transmission and distribution networks, modern electric power systems are dense networks. Due to significant energy and economic costs, power quality is a key problem in today's industry. Many power quality issues, including voltage sags, swells, and harmonics, as well as the loss of sine waveform purity, are caused by a growing number of sophisticated electrical and electronic devices, such as computers, programmable logic controllers, and variable speed drives. These devices are highly sensitive to disturbances and non-linear loads at distribution systems. One of the worst disruptions to industrial equipment is thought to be voltage sags.

Using a dynamic voltage restorer (DVR) is another power electronic approach for voltage management. One type of specialized power equipment for dependable distribution power quality is the DVR. In order to compensate for fluctuations in voltage, they employ a range of voltage boost methods utilizing solid state switches. DVRs are mostly used for vulnerable loads, where variations in system voltage might have a negative impact on performance.

The DVR is a simple, flexible, and reliable solution for voltage sag problems. In a couple of milliseconds, it may restore the voltage and avoid the load from losing power. The primary function of the DVR is to identify voltage sags and use an injection transformer to inject the missing voltage in series with the bus.

The DVR's output voltage waveform has excellent stability and uniformity. Harmonic adjustment and voltage transient mitigation are features of the DVR. A DVR can be implemented using a variety of circuit topologies and control approaches. Apart from compensating for voltage sags and swells, DVRs can have additional functionalities including line voltage harmonics correction, minimizing voltage transients, and fault current restrictions. An Injection/Booster transformer, a Harmonic filter, a Voltage Source Converter (VSC), a DC charging circuit, and a Control and Protection system make up the overall DVR setup.

II. DYNAMIC VOLTAGE RESTORER

The basic operation principle of DVR is measuring the missing voltage by using control unit and injecting the dynamically controlled missing voltage in series to the line and providing the load voltage unchanged during sag. The phase angle and amplitude of the injected voltage fluctuate during sag. As a result, the distribution network and DVR will be able to govern the interchange of active and reactive electricity.

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An injection transformer, a bank of capacitors for energy storage, and a GTO or IGBT make up a DVR, a solid state power electronics switching device. The load depicted in Fig. 1 is connected in series with a distribution system. Using an injecting transformer, the DVR's main concept is to inject a regulated voltage produced by a forced commuted converter in series with the bus voltage. This voltage is controlled by a DC to AC converter using a sinusoidal PWM approach.

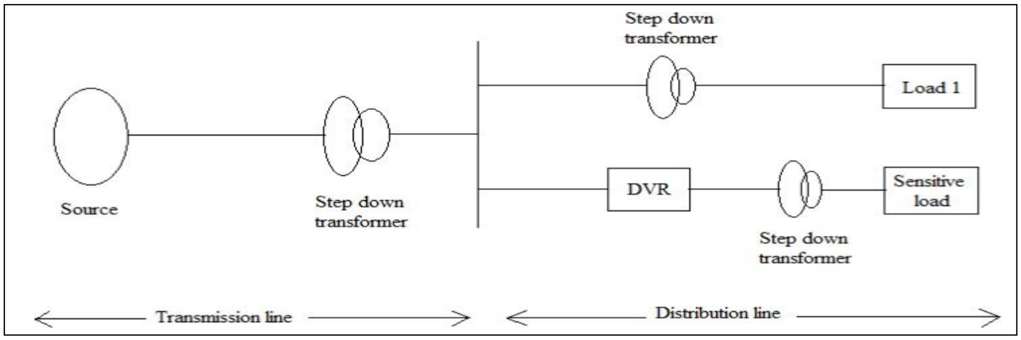

Fig. 1 Location of DVR

The DVR only injects a little voltage during regular operation to make up for device losses and the injection transformer's voltage drop. Nevertheless, in order to maintain output voltage to the load when the distribution system voltage drops, the DVR control system measures and synthesizes the required voltage by injecting a controlled voltage into the distribution system at a certain magnitude and phase angle. This allows it to reach the critical load. It should be mentioned that while the DVR can generate or absorb reactive power, the active power injection for the device has to come from an external energy source or energy storage system. The very quick reaction time of the DVR is restricted by the voltage sag detection time and power electronics components. About 25 ms is the predicted reaction time, which is significantly smaller than some of the more conventional techniques for voltage adjustment, including tap-changing transformers. The primary factors taken into account in a DVR's control system are protection of the system, transient and steady-state regulation of the injected voltage, and voltage reference generation and sag start and end detection.
A controller is a device that is needed to operate or control the DVR only in the event of a malfunction. The linear load voltage is sensed and sent via a sequence analyzer. The benefit of the ABC to DQO transformation is the removal of zero sequence components from the ABC components. There is a different PI controller for the d- and q-coordinates. As shown in fig. 2, the Proportional-integral controller is a feedback controller that is controlled by the summation of the error and integral of those values.

