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Reduction of Harmonics in Adjustable Speed Driveusing Multi-Objective Photovoltaic Based Dynamic Voltage Restorer

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ABSTRACT
Electronic devices function properly as long as the voltage of the supply system feeding the device stays within a consistent range. There are different types of voltage fluctuations that can cause Power quality problems, including, sags, harmonic distortions, surges and spikes and momentary disruptions, nonstandard voltage, current or frequency that results in a failure or miss operation of end user equipment. The steady-state PQ characteristics of the supply voltage include surges and spikes. Voltage sags and swells are the common events on the electric power network. Voltage sags and swells are the common events on the electric power system. The common causes of voltage sag are short circuit or faults in power system, at starting of large loads and faulty conductor.These problems can be mitigated with voltage injection method using custom power device, Dynamic Voltage Restorer (DVR).A DVR is connected in series with the linear load to compensate for the harmonics and unbalance in the source voltages and improve the power factor on the source sideA series connected converter based mitigation device, the Dynamic Voltage Restorer(DVR), is the most economical and technically advanced mitigation device proposed to protect sensitive loads from voltage sags. In this paper, A control technique for dynamic voltage restorer (DVR) based on DC-link voltage of uncontrolled rectifier fed adjustable speed drive (ASD) is described in this paper. This control technique maintains constant DC-link voltage during harmonics, unbalance, sag and swell. Moreover, using this control technique, voltage harmonic introduced by ASD in utility is also suppressed by DVR during idle mode. A typical topology of ASD, implemented with uncontrolled rectifier is presented in this paper. A mathematical description to generate reference DClink voltage is illustrated in this paper using the dq0 reference frame. A simulation study of the proposed control technique of DVR protecting ASD during source harmonics, unbalance, sag and swell is carried out using MATLAB/Simulink software and results of ASD parameters are presented. Moreover, the simulation results of ASD voltage harmonics mitigation by DVR is also presented. The performance of the proposed technique shows satisfactory results with a less complex control system.
Index Terms—Adjustable speed drives, Power quality, DC link voltage, Voltage sag, Voltage swell, Harmonics, Active filter, Dynamic voltage restorer

(1) Introduction

Voltage, sag and swells are considered to be one of the most severe disturbances to the sensitive loads [1]. Dynamic Voltage Restorer (DVR) is a power electronics device which protects sensitive loads from disturbances in the power supply. It ensures high power quality for sensitive loads. The dynamic voltage restorer has become popular as a cost effective solution for the protection of sensitive loads from voltage sag and voltage swell. It injects voltage in series and synchronism with the grid supply voltage in order to compensate for voltage sag and voltage swell [2]. DVR is connected in series with line through injection transformer. Fig.1 shows the single phase DVR, which is connected in series with feeder. When short circuit fault occurs in load 1, voltage at the distribution bus decreased and voltage sag occurs across the sensitive load 2. To restore the voltage across this load, DVR is used [3]. During the period of voltage sag or swell, DVR injects the voltage so as to restore the load voltage to its normal value. During this operation, the DVR exchanges the active and reactive power with the load. In case of voltage sag, active power has to be supplied by DVR. This motivates the use of energy storage element in the DVR. Various energy storage devices like batteries, capacitors, flywheels etc are used in DVR [4]. However, this increases the cost of DVR. Further, due to presence of battery, regular maintenance is required. Three voltage injection techniques are popularly used in DVR, to restore the phase and magnitude of voltage across the sensitive

