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Modeling & Design of A Transformer less Active Voltage Quality Regulator With A Novel DVR

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Abstract

In Restructured power systems, Power quality is one of the major concerns in the present era. The problem of voltage sags and swells and its major impact on sensitive loads are well known. To (DVR), which is one of the most efficient and effective modern custom power devices used in power distribution networks. A new FLC control algorithm for the DVR is proposed in this paper to regulate the load terminal voltage during sag, swell in the voltage at the point solve this problem, custom power devices are used. One of those devices is the Dynamic Voltage Restorer of common coupling (PCC).This new control scheme, it is based on fuzzification rules are used for the generation of reference voltages for a dynamic voltage restorer (DVR). These voltages, when injected in series with a distribution feeder by a voltage source inverter (VSI) with PWM control, can regulate the voltage at the load terminals against any power quality problem in the source side. Wavelets based analyzes the power circuit of the system in order to come up with appropriate control limitations and control targets for the compensation voltage control through the DVR. The control of the DVR is implemented through derived reference load terminal voltages.

Keywords: *sag, swell, Mitigation, fuzzy logic, DVR and VSI*

I. INTRODUCTION

There are many different methods to mitigate voltage sags and swells, but the use of a custom power device is considered to be the most efficient method, e.g. FACTS for transmission systems which improve the power transfer capabilities and stability margins. The term custom power pertains to the use of power electronics controller in a distribution system, especially, to deal with various power quality problems. Custom power assures customers to get pre-specified quality and reliability of supply. This pre-specified quality may contain a combination of specifications of the following: low phase unbalance, no power interruptions, low flicker at the load voltage, and low harmonic distortion in load voltage, magnitude and duration of over voltages and under voltages within specified limits, acceptance of fluctuations, and poor factor loads without significant effect on the terminal voltage. There are different types of Custom Power devices used in electrical network to improve power quality problems. Each of the devices has its own benefits and limitations. A few of these reasons are as follows. The SVC pre-dates the DVR, but the DVR is still preferred because the SVC has no ability to control active power flow. Another reason include that the DVR has a higher energy capacity compared to the SMES and UPS devices. Furthermore, the DVR is smaller in size and cost is less compared to the DSTATCOM and other custom power devices. Based on these reasons, it is no surprise that the DVR is widely considered as an effective custom power device in mitigating voltage sags. In addition to voltage sags and swells compensation, DVR can also add other features such as harmonics and Power Factor correction. Compared to the other devices, the DVR is clearly considered to be one of the best economic solutions for its size and capabilities

II. DYNAMIC VOLTAGE RESTORER (DVR)

DVR is a Custom Power Device used to eliminate supply side voltage disturbances. DVR also known as Static Series Compensator maintains the load voltage at a desired magnitude and phase by compensating the voltage sags/swells and voltage unbalances presented at the point of common coupling.

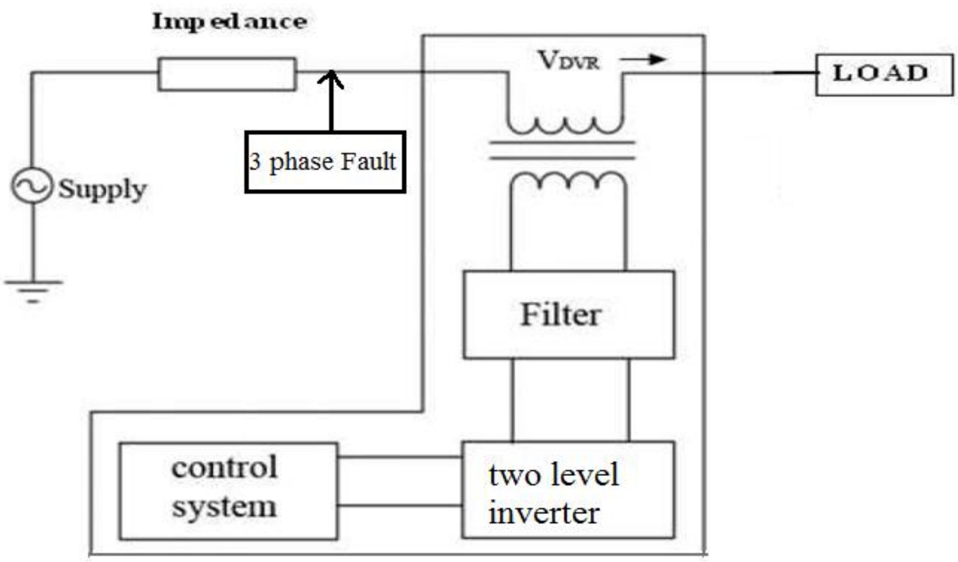

Fig-1. Schematic diagram of a Dynamic Voltage Restorer

Basic Configuration of Dynamic Voltage Restorer: The general configuration of the DVR consists of:

i. Injection/ Booster Transformer: The Injection / Booster transformer is a specially designed transformer that attempts to limit the coupling of noise and transient energy from the primary side to the secondary side. Its main tasks are:

- 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.
- In addition, the Injection / Booster transformer serves the purpose of isolating the load from the system (VSC and control mechanism).

ii. Harmonic Filter: The main task of harmonic filter is to keep the harmonic voltage content generated by the VSC to the permissible level.

iii. Storage Devices: Batteries, flywheels or SMEs can be used to provide real power for compensation. Compensation using real power is essential when large voltage sag occurs.

iv. Voltage Source Converter: A VSC is a power electronic system 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 missing. There are four main types of switching devices: Metal Oxide Semiconductor Field Effect Transistors (MOSFET), Gate Turn-Off thyristors (GTO), Insulated Gate Bipolar Transistors (IGBT), and Integrated Gate Commutated Thyristors (IGCT). Each type has its own benefits and drawbacks. The IGCT is a recent compact device with enhanced performance and reliability that allows building VSC with very large power ratings. Because of the highly sophisticated converter design with IGCTs, the DVR can compensate dips which are beyond the capability of the past DVRs using conventional devices. The purpose of storage devices is to supply the necessary energy to the VSC via a dc link for the generation of injected voltages. The different kinds of energy storage devices are Superconductive magnetic energy storage (SMES), batteries and capacitance.

v. DC Charging Circuit: The DC Charging Circuit has two main tasks.

- The first task is to charge the energy source after a sag compensation event.
- The second task is to maintain dc link voltage at the nominal dc link voltage

vi. Control and Protection: The control mechanism of the general configuration typically consists of hardware with programmable logic. All protective functions of the DVR should be implemented in the software. Differential current protection of the transformer, or short circuit current on the customer load side are only two examples of many protection functions possibility.

CARRIER PHASE SHIFTING PULSE WIDTH MODULATION: Carrier phase-shift sinusoidal pulse width modulation (PS-SPWM) switching scheme is proposed to operate the switches in the system. Optimum harmonic cancellation is achieved by phase shifting each carrier by (k-1) π/n. Where k is the kTh inverter, n is the number of series-connected single phase inverters. n= (L-1)/2

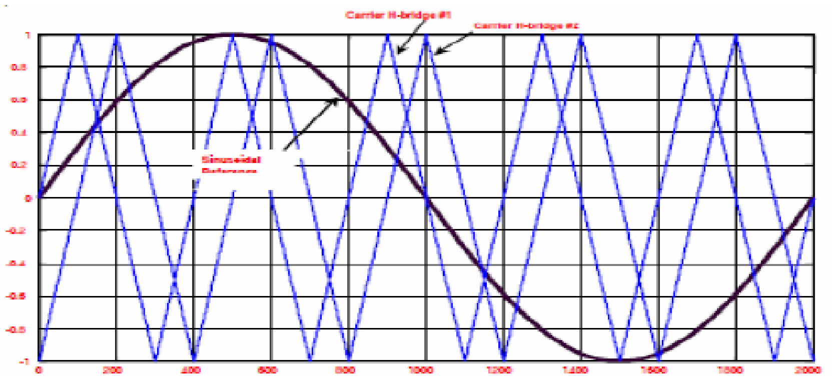

Fig.2 Phase shifted carrier PWM

Fig-2 shows the PSCPWM. In general, a multilevel inverter with *m* voltage levels requires (*m*–1) triangular carriers. In the PSCPWM, all the triangular carriers have the same frequency and the same peak-to-peak amplitude, but there is a phase shift between any two adjacent carrier waves, given by φcr=3600/ (m–1). The modulating signal is usually a three-phase sinusoidal wave with adjustable amplitude and frequency. The gate signals are generated by comparing the modulating wave with the carrier waves. It means for five-level inverter four triangular carriers are needed with a 90° phase displacement between any two adjacent carriers. In this case the phase displacement of $Vcr1 = 0°$, $Vcr2 = 90°$, $Vcr1- = 180°$ *and* $Vcr2- = 270°$.