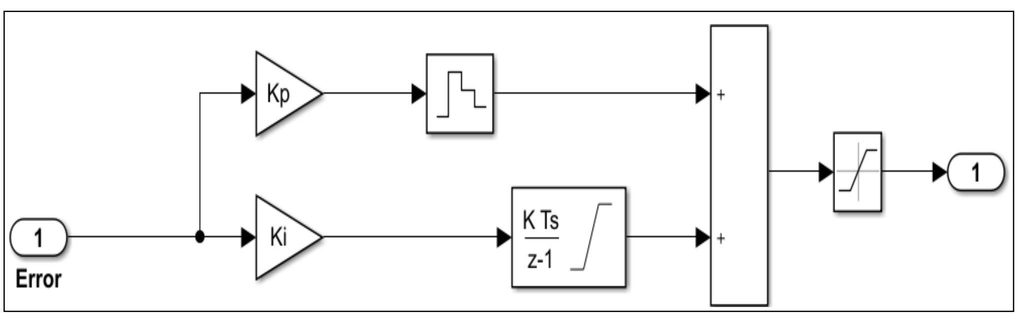

Fig. 2 PI Controller

The PI controller's input is the difference between the real voltage (F2 voltage) and the reference voltage. There are 1 and 0 p.u. as the reference voltages for the d- and q-coordinates, respectively. There are 40 and 154 proportional and integral gains in the d-coordinate PI controller, respectively. The q-coordinate PI controller has a proportional gain of 25 and an integral gain of 260. The PI controller converts its output to a three-phase voltage, which is then fed into a standalone PWM pulse generator. To turn on the IGBT switches, the generated pulse is received by the VSI.

III. SIMULATION AND RESULTS

The simulation work being done in MATLAB/SIMULINK is presented in this paper. An analysis of the simulation's output to demonstrate DVR's effectiveness and efficiency.

Parameter	Values
Power Supply voltage Frequency	3-Phase, 400V, 50Hz ,
Step down Transformer	11KV /400V, r1= r2= 0.0003 pu , L1=L2= 0.001pu,
Linear load	Active power= 1.5KW, Reactive power= 100VAR
DC voltage	200V DC
Injection Transformer & Ratio	1.5kva, 1:10, r1= r2= 0.00001 pu, x1=x2= 0.0003 pu
PI controller	KPd=40, kId=154 ; KPq=25, kIq=260 ;
LC filter	L=6mH C=20μF
DVR switching frequency	Fs = 2250 (Hz)

The DVR is modelled and simulated using the MATLAB and its Simulink and Sim Power System toolboxes. The MATLAB model of the DVR connected system is revealed in fig. 3, fig. 4, fig. 5.