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load. These are pre-sag voltage compensation, energy optimization technique and in-phase voltage injection technique. In presag compensation both real and reactive power are required. This method provides the compensation for voltage magnitude and its phase. The difference between sag and presag voltage is detected by DVR and injected voltage, provides compensation for voltage amplitude without any phase shift [5], [6]. This technique mainly used for loads equally sensitive for voltage magnitude as well as phase shift. This technique lead to increment in capacity of energy storage device as the magnitude of voltage to be injected is more. Other technique is zero active power injection technique [7]. This method reduces the energy storage size. Active power PDV R supplied by the DVR depends on the angle between the load current IL and the injected voltage Vinj . In this technique, these two vectors are maintained in quadrature, thereby, ensures PDV R remains almost zero. Only reactive power has to be supplied. This leads to reduction of the size of battery. However, the magnitude of injected voltage is governed by following relation, $\Delta Vsag \leq VL(1 - \cos\varphi)$ (1) From the above relation, it is clear that for the loads with poor pf, it is easier to compensate voltage sag without real power injection. Therefore, proposed technique has limitation to compensate the voltage sag with loads having leading power factor [5], [8], [7]. In-phase voltage injection technique requires, minimum voltage injection to compensates either sag or swell [3]. However, the compensated voltage suffers a phase shift with respect to presag voltage. This technique is not suitable for loads sensitive to voltage phase shift.

2 ADJUSTABLE SPEED DRIVE

ASD is used to have a wide range, speed control of the motor. Mainly, ASD consists of a rectifier, filter circuitry and inverter. There are many different configurations of ASD. Fig. 1 shows ASD implemented with uncontrolled rectifier, LC filter circuitry and pulse width modulation (PWM) inverter. Some ASDs are designed with half controlled or fully controlled rectifier. In some cases, PWM inverter is either 2-level or 3-level H-bridge inverter or multi-level inverter (MLI). In Fig. 1, Ls is the source inductance, D1 - D6 are the diodes of uncontrolled rectifier. Inductor Ld and capacitor Cd are the components of filter circuitry. Filter circuitry is used to remove ripples in DC-link voltage Vdc voltage and to smoothen DClink current. If the motor is considered as induction motor then different speed control strategies like V/F control, fieldoriented method, direct torque method, etc, are debugged in microcontroller and desired PWM gate signals are generated to drive inverter. In this paper, V/F control technique is used to

drive induction motor. Different PQD ride through techniques for ASD are discussed in [12].

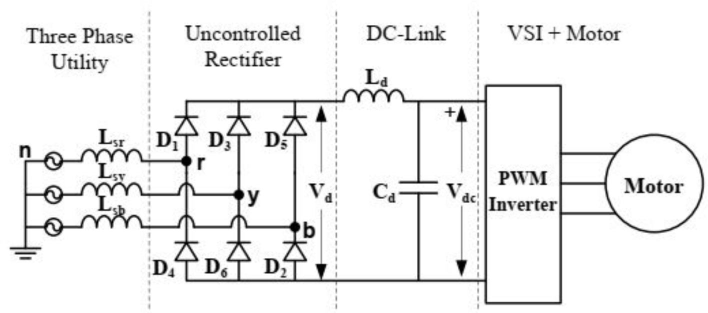

Fig. 1. Typical topology of ASD with uncontrolled rectifier

3 DESCRIPTION OF DYNAMIC VOLTAGE RESTORER

DVR can mitigate voltage related PQD efficiently [4], [13], [14]. However, it can also be used to mitigate voltage harmonics [15], [16]. To protect ASD (sensitive load) from different voltage power quality disturbances like sag, swell, unbalance and source harmonics, a DVR is connected in series between PCC and ASD as shown in Fig. 2. DVR consists of a ripple circuit (Rf; Cf), injection transformer, interfacing inductor (Lf), voltage source converter (VSC) along with

microcontroller and a DC power supply as an energy storage device. Injection transformer is used to connect DVR in series with ASD as well as to inject voltage. Ripple filter circuitry is used to reduce harmonics from injected voltage. Interfacing inductor is used to restrict the maximum ripple current allowed in the primary of injection transformer. Due to the advantages of a multi-level inverter over conventional H-bridge inverter, a set of three phase five-level transistor-clamped H-bridge (TCHB) multi-level inverter (MLI) is used as a VSC of DVR in this paper as shown in Fig 3. The switching states of switches to generate five-level voltage output for TCHB MLI is given in table 1. A single carrier with two references is compared to generate the desired switching pulses [17]