III ADAPTIVE FUZZY DIVIDING FREQUENCY-CONTROL METHOD

The conventional linear feedback controller (PI controller, state feedback control, etc.) is utilized to improve the dynamic response and/or to increase the stability margin of the closed loop system. However, these controllers may present a poor steady-state error for the harmonic reference signal. An adaptive fuzzy dividing frequency control method is presented in Fig., which consists of two control units: 1) a generalized integrator control unit and 2) a fuzzy adjustor unit. The generalized integrator, which can ignore the influence of magnitude and phase, is used for dividing frequency integral control, while fuzzy arithmetic is used to timely adjust the PI coefficients.

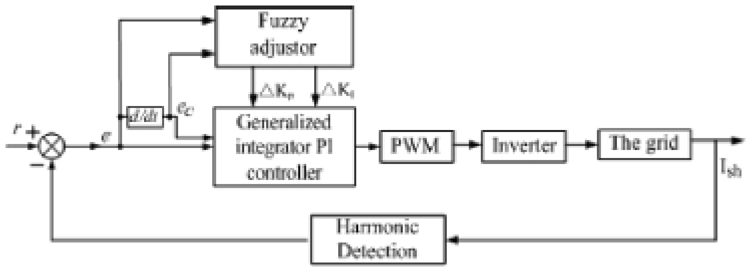

Fig.3 Configuration of the adaptive fuzzy dividing frequency controller

Since the purpose of the control scheme is to receive a minimum steady-state error, the harmonic reference signal r is set to zero. First, supply harmonic current is detected. Then, the expectation control signal of the inverter is revealed by the adaptive fuzzy dividing frequency controller. The stability of the system is achieved by a proportional controller, and the perfect dynamic state is received by the generalized integral controller. The fuzzy adjustor is set to adjust the parameters of proportional control and generalized integral control. Therefore, the proposed harmonic current tracking controller can decrease the tracking error of the harmonic compensation current, and have better dynamic response and robustness.

A. Fuzzy Adjustor

The fuzzy adjustor is used to adjust the parameters of proportional control gain K_P and integral control gain K_I, based on the error e and the change of error e_c

$$\begin{cases} K_P = K_P^* + \Delta K_P \\ K_I = K_I^* + \Delta K_I \end{cases}$$

Where K_P^* and K_I^* are reference values of the fuzzy-generalized integrator PI controller. In this paper, K_P^* and K_I^* are calculated offline based on the Ziegler–Nichols method. In a fuzzy-logic controller, the control action is determined from the evaluation of a set of simple linguistic rules. The development of the rules requires a thorough understanding of the process to be controlled, but it does not require a mathematical model of the system. A block diagram fuzzy-logic adjustor is shown in Fig.

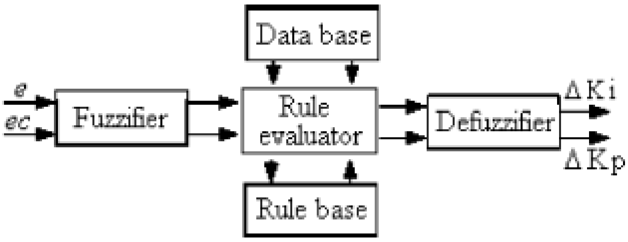

Fig.4 Block diagram of the fuzzy adjustor unit

In this way, system stability and a fast dynamic response with small overshoot can be achieved with proper handing of the fuzzy-logic adjustor. Fuzzification converts crisp data into fuzzy sets, making it comfortable with the fuzzy set representation of the state variable in the rule. In the fuzzification process, normalization by reforming a scale transformation is needed at first, which maps the physical values of the state variable into a normalized universe of discourse.

The error e and change of error e_c are used as numerical variables from the real system. To convert these numerical variables into linguistic variables, the following seven fuzzy levels or sets are chosen as [7]: negative big (NB), negative medium (NM), negative small (NS), zero (ZE), and positive small (PS), positive medium (PM), and positive big (PB). To ensure the sensitivity and robustness of the controller, the membership function of the fuzzy sets for $e(k)$, $e_c(k)$, ΔK_P, and ΔK_I in this paper are acquired from the ranges of e, e_c, ΔK_P, and ΔK_I, which are obtained from project and experience. And the membership functions are shown in Fig., respectively.