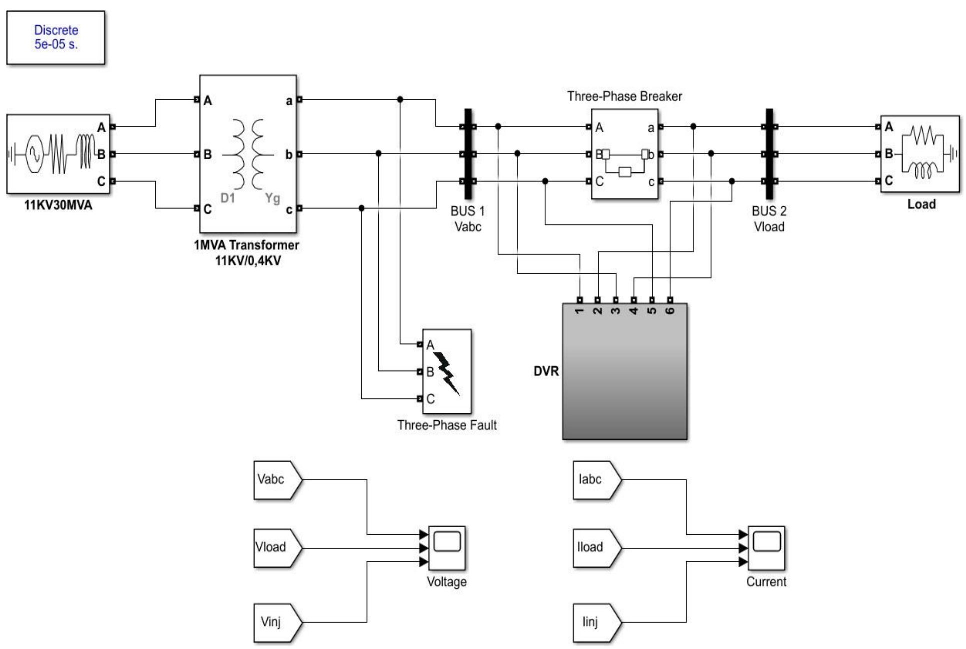

Fig.3 Simulink model of test system

A three-phase voltage source of 11kV has been employed and it is step down to 400 through a three phase delta connected transformer. Intentional fault has been created in all the phase using a three phase fault block. In this distribution system take a RL load, fault time 0.03 to 0.07 sec.

As demonstrated, a two-level converter was used to convert DC to AC. To give the load the proper voltage for operation, a 12-terminal 3-phase transformer has been employed. As mentioned, the controller subsystem is responsible fopr generating the pwm signal for the DC to AC converter. In the next section all the two type of controller is discussed. The PI controller's general characteristic modelling equation is as follows':

$$y(t) = Kpe(t) + Ki\int e(t)dt \quad (1)$$

y(t) is the controller's output, while e(t) is the error signal. Among the benefits of developing the feedback PI controller this way is that the steady state error is zero. The feedback controller is in control of the plant, which uses a weighted sum of the errors and the integral of that value.

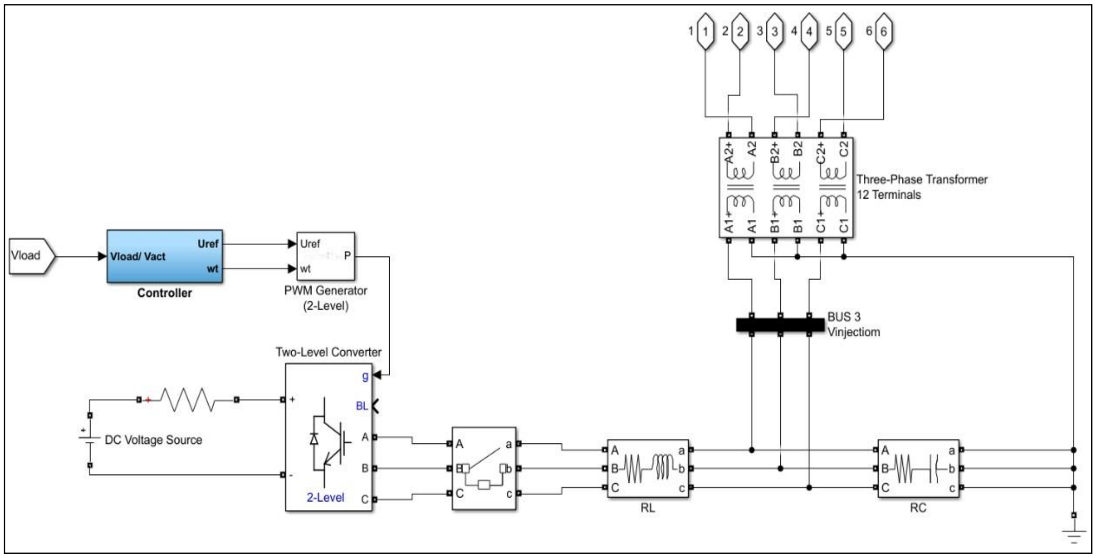

Fig.4 Internal view of DVR

The proportional response is obtained by accumulate the error by the proportional gain constant, Kp. The donation of the integral terms is proportional to the error size and period. The values of Kp and Ki have A significant impact on the PI controller's performance. For each of the quadrature phases ‘d' and ‘q,' two PI controllers were employed individually. For the d-controller, values of Kp and Ki are 40 and 154, respectively, and for the q-controller, they are 25 and 260. All of the gains are used to fine-tune the error signal d and q, ensuring that it is durable and responsive to system disruptions.