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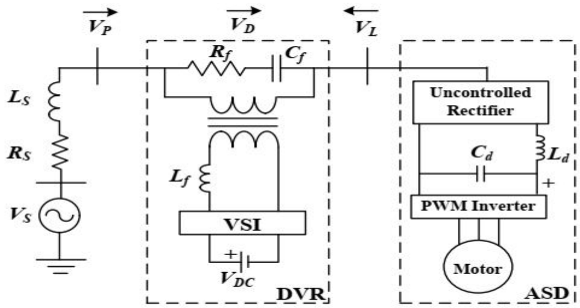

Fig.2. Block diagram of DVR with ASD system

TABLE 1

FIVE LEVEL TCHB INVERTER SWITCHING STATES

Switching state					
S_1	S_2	S_3	S_4	S_5	Output Voltage
0	1	0	0	1	$+V_{dc}$
1	0	0	0	1	$V_{dc}/2$
0	0	1	0	1	0
0	1	0	1	0	0
1	0	0	1	0	$-V_{dc}/2$
0	0	1	1	0	$-V_{dc}$

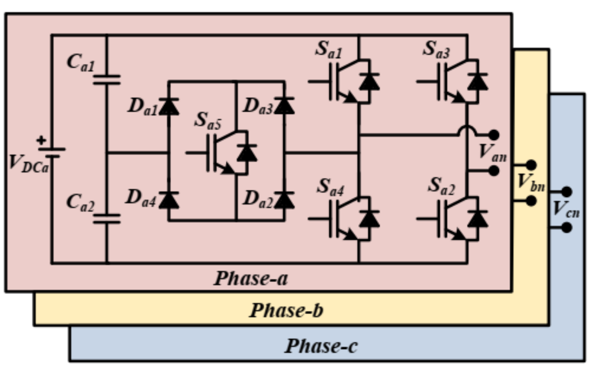

Fig. 3. A set of three TCHB MLI as a three phase VSC of DVR

4 MATHEMATICAL DESCRIPTION OF GENERATION OF REFERENCE DC-LINK VOLTAGE OF ASD

If Vm is the maximum amplitude of voltage, !e is the angular frequency and δ is the angle between PCC voltages and the load voltages during disturbance then the equations of three phase load voltages are

$$v_{La} = V_m sin(\omega_e t + \delta_a) \tag{1}$$

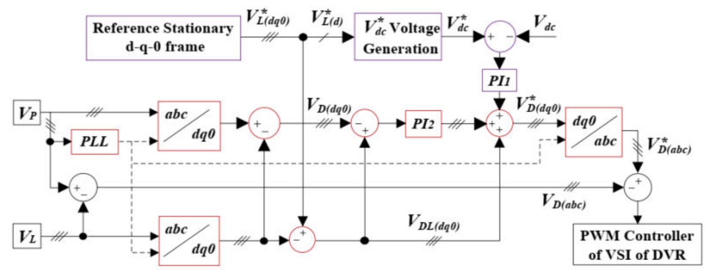

Fig. 4. Block diagram of DC-link voltage controller for DVR of uncontrolled rectifier fed

ASD.

$$v_{Lb} = V_m sin(\omega_e t + \delta_b - \frac{2\pi}{3}) \tag{2}$$

$$v_{Lc} = V_m sin(\omega_e t + \delta_c + \frac{2\pi}{3}) \tag{3}$$

For unsymmetrical voltage sag with phase angle jump, δa, δb and δc are not equal. During healthy condition, δ is equal to zero. Hence, reference load voltage is equal to the load voltage during healthy condition. If Vm∗ is the maximum amplitude of voltage during healthy condition then (1)-(3) are given as

$$v^*_{La} = V^*_m sin(\omega_e t)$$
$$v^*_{Lb} = V^*_m sin(\omega_e t - \frac{2\pi}{3})$$
$$v^*_{Lc} = V^*_m sin(\omega_e t + \frac{2\pi}{3}) \tag{4}$$