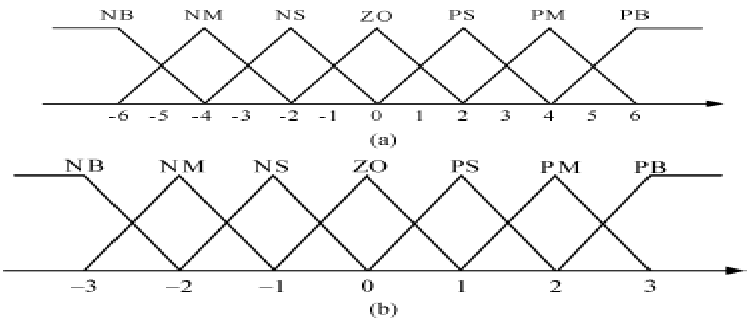

Fig.5 Membership functions of the fuzzy variable. (a) Membership function of $e(k)$ and $e_c(k)$ (b) Membership function of ΔK_P and ΔK_I.

The core of fuzzy control is the fuzzy control rule, which is obtained mainly from the intuitive feeling for and experience of the process. The fuzzy control rule design involves defining rules that relate the input variables to the output model properties.

For designing the control rule base for tuning ΔK_P and ΔK_I, the following important factors have been taken into account.

1) For large values of $|e$, a large ΔK_P is required, and for small values of $e|$, a small ΔK_P is required.

2) For $e \cdot e_c > 0$, a large ΔK_P is required, and for $e \cdot e_c < 0,$ a small ΔK_P is required.

3) For large values of $|e$ and $e_c|$, ΔK_I is set to zero, which can avoid control saturation.

4) For small values of $|e$, ΔK_I is effective, and ΔK_I is larger when $e|$ is smaller, which is better to decrease the steady-state error. So the tuning rules of ΔK_P and ΔK_I can be obtained as Tables.

TABLE: ADJUSTING RULE OF THE ΔK_P PARAMETER

ΔKp		e_c						
		NB	NM	NS	0	PS	PM	PB
e	NB	PB	PB	NB	PM	PS	PS	0
	NM	PB	PB	NM	PM	PS	0	0
	NS	PM	PM	NS	PS	0	NS	NM
	0	PM	PS	0	0	NS	NM	NM
	PS	PS	PS	0	NS	NS	NM	NM
	PM	0	0	NS	NM	NM	NM	NB
	PB	0	NS	NS	NM	NM	NB	NB

TABLE: ADJUSTING RULE OF THE ΔK_I PARAMETER

ΔK_I		e_c						
		NB	NM	NS	0	PS	PM	PB
e	NB	0	0	NB	NM	NM	0	0
	NM	0	0	NM	NM	NS	0	0
	NS	0	0	NS	NS	0	0	0
	0	0	0	NS	NM	PS	0	0
	PS	0	0	0	PS	PS	0	0
	PM	0	0	PS	PM	PM	0	0
	PB	0	0	NS	PM	PB	0	0

The inference method employs the MAX-MIN method. The imprecise fuzzy control action generated from the inference must be transformed to a precise control action in real applications. The center of gravity method is used to defuzzify the fuzzy variable into physical domain

$$\begin{cases} K_P = K_P^* + \dfrac{\sum_{j=1}^{n} \mu_j(e,e_c)\Delta K_{Pj}}{\sum_{j=1}^{n} \mu_j(e,e_c)} \\ K_I = K_I^* + \dfrac{\sum_{j=1}^{n} \mu_j(e,e_c)\Delta K_{Ij}}{\sum_{j=1}^{n} \mu_j(e,e_c)} \end{cases}.$$