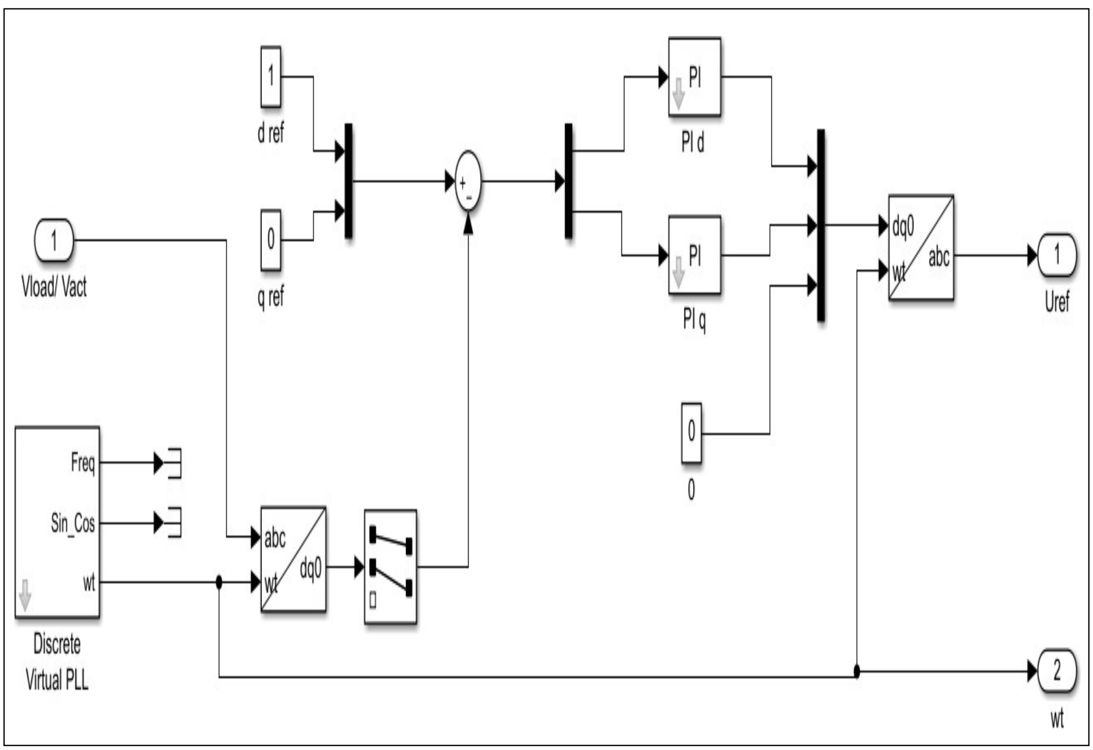

Fig. 5 DVR with PI Controller

A Park transformation in the abc to dq0 block converts a three-phase (abc) signal into a rotating reference frame (dq0). The angular location of the spinning frame is given by the input wt, in rad. PI controllers have been used to identify errors, as seen in the figure. Using the dq0 to ABC block, this error signal is reverse converted to the injected voltage signal.

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In this case we simulate three fault likewise: Three-line to ground fault, Double- line to ground fault and Single-line to ground fault with PI controller to study the THD. All Three faults simulated with PI controllers has been discussed in this.

Case 1: Three line to ground fault with PI controller: Whenever a three-line to ground fault (TLGF) occur while causing the voltage to drop below its normal levels. From 0.03 to 0.07 seconds, the entire fault duration is 0.04 seconds. Figure 6 depicts the source, load, and injected voltages in a TLGF situation.

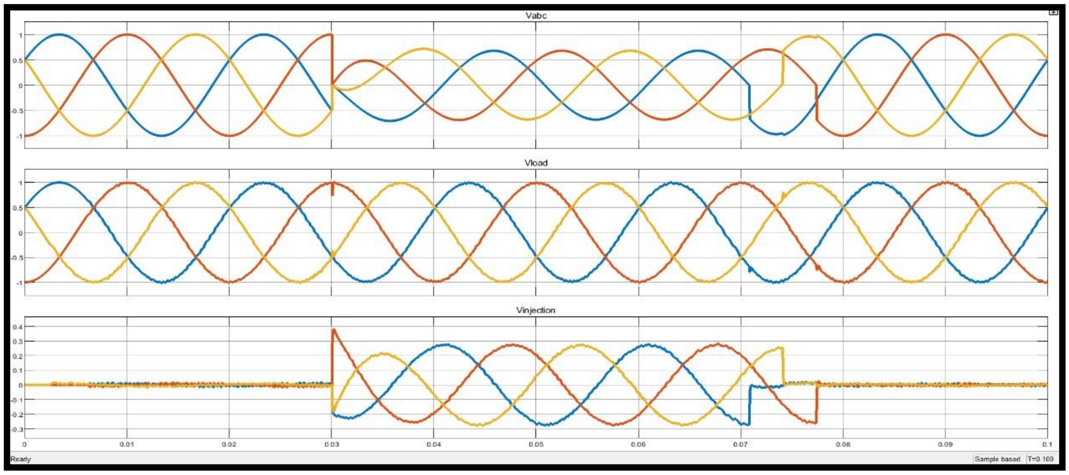

Fig. 6 : Three line to ground fault with PI controller

The FFT analysis of the sensitive load voltage reveals that the load voltage is a perfect sinusoid with an extremely low THD of 2.00% as shown in figure 7.

