Comparison of Control Techniques in Power Quality Improvement by Using Small Energy Storage System DVR

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Abstract— Power quality problems especially caused by industrial distribution system have huge impact on system power quality. This paper deals with custom power device DVR to mitigate power quality problems. The control of compensation voltage in DVR has been proposed feed forward control technique with PWM controller and hysteresis voltage control technique with hysteresis controller. Both test system are simulated in Matlab/Simulink with different DVR configurations that prove the effectiveness and robustness of the proposed control strategy with dynamic voltage restorer for voltage sag mitigation. The results show the comparison in between different control technique results with DVR to compensate power quality problem with second topology of DVR.

Keywords: Dynamic voltage restorer, voltage sags, voltage swells, power quality.

I. INTRODUCTION

At least 50% of all PQ disturbances are of the voltage quality type, where the interest is the study of any deviation of the voltage waveform from its ideal form . The best well-known disturbances are voltage sags and swells, harmonic and inter harmonic voltages, and, for three-phase systems, voltage imbalances [19]. Some special equipment is sensitive to voltage disturbances, especially if these take up to several periods, the circuit does not work [16]. At present, a wide range of very flexible controllers which capitalize on newly available power electronics components are emerging for custom power applications [4]. Among these, the distribution static compensator (D-STATCOM) and the dynamic voltage restorer (DVR) which operate based on voltage source converter (VSC) principle are most effective devices [9].Restorer (DVR) are now becoming more established in industry to mitigate the impact of voltage disturbances on sensitive loads [5].

First Dynamic voltage restorer was built in U.S by Westinghouse for the Electric Power Research Institute (EPRI), and first installed in 1996 on Duke Power Company grid system to protect an automated yarn manufacturing and weaving factory [14]. Dynamic voltage restorer (DVR) is one of the device which is connect series to network and near to customer by feeding three-phase AC controlled voltage, restore voltage sag immediately [11]. The DVR is connected between the point of common coupling (PCC) and the load.

The basic principle of a DVR is simple: by inserting a voltage of desired magnitude and frequency, in order to restore the load-side voltage balanced and sinusoidal [13]. This method uses real power in order to inject the faulted supply voltages and is commonly known as the Dynamic Voltage Restorer [17]. In addition to voltage sags and swells compensation, DVR can also added other features such as: line voltage harmonics compensation, reduction of transients in voltage and fault current limitations [18]. The single phase DVR can be employed for low power loads while three phase DVR is employed for all practical high power industrial loads and domestic loads.

II. PRINCIPAL OF DVR

The single phase DVR is employed for low power loads while three phase DVR is employed for all practical high power applications as in industrial loads and domestic loads [8]. The basic function of the DVR is to inject a dynamically controlled voltage *generated* by a voltage converter (IGBT) in series with the bus voltage with the help of a booster transformer.

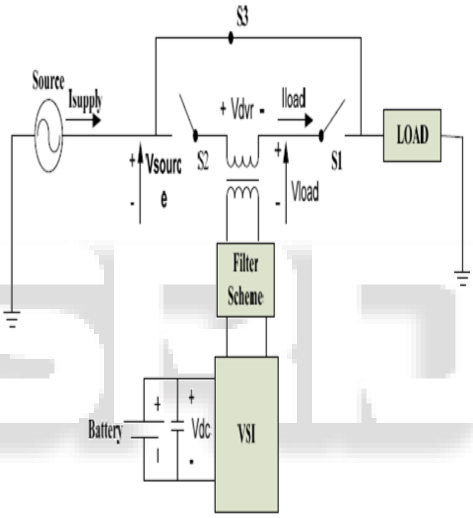

Fig. 1: Operation of DVR

III. REQUIREMENTS OF DVR

- Energy Storage Units
- Voltage storage Converter
- Harmonic Filter
- Voltage Injection Transformer
- By Pass Switch
- Capacitor
- Control System

A. Energy storage Unit

The DC energy storage device provides the real power which is requirement of the DVR during compensation of power quality problems. Examples of energy storage devices are dc capacitors, batteries, super-capacitors, super-conducting magnetic energy Storage and flywheels [5]. An alternative is the use of lead-acid battery. Batteries are now considered of limited suitability for DVR applications since it takes considerable time to release stored energy from them.