IV. SIMULATION MODEL & RESULTS

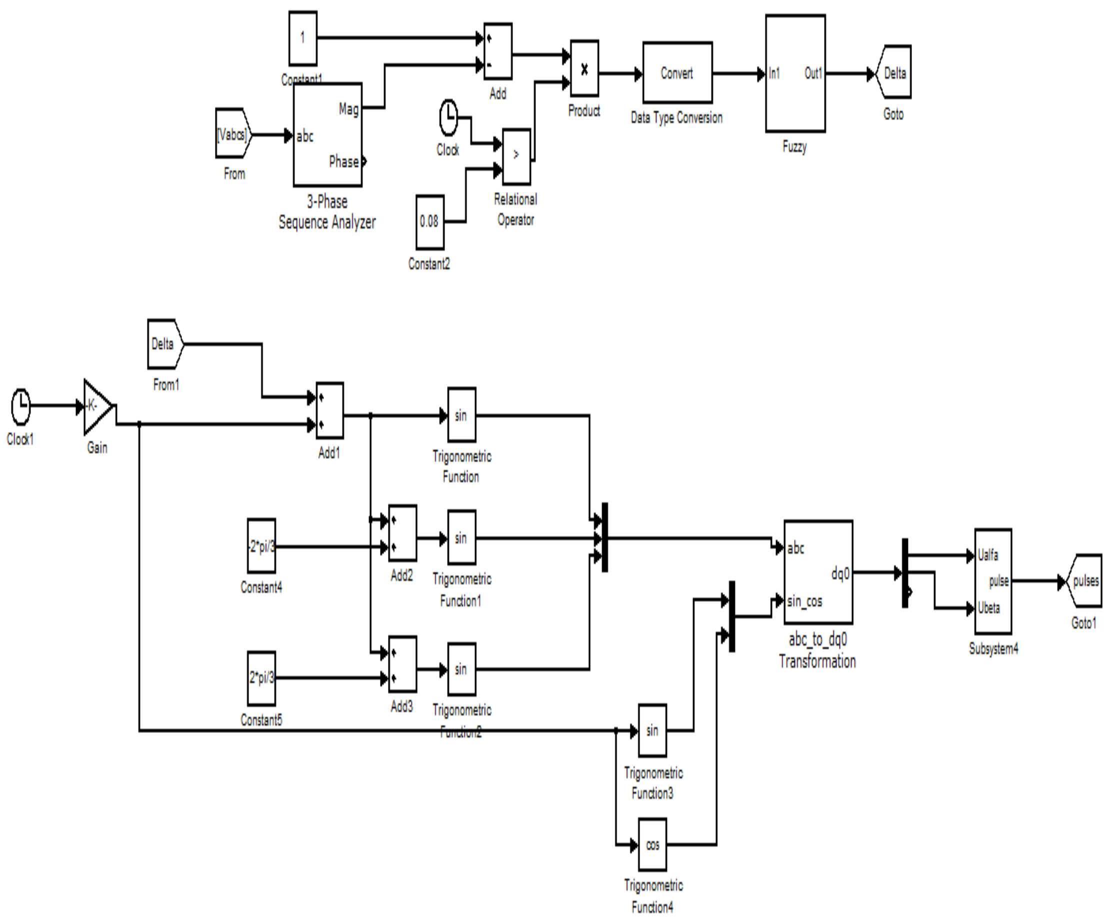

Fig.6 control structure

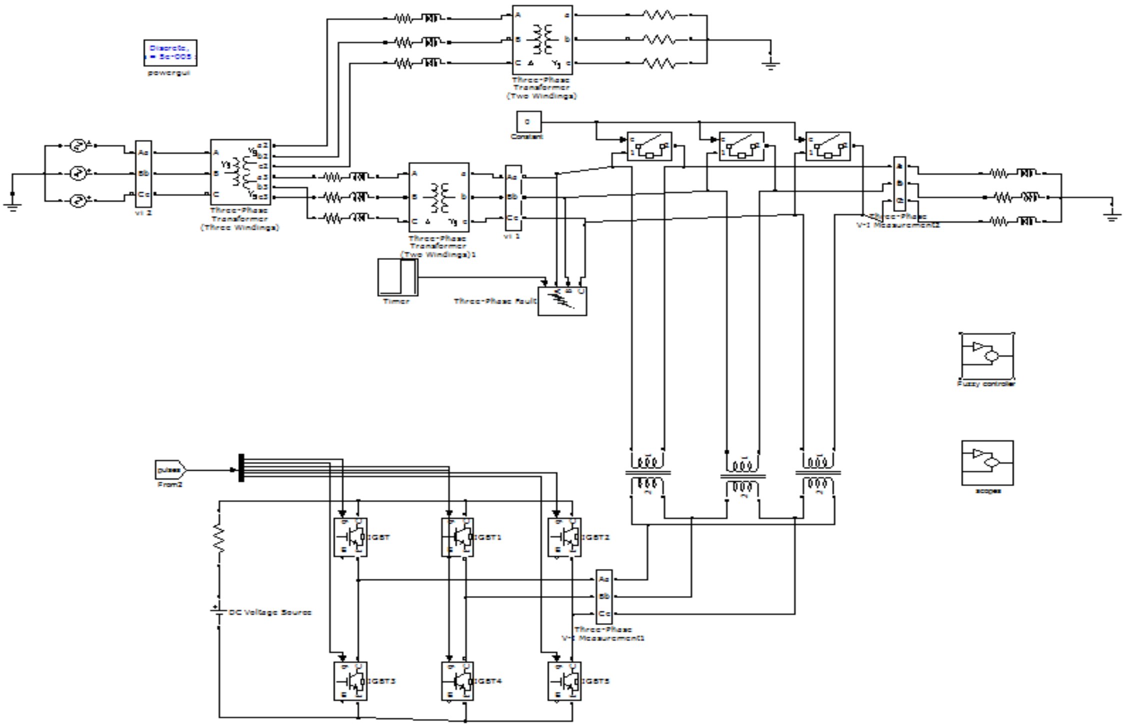

Fig.7 Simulink diagram of closed loop system for voltage sag and swell

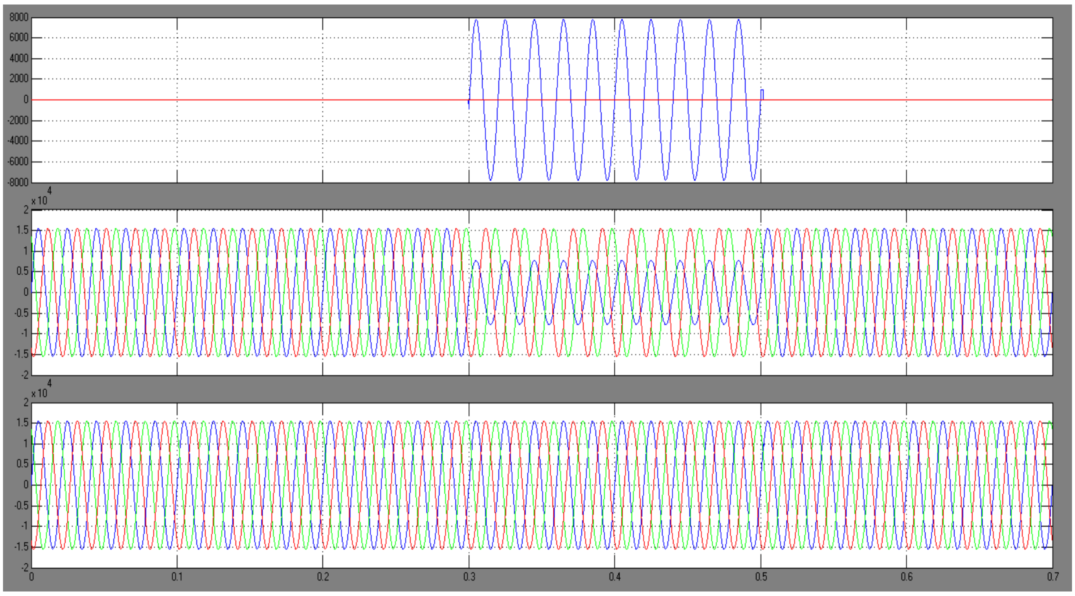

Fig.8 source voltage, voltage sag, compensated output voltage