Using Park's transformation, a-b-c frame is converted into the stationary reference d-q-0 frame as below,

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$$\begin{bmatrix} v^*_{Ld} \\ v^*_{Lq} \\ v^*_{L0} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} sin\theta & sin(\theta - \frac{2\pi}{3}) & sin(\theta + \frac{2\pi}{3}) \\ cos\theta & cos(\theta - \frac{2\pi}{3}) & cos(\theta + \frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} v^*_{La} \\ v^*_{Lb} \\ v^*_{Lc} \end{bmatrix}$$

$$v^*_{Ld} = \frac{2\pi}{3}[v^*_{La}sin\theta + v^*_{Lb}sin(\theta - \frac{2\pi}{3}) + v^*_{Lc}sin(\theta + \frac{2\pi}{3})]$$

(5)

where, θ is the angle between d-q-0 frame and a-b-c frame. If θ is equal to zero [8], then equation (8) will be

$$v^*_{Ld} = \frac{2}{3}[-v^*_{Lb}sin(\frac{2\pi}{3}) + v^*_{Lc}sin(\frac{2\pi}{3})]$$

$$v^*_{Ld} = \frac{2}{3}[-\frac{\sqrt{3}}{2}v^*_{Lb} + \frac{\sqrt{3}}{2}v^*_{Lc}]$$

$$v^*_{Ld} = \frac{1}{\sqrt{3}}[-v^*_{Lb} + v^*_{Lc}]$$

(6)

By substituting the values of vLb ∗ and vLc ∗ from equation

$$v^*_{Ld} = \frac{V^*_m}{\sqrt{3}}[sin(\omega_e t + \frac{2\pi}{3}) - sin(\omega$$

(7)

$$v^*_{Ld} = \frac{V^*_m}{\sqrt{3}}[\{sin(\omega_e t) \cdot cos(\frac{2\pi}{3}) + cos(\omega_e t) \cdot si$$

$$- \{sin(\omega_e t) \cdot cos(\frac{2\pi}{3}) - cos(\omega_e t) \cdot sin($$

$$v^*_{Ld} = \frac{V^*_m}{\sqrt{3}}[\frac{\sqrt{3}}{2}cos(\omega_e t) + \frac{\sqrt{3}}{2}cos(\omega_e t)$$

$$v^*_{Ld} = V^*_m cos(\omega_e t)$$

(8)

consider, the system operating frequency is 50 Hz then the time taken by signal to complete one cycle will be 20 ms and the angular frequency will be 100π rad/s.

$$v^*_{Ld} = V^*_m$$

(9)

From equation (9), it is clear that in the reference stationary frame v∗Ld is equal to the maximum amplitude of voltage during healthy condition. Similarly, vLq ∗ and vL∗ 0 are equal to

zero during healthy condition. The DC-link voltage of ASD for three phase uncontrolled bridge rectifier is given as

$$V^*_{dc} = \frac{3\sqrt{6}}{\pi}v^*_{ph}$$

$$V^*_{dc} = \frac{3\sqrt{3}}{\pi}V^*_m$$

(10)

Therefore, the reference DClink voltage of ASD is given as

$$V^*_{dc} = \frac{3\sqrt{3}}{\pi}v^*_{Ld}$$

(11)

5) MATLAB/SIMULINK RESULTS:

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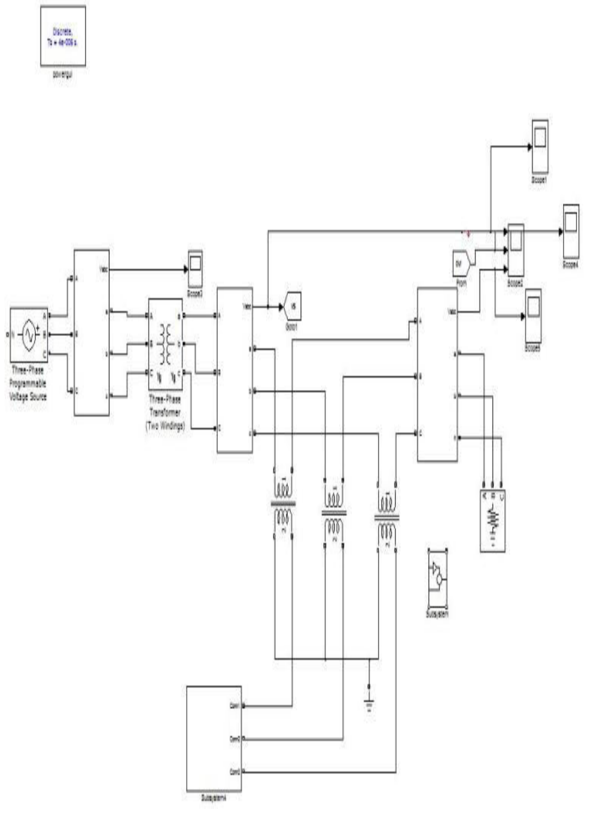

Fig 4 Simulink daigaram of proposed system with sag Condition

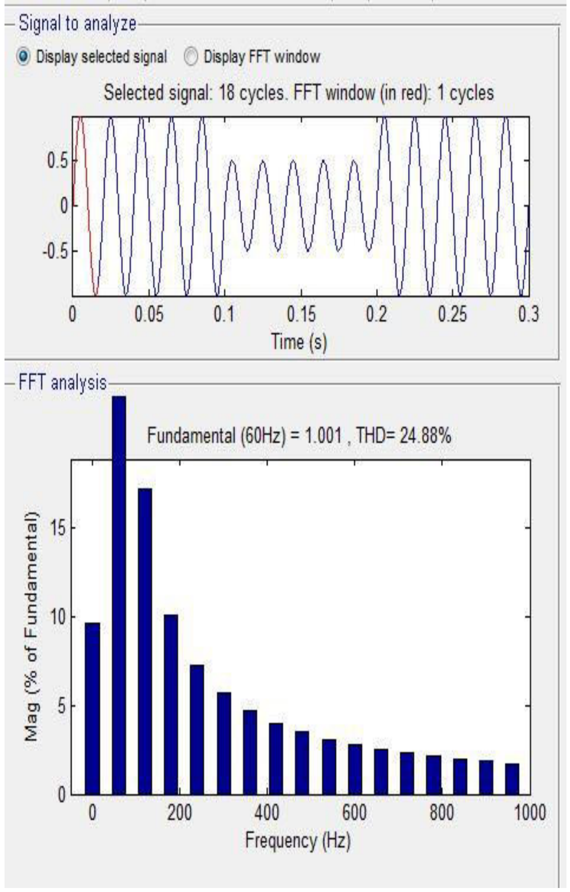

Fig 6 FFT analysis Source voltage

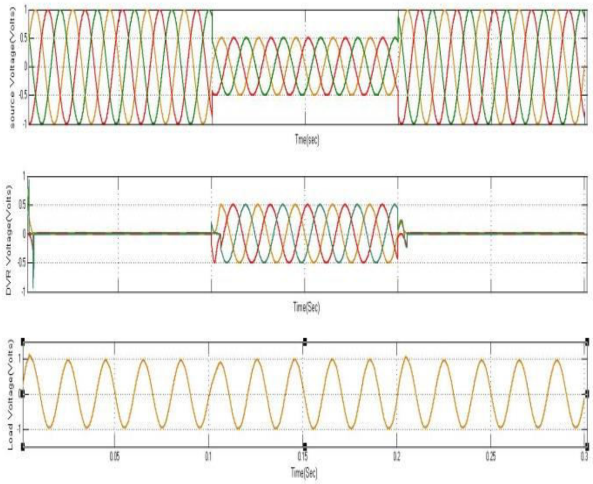

Fig. 5 Simulation Wave forms of load voltages by DVR with sag condition (a) source Voltages, (b) DVR Voltages and (c)Load Voltages