B. Voltage Source Inverter (VSC)

A VSC is power electronic system consists of a storage device and switching devices. It generates a sinusoidal voltage at any required frequency, magnitude, and phase angle [2]. The inverter switches are normally fired using a sinusoidal Pulse Width Modulation (PWM) scheme. The PWM generates sinusoidal signals by comparing a sinusoidal wave with a saw tooth wave and sending appropriate signals to the inverter switches. Usually the rating of VSI is low voltage and high current due to the use of step up injection transformers [8].

C. Harmonic Filter

The main task of the harmonic filter is to keep the harmonic voltage content or total harmonic distortion level generated by the voltage source converters (VSC) below the permissible level. Higher orders harmonic components distort the compensated output voltage. The unnecessary switching harmonics generated by the voltage source inverter must be removed from the injected voltage waveform in order to maintain an acceptable Total Harmonics Distortion (THD) level [17].

D. Voltage Injection Transformer

With the help of booster transformer the power is transformed to secondary side, and it is also used to reduce the coupling of noise [12]. Now three single phase transformers or one three phase transformer can be used for 3 phase DVR whereas 1 single phase transformer can be used for 1 phase DVR. The type of connection used for 3 phase DVR if 3 single phase transformers are used is called "Delta-Delta" type connection. If a winding is missing on primary and secondary side then such a connection is called "Open-Delta" connection which is as widely used in DVR systems [7].

E. By Pass Switch

If the current present on the load side exceeds a reasonable value because of short circuit on the burden and huge inrush current, the DVR could be separated from the system by utilizing the bypass switches and supplying a different path for current [12]. The bypass switch will become in inactive when the source current is in rated value or in normal condition [17].

F. Capacitor

DVR consists of a capacitor having large rating. In addition, it is used for stiff DC voltage for the input of inverter [12]. The most important advantage of these capacitors is the capability to supply high current pulses repeatedly for hundreds of thousands of cycles. Selection of capacitor rating is discussed on the basis of RMS value of a capacitor current, rated voltage of a capacitor and VA rating of the capacitor [3].

G. Control System

The main purpose of the control system is to maintain a constant voltage magnitude at the point of common coupling where a sensitive load is connected. The control mechanism of the general configuration typically consists of hardware with programmable logic. In past DVR development, this would normally consist of Digital Signal Processing (DSP) boards. The software on the DSP board provides the controls such as detection and correction. Filters are commonly used for these purposes. The type of filter algorithm has varied. It ranges from the Fourier Transform (FT), the Phase-Locked Loop (PLL), to the Wavelet Transform (WT), just to name a few. Although, the Fourier Transform still remains the most common type [18].

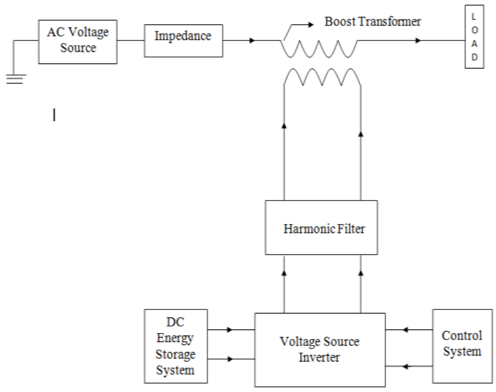

Fig 2: DVR Structure

IV. TOPOLOGIES OF DVR

There is no. of topologies in DVR. But In this paper two topologies of DVR will considered:

A. DVR With energy storage system:

In the first topology DC energy storage system is used in DVR. DC energy storage system may be SMES, battery or super capacitors. The type of this topology is considered as a simple topology and it can be running with a variable dc-link voltage. The energy storage required to activate the DVR is proportional to the square of the rated dc-link voltage [17].