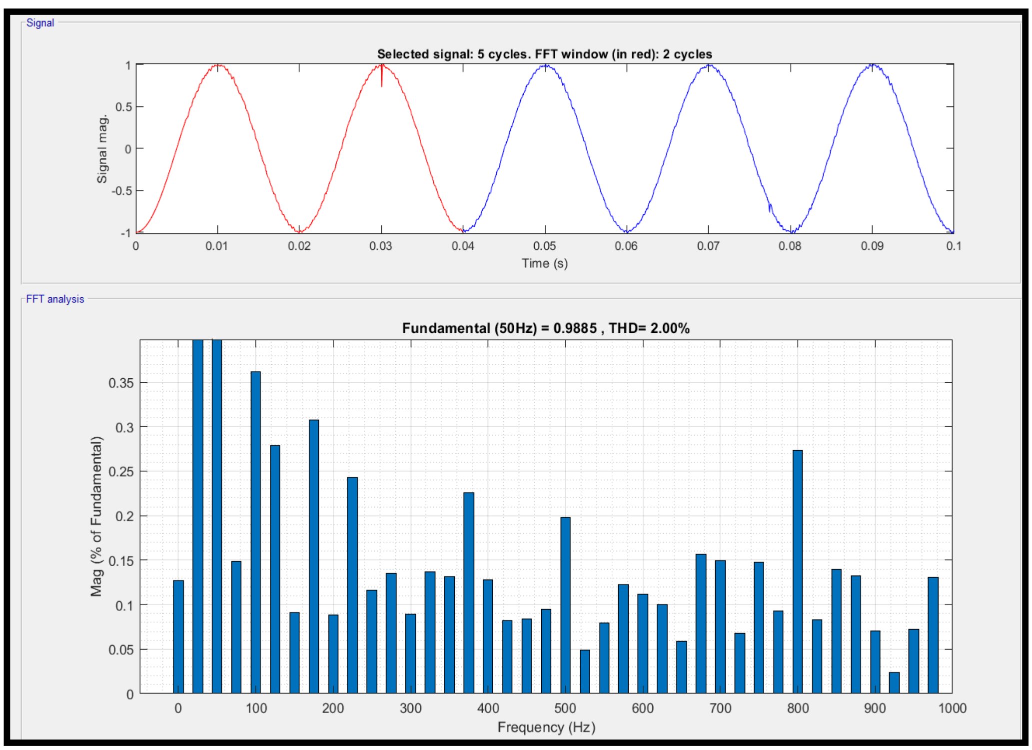

Fig.7 : THD analysis for three line to ground fault with PI controller

Case 2: Double line to ground fault with PI controller: Fig. 8 displays the source voltages, load voltages, and injected voltages observed during this DLGF event. Phase A and B are both affected by a double-line to ground fault (DLGF), which drops the voltage compared to its nominal levels. The fault persists for a total duration of 0.04 seconds, specifically from 0.03 seconds to 0.07 seconds.

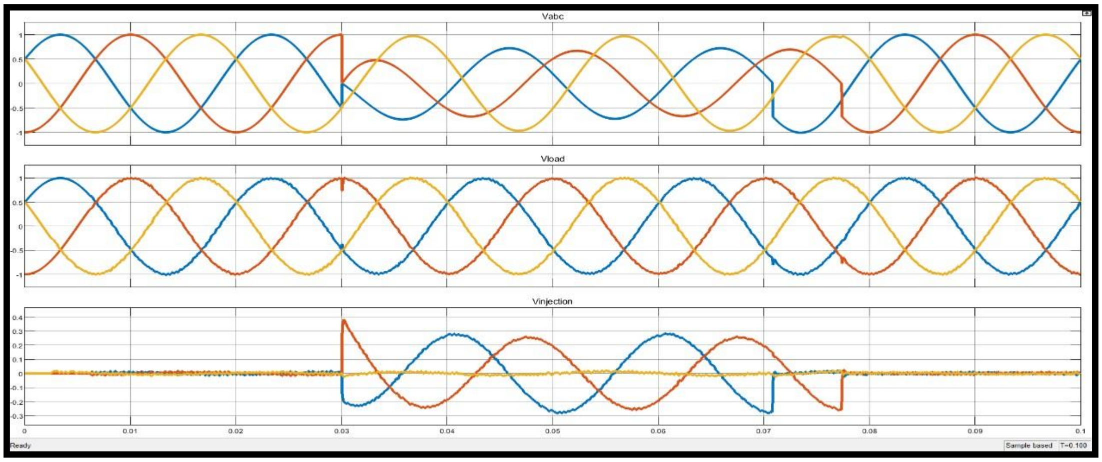

Fig.8 : Double line to ground fault with PI controller

An FFT analysis of sensitive load voltage using a PI-based DVR reveals a THD of around 2.06 %.