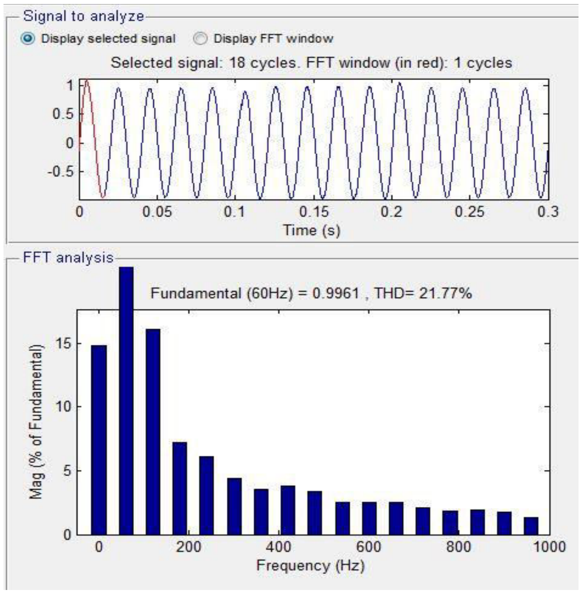

Fig 7 FFT analysis Load voltage

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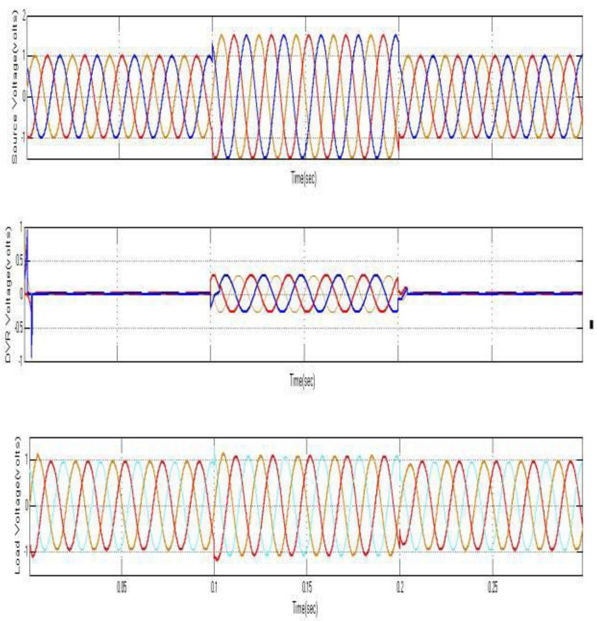


Fig. 8 Simulation Wave forms of load voltages by DVR with swell condition (a) source Voltages, (b) DVR Voltages and (c)Load Voltages