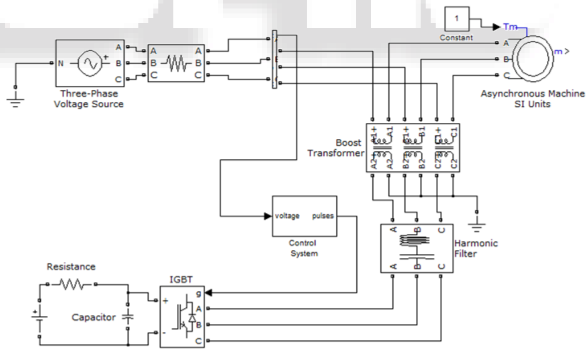

Fig. 3: DVR with energy storage system

B. DVR with no energy storage system

In the second topology small energy storage system is used as compare to first topology. In the second topology rectifier i.e. voltage converter is used as a DC supply source. But this is not pure DC. So capacitor is used to reduce variable voltage. It means small energy storage system is required. The second topology of DVR is shown in fig 3. DVR topologies with no energy storage use the fact that a significant part of the source voltage continuous maintain during the disturbances, and this source can be used to provide the boost energy required to maintain full power at its nominal voltage [17].

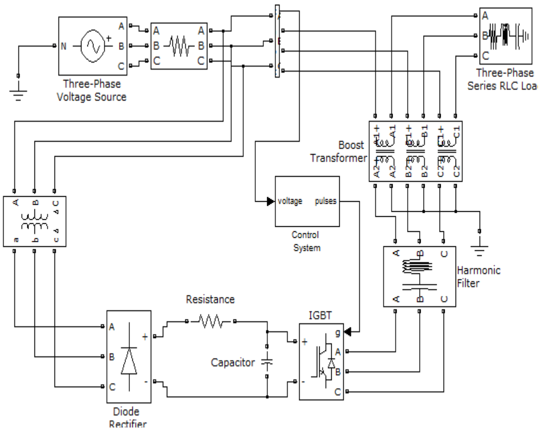

Fig. 4: DVR with no energy storage system and supply side connected rectifier

V. CONTROL TECHNIQUES

When voltage sags/swells are detected, the DVR should react as fast as to inject ac voltage to grid. It can be implemented using any control technique based on difference between reference voltage and instantaneous value of supply voltage. The basic functions of a controller in a DVR are the detection of voltage sag/swell events in the system; computation of the correcting voltage, generation of trigger pulses to the sinusoidal PWM based or hysteresis based DC-AC inverter, correction of any anomalies in the series voltage injection and termination of the trigger pulses when the event has passed. The controller may also be used to shift the DC-AC inverter into rectifier mode to charge the capacitors in the DC energy link in the absence of voltage sags/swells [10].

A. Feed Forward Control Technique

Control of DVR is performed by using d-q coordinate system. This transformation allows DC components, which is much simpler than AC components. The dqo transformation or Park's transformation is used to control of DVR. The dqo method gives the sag depth and phase shift information with start and end times [15]. Fig 18 shows the control system with feed forward control technique.

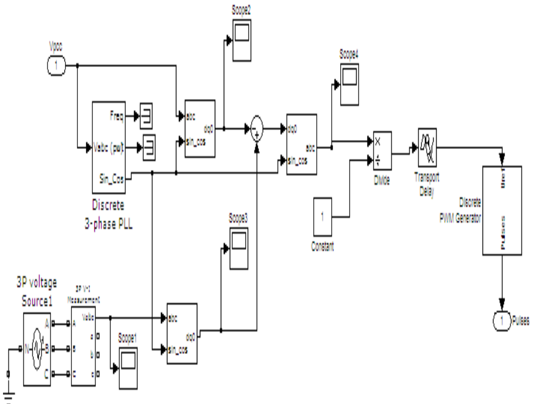

Fig. 5: Simulink model of feed forward control technique

Firstly convert the voltage from a-b-c reference frame to d-q-o reference. For simplicity zero phase sequence components are ignored [10]. During normal and symmetrical condition the voltage will be constant and d voltage is unity in pu and q voltage is zero in pu. But during abnormal condition it varies. After comparison d voltage and q voltage with the desired voltage, error d and error q are generated. These error components are converted in abc components using dq0 to abc transformation [6]. The angle θ of the source voltage can be obtained using three-phase phase logic loop (PLL). The information extracted from the PLL is used for detection and reference voltage generation is the detection scheme for the voltage unbalance compensator [1].