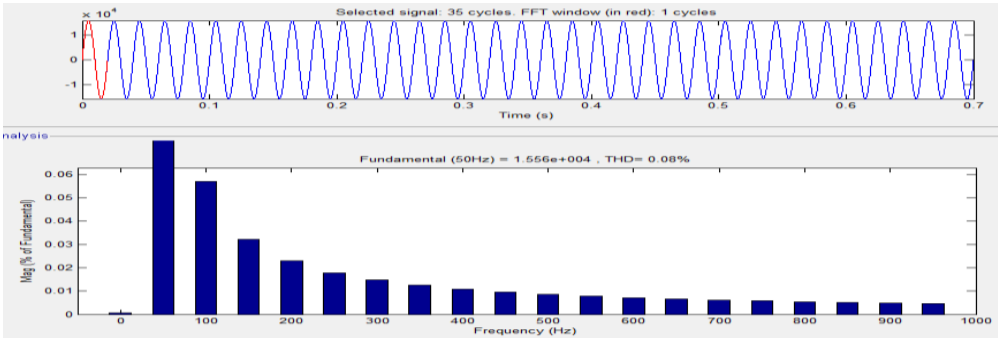

Fig.9 FFT analysis of voltage sag of DVR

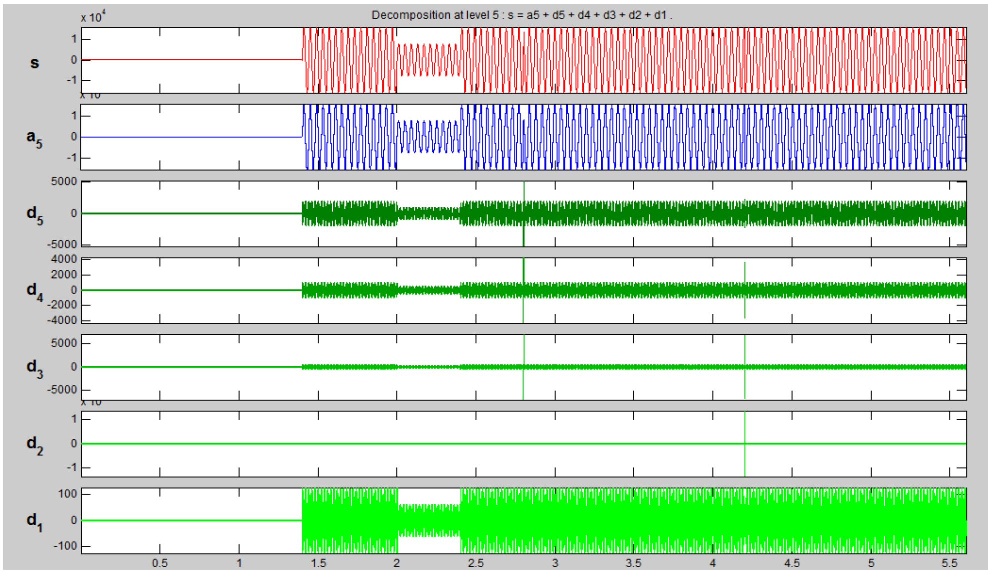

Fig.10 wavelet analysis of sag

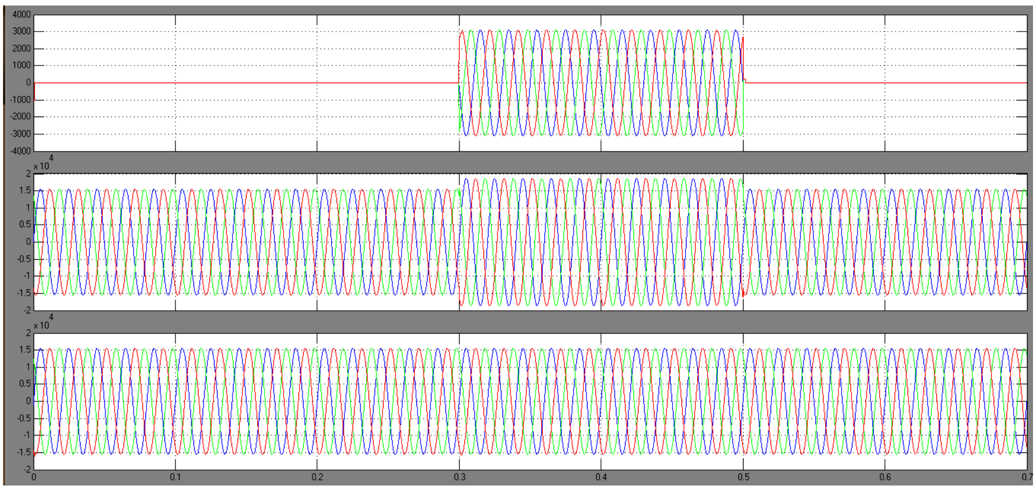

Fig.11 source voltage, voltage swell, compensated output voltage

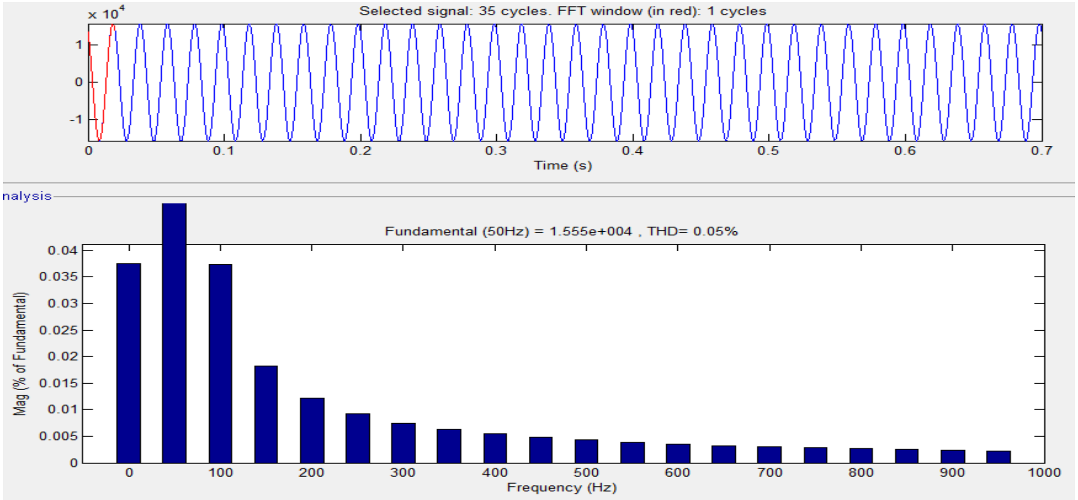

Fig 12 THD analysis of voltage swell of DVR