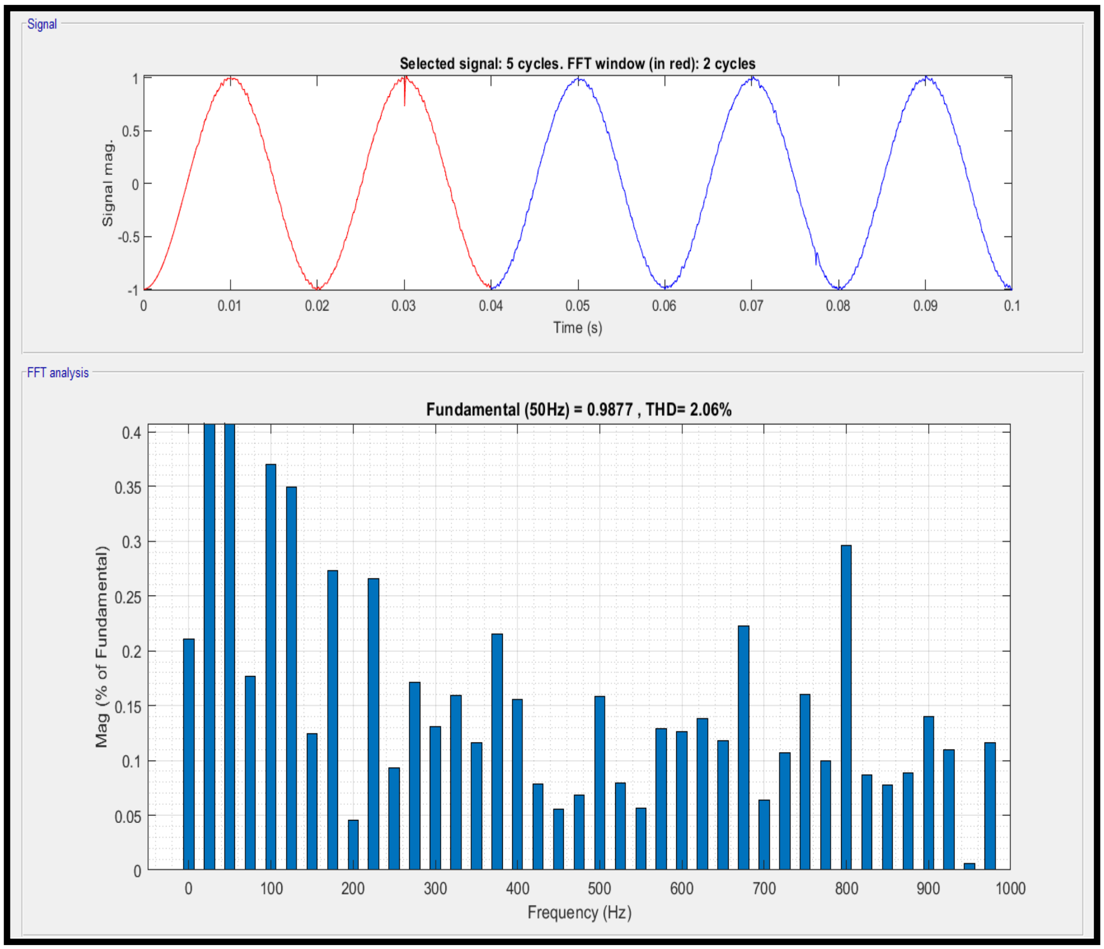

Fig. 9 : THD analysis for Double-line to ground fault with PI controller

Case 3: Single-line to ground fault with PI controller: The source voltage, load voltage, and injected voltage waveforms of the DVR under a single line to ground failure scenario can be seen in Figure 10. A SLGF happens, which causes the voltage to drop below its nominal levels. The whole fault duration, from 0.03 to 0.07 seconds, is 0.04 seconds. Using a PI controller, the voltage sag is rectified by injecting the necessary voltage that is absent during the fault situation.