The following transformation is used:

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta & 1 \\ \cos\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta - \frac{2\pi}{3}\right) & 1 \\ \cos\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta - \frac{2\pi}{3}\right) & 1 \end{bmatrix} \begin{bmatrix} V_d \\ V_q \\ V_o \end{bmatrix}$$

The following reverse transformation is used:

$$\begin{bmatrix} V_d \\ V_q \\ V_o \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ -\sin\theta & -\sin\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}$$

This straight-forward comparison allows to obtain the desired extract voltage (compensating voltage) without any further control techniques (PI control or feedback loops). So, the control strategy is simplified and consistent [9].

B. Hysteresis Voltage Control Technique

A hysteresis voltage control technique is one type of nonlinear voltage control based on voltage error. Hysteresis Band Voltage control is used to control load voltage and determine switching signals for inverter switches [16]. DVR with hysteresis controller consists of a comparison between the output voltage and the tolerance limits (VH, VL)around the reference voltage, While the output voltage is between upper limit and lower limit , no switching occurs and when the output voltage increases to the upper limit (lower band) the output voltage is decreased (increased) [12]. Fig 19 shows the principle of hysteresis voltage controller. Fig 20 shows hysteresis controller in MATLAB and Fig 21 shows the Hysteresis voltage control technique.

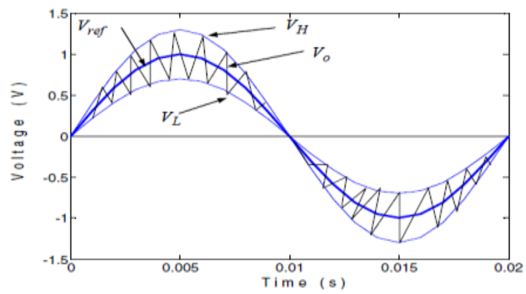

Fig. 6: Principle of operation of hysteresis voltage controller [8]

It consists of a comparison between the output voltage Vo and the tolerance limits (VH, VL) around the reference voltage Vref. while the output voltage Vo is between upper limit VH and lower limit VL, no switching occurs and when the output voltage crosses to pass the upper limit (lower band) the output voltage is decreased (increased) [8].

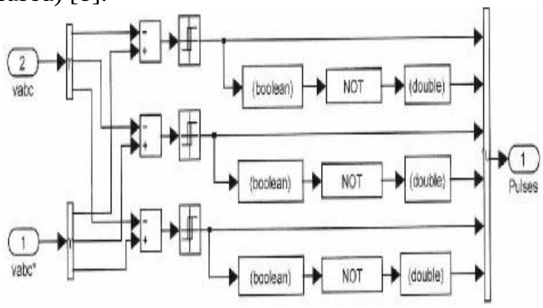

Fig. 7: Hysteresis Controller

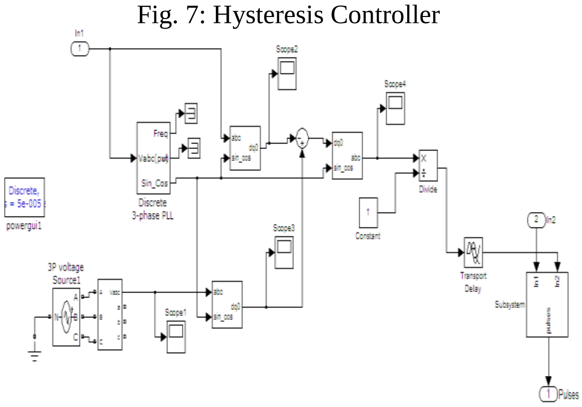

Fig. 8: Hysteresis Voltage Control Technique

VI. SIMULATION AND RESULT

A. Source and Load induction motor and Voltage Sag compensated by second topology of DVR using feed forward control technique with PWM controller and hysteresis voltage controller:

Simulink model of proposed DVR technique with second topology is shown in fig 29 with PWM controller. Fig 30 shows proposed DVR scheme with Hysteresis controller. The parameter of components used in DVR technique shown in fig table1. This proposed scheme is used to compensate voltage sag which is generated by induction motor i.e. inductive load.