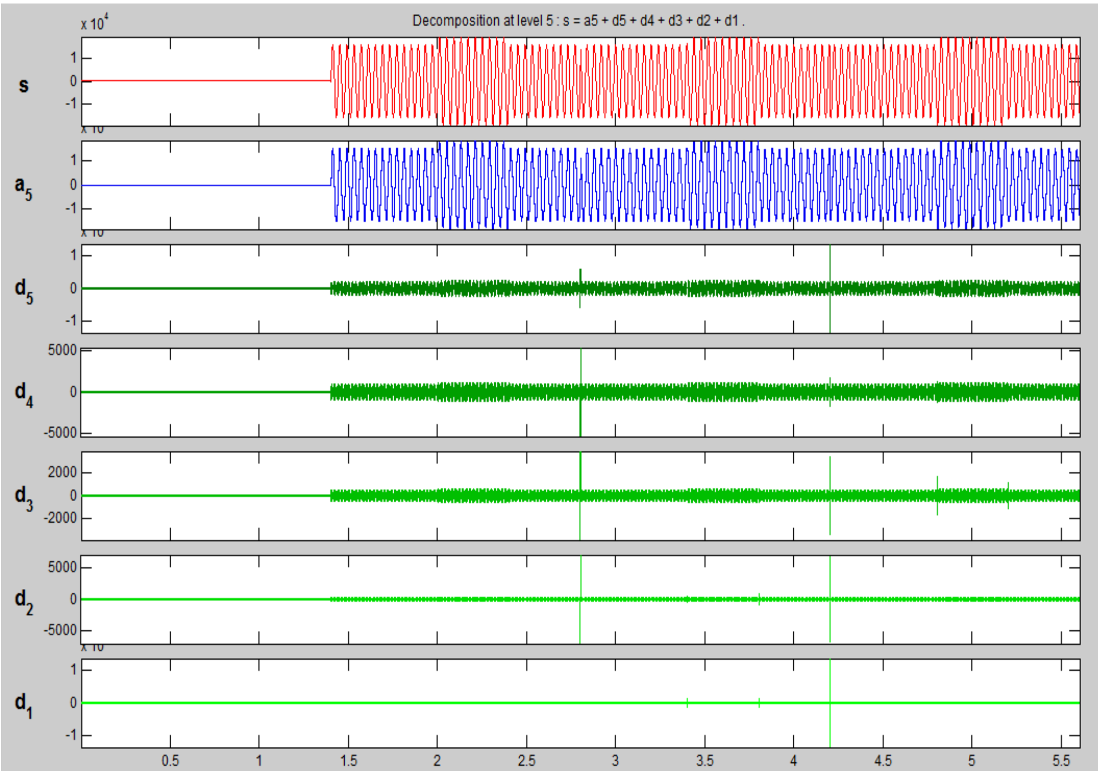

Fig. 13 wavelet analysis of swell

V. CONCLUSION

In this paper cascaded H-Bridge Seven level multilevel inverter is implemented as Dynamic Voltage Restorer to compensate voltage sag, voltage swell and interruption. Closed loop control of Dynamic Voltage Restorer is designed for better regulation of the load voltage. Reference signal is generated using PQ theory for closed loop control with voltage Sag, voltage Swell and interruption are compensated using Dynamic Voltage Restorer and MATLAB simulations are carried for the above to maintain load voltage constant.

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