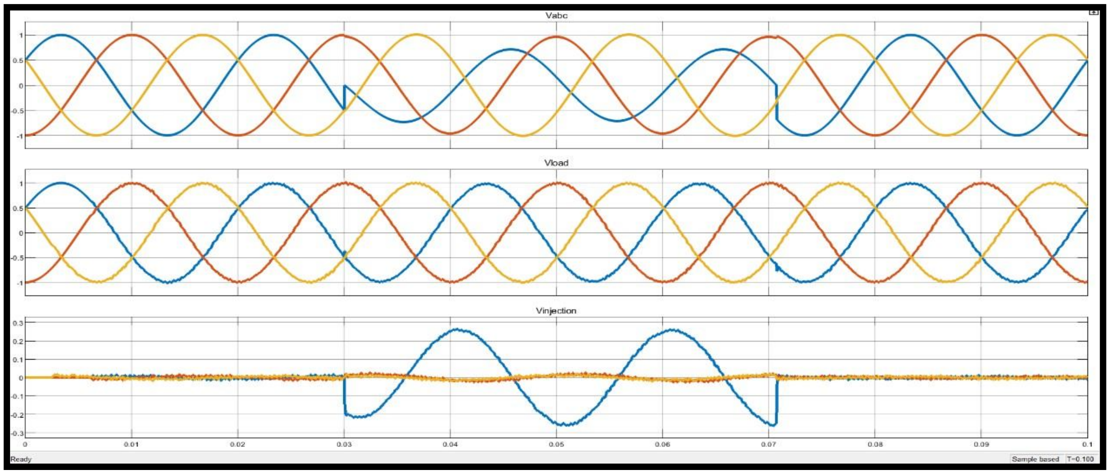

Fig. 10 : Single-line to ground fault with PI controller

The FFT analysis of the sensitive load voltage reveals that the load voltage is a perfect sinusoid with a very low THD of 1.73%.

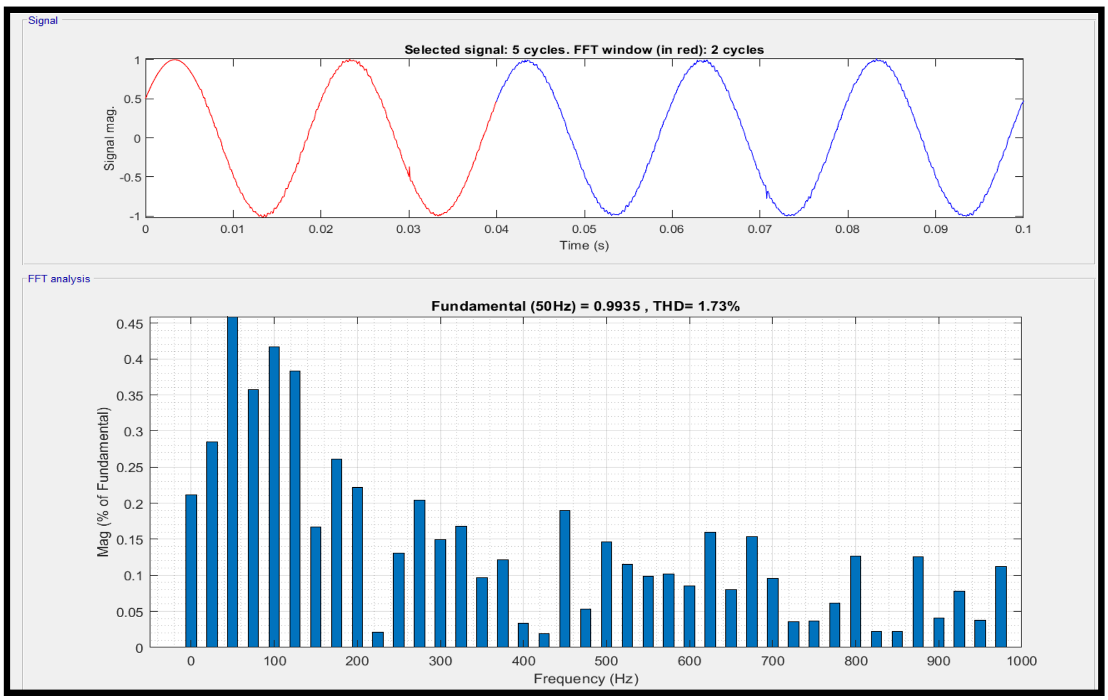

Fig. 11: THD analysis for Single-line to ground fault with PI controller

TABLE I
THD WITH PI CONTROLLER

Faults	THD (%) with PI Controller
Three-Line to Ground Fault (L_L_L_G Fault)	2.00 %
Double-Line to Ground Fault (L_L_G Fault)	2.06 %
Single-Line to Ground Fault (L_G Fault)	1.73 %

The investigation leads to the conclusion that using an PI controller improves system performance by lowering THD values.