1) Case 1: Sag Compensated with PWM Controller

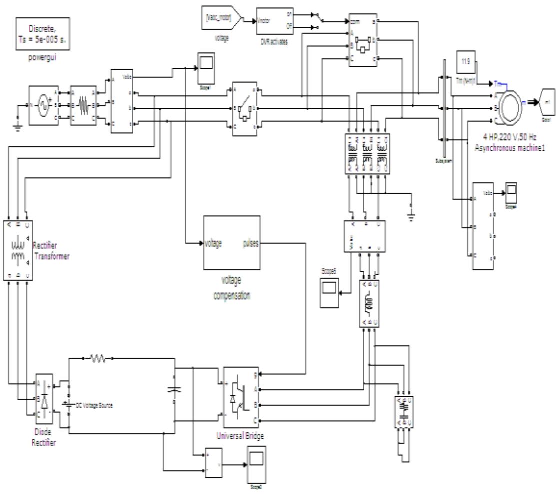

Fig. 9: Matlab/Simulink of proposed scheme with PWM Controller

2) Case 2: Sag Compensated by Hysteresis controller

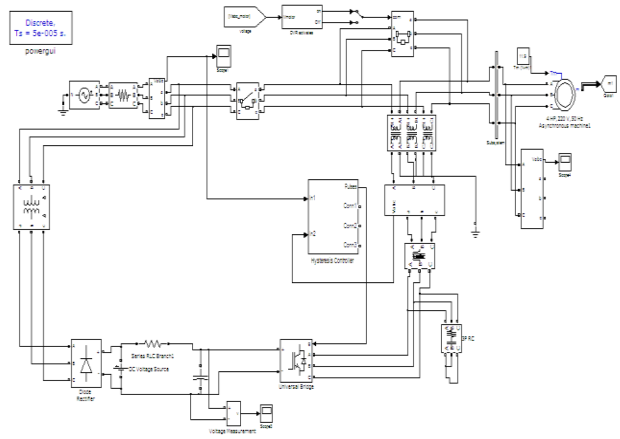

Fig. 10: Matlab/Simulink of proposed scheme with Hysteresis Controller

Table. 1: Test System Parameter

Components	Ratings
Voltage Source	400 V, 50Hz
Resistance Ω	0.4Ω
Rectifier Transformer	200/200 V, 200VA
Asynchronous machine motor ratings	10 HP, 200 V,50Hz
Motor stator resistance and inductance	0.435Ω, 2mH
Motor rotor resistance and inductance	0.816Ω, 4mH
Diode Rectifier	100Ω, 0.1µ
DC Battery Voltage	100 V
Voltage Source converter	IGBT Based
Boost Transformer	10KVA, 200/200 V

a) Simulation Results

The test system is started with voltage sag in case of starting induction motor in between 0.4 to 0.6 sec. During starting of induction motor, the motor absorb large reactive power. As the result voltage reduced 1.3pu for 0.2 sec. Fig 11(a) shows the voltage sag. Fig 11(b) shows voltage injected by DVR in system to compensate voltage sag with the help of boost transformer. Fig11(c) represent load voltage after mitigation voltage sags by PWM controller.

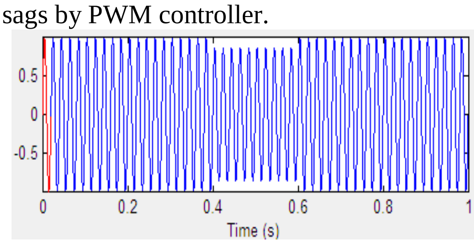

Fig. 11(a): Voltage Sag

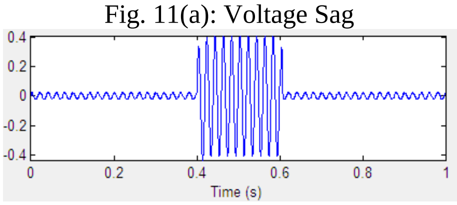

Fig. 11(b): Voltage Injected By DVR With hysteresis controller

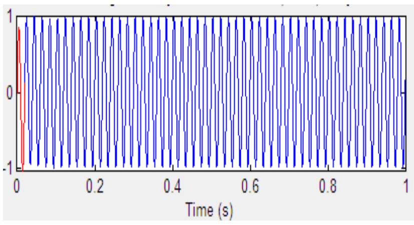

Fig 11(C): Load Voltage

Fig. 11: Three phase Voltage: a) Source voltage b) Injected voltage, c) Load voltage

Fig 12(a) shows the voltage sag. Fig 12(b) shows voltage injected by DVR in system to compensate voltage sag with the help of boost transformer. Fig12(c) represent load voltage after mitigation voltage sags by Hysteresis controller.

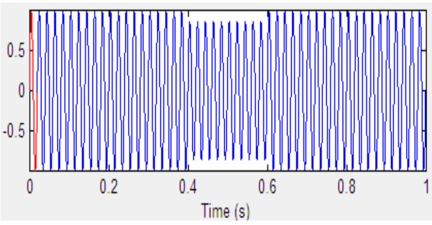

Fig. 12(a): Voltage Sag

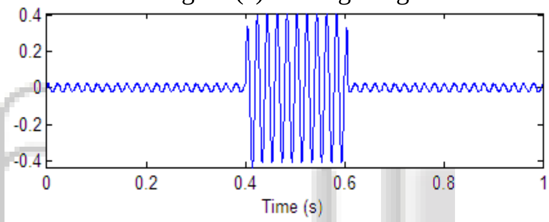

Fig. 12(b): Voltage Injected By DVR With hysteresis controller

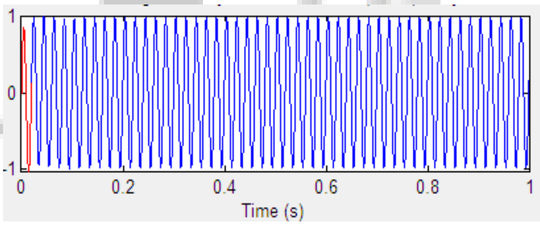

Fig 12(C): Load Voltage

Fig. 12: Three phase Voltage: a) Source voltage b) Injected voltage, c) Load voltage

3) Value of THD (Without DVR)

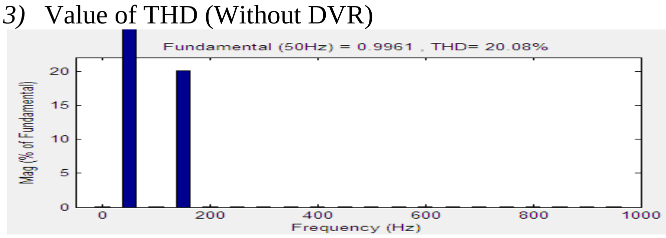

Fig. 13: Value of THD (Without DVR)

4) Value of THD (With DVR)

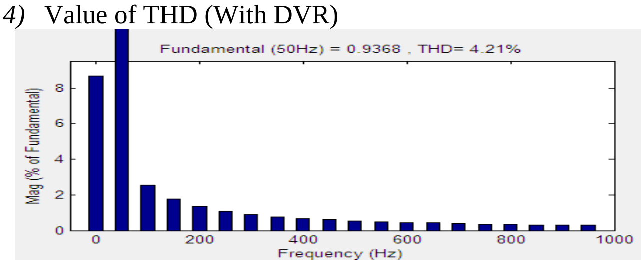

Fig. 14: Value of THD (Without DVR)

B. Source and load with RLC load and Voltage Swell compensated by second topology of DVR using feed forward control technique with PWM and Hysteresis controller:

In second case, the simulation started with supply voltage swell is generated by RLC load as shown in Fig 15(a). As observed from this fig the amplitude of supply voltage is increased by 30% from its nominal value with voltage swell. Fig 15 shows proposed DVR scheme with PWM Controller and table2 show proposed scheme parameter. Fig 16 shows proposed DVR scheme with Hysteresis controller.