IV. CONCLUSIONS

Quality power has become a difficult problem for consumers, Among them is the imbalance of voltage and is thought to be the main factor for electrical device performance to decrease. Using FACTS devices for compensation is the most effective way to deal with this kind of issue. DVR is said to be the most economical and efficient of them all. To demonstrate the efficacy of DVR in mitigating various errors, MATLAB is utilized to model a basic distribution network. In this work, a simulation model of a nonlinear load linked power distribution system with a dynamic voltage restorer controlled by a PI controller is built using Matlab/Simulink. The study's conclusions show that the recommended DVR system effectively corrects for voltage sag brought on by single-, double-, and three-phase line to ground faults as well as harmonics generated by nonlinear loads.

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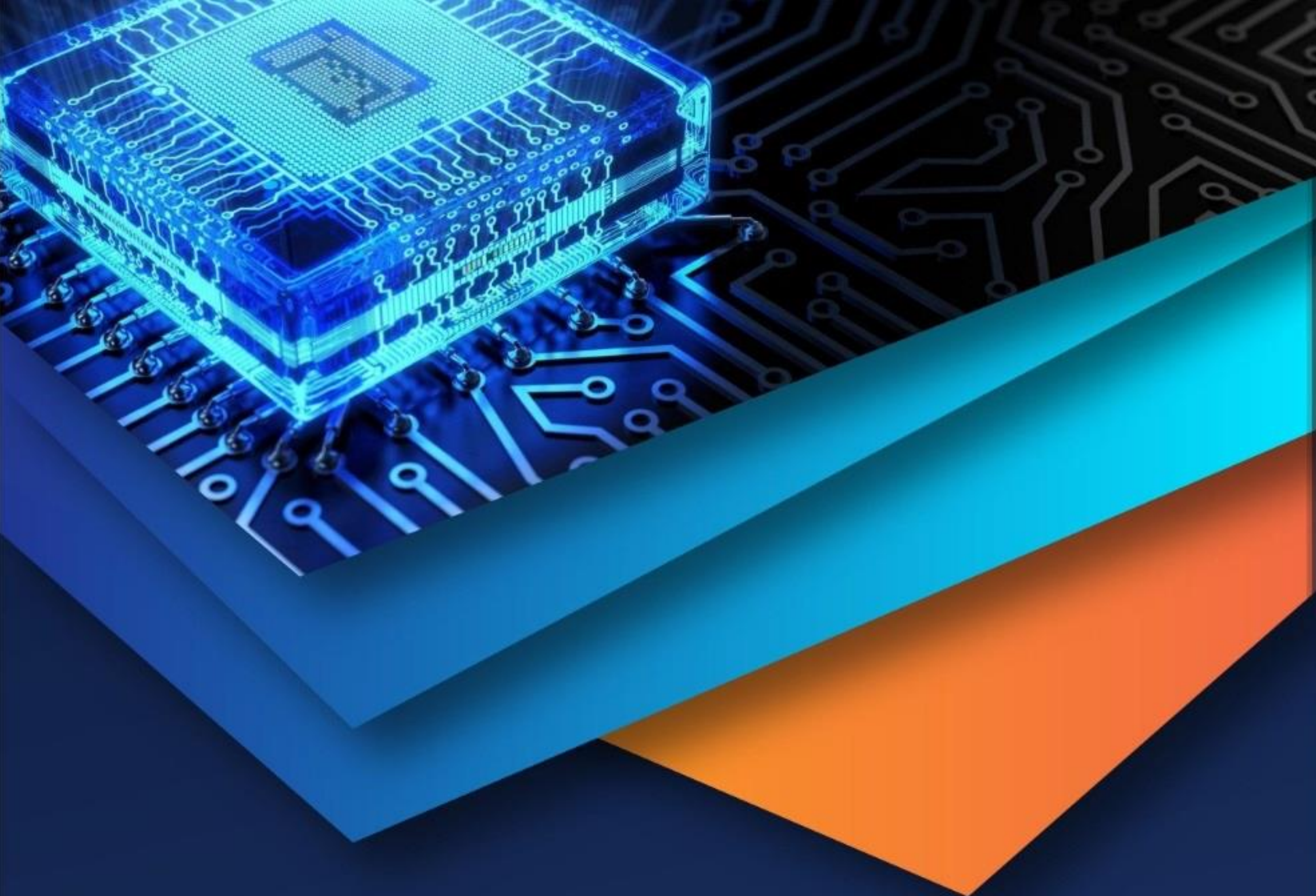

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