1) Case 3: Voltage swell Compensated with PWM Controller

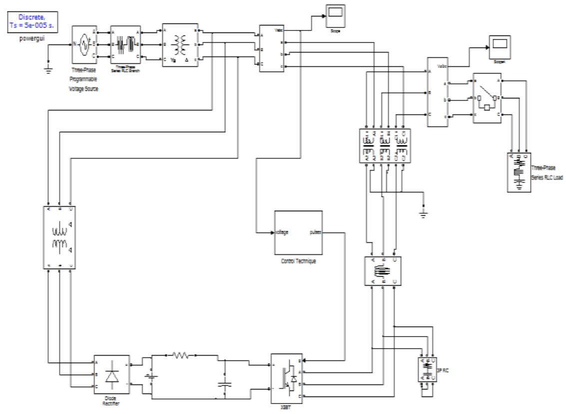

Fig. 15: Matlab/Simulink of proposed scheme

2) Case 4: Swell Compensated with Hysteresis Controller

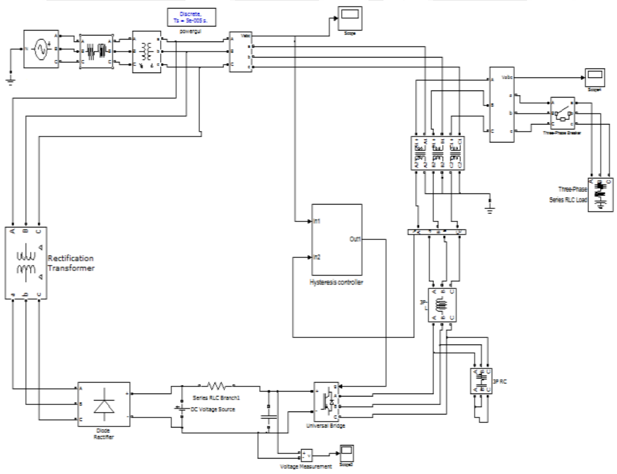

Fig. 16: Matlab/ Simulink of proposed scheme with Hysteresis controller

Table 2. :Test System Parameter

Components	Ratings
Voltage Source	400 V, 50Hz
Resistance Ω	0.4Ω
Rectifier Transformer	200/200 V, 200VA
Active Power	180 W
Inductive reactive power	0.1
Capacitive reactive power	250
Diode Rectifier	100Ω, 0.1μ
DC Battery Voltage	100 V
Voltage Source converter	IGBT Based
Boost Transformer	10KVA, 200/200 V

In this proposed scheme second topology of DVR is used i.e. there are two energy source supply to IGBT. DVR activate block is created to test the system operation with or without DVR. Because DVR works only in swell period.

a) Simulation Result

The test system is started with voltage swell in case of starting induction motor in between 0.4 to 0.6 sec. Due to voltage 1.3pu for 0.2 sec. Fig 17(a) shows the voltage swell. Fig 17(b) shows the injected voltage by boost transformer in series with supply voltage to compensate voltage swell. Fig 17(c) shows the load voltage after compensate voltage swell by DVR. Fig 30 shows the performance of second topology of DVR by PWM Controller.

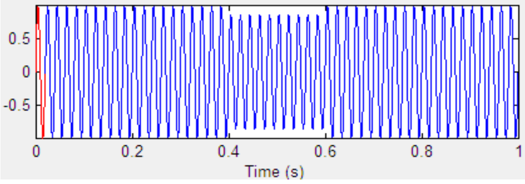

Fig. 17(a): Voltage Sag

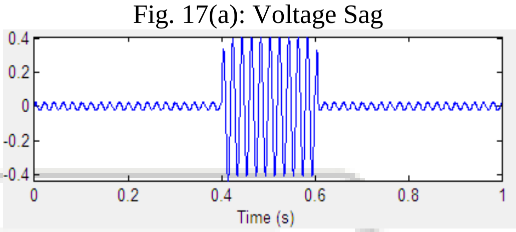

Fig. 17(b): Voltage Injected By DVR With hysteresis controller

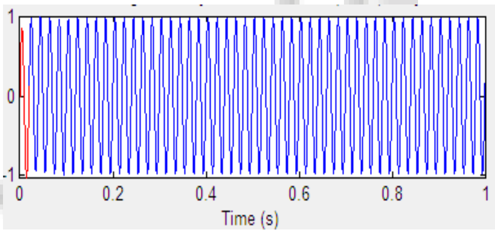

Fig. 17(C): Load Voltage

Fig 31: Three phase Voltage: a) Source voltage b) Injected voltage, c) Load voltage

Fig 18(a) shows the voltage sag. Fig 18(b) shows voltage injected by DVR in system to compensate voltage sag with the help of boost transformer. Fig18(c) represent load voltage after mitigation voltage sags by Hysteresis controller.

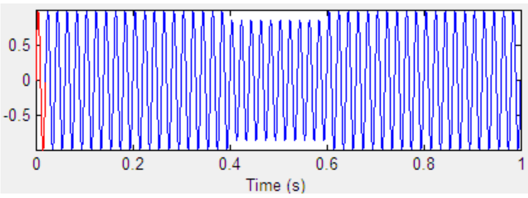

Fig. 18(a): Voltage Sag

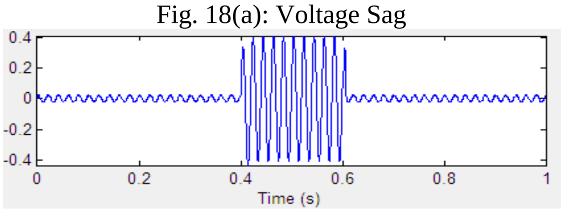

Fig. 18(b): Voltage Injected by DVR With hysteresis controller

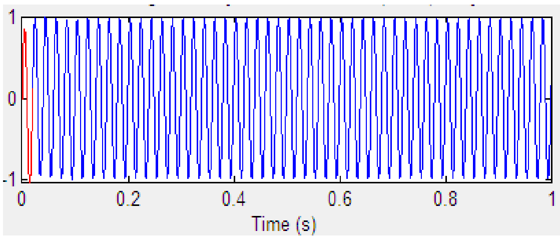

Fig. 18(C): Load Voltage

Fig. 18: Three phase Voltage: a) Source voltage b) Injected voltage, c) Load voltage

3) Value of THD (Without DVR)

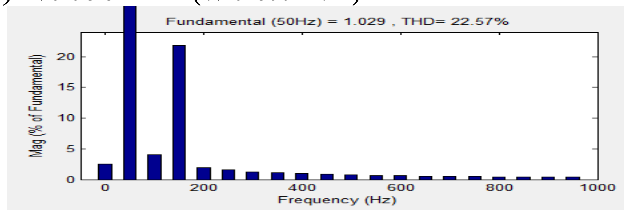

Fig. 19: Value of THD (Without DVR)

4) Value of THD (With DVR)

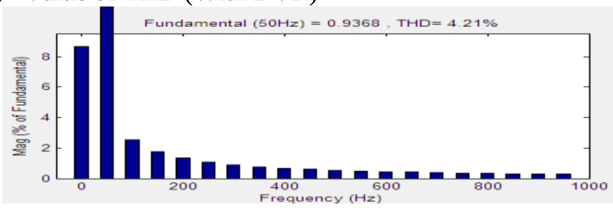

Fig. 20: Value of THD (With DVR)

VII. CONCLUSION

This paper presents a new solution for mitigating voltage sag and swells due to the starting of three phase induction motors and due to three phase RLC load in industrial electric networks. For the problem of voltage compensation like the case under paper's consideration, simulation shows that the DVR performance is satisfactory. The feed forward control technique which is a scaled error of the between source side of the DVR and its reference to trigger the switch of an inverter using (Pulse Width modulation)PWM scheme and Hysteresis voltage control scheme also proves its reliability and suitability for DVR application. It is clear from the result that the power quality of the system with induction motor as a load is increased in the sense that the THD and the amount of THD are decreased with the application of DVR. The simulation result shows that proposed DVR scheme with hysteresis controller is better than PWM controller to compensate voltage sag/swell quickly and provide better performance. This work can be further developed with regards to further different control strategy i.e. PI controller, Fuzzy Controller and the combination with DSTATCOM for including other compensation objectives in industrial distribution systems.

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