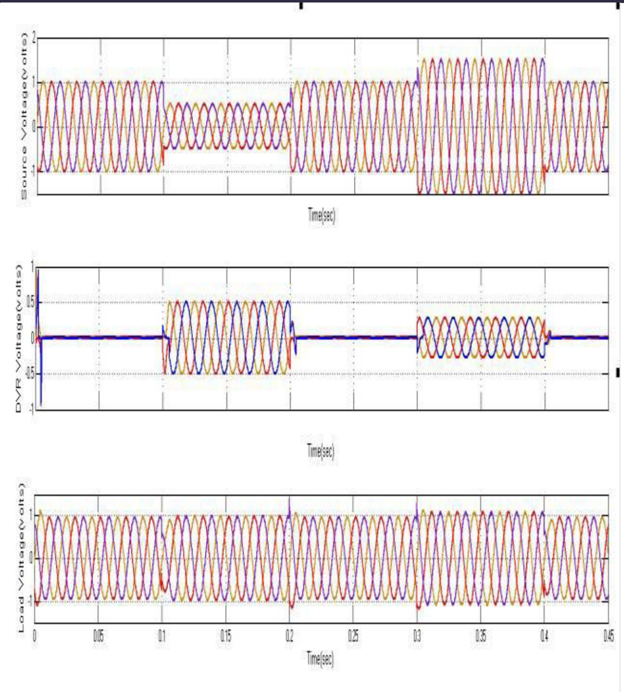


Fig. 10 Simulation Wave forms of load voltages by DVR with sag-swell condition (a) source Voltages, (b) DVR Voltages and (c)Load Voltages

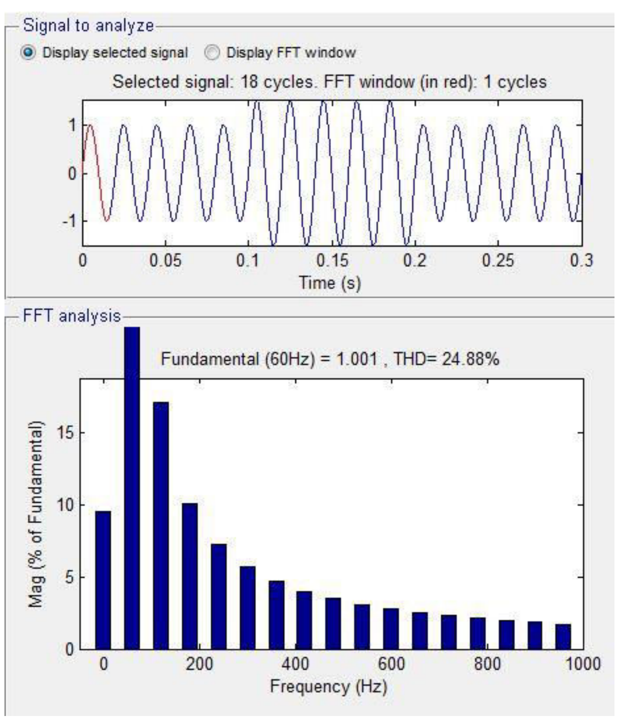


Fig 9 FFT analysis Load voltage of proposed system with swell condition

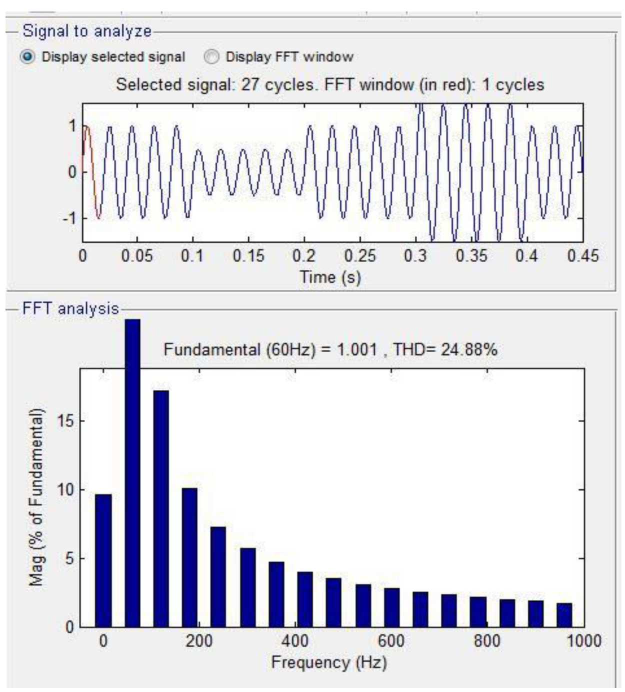


Fig 11 FFT analysis Load voltage of proposed system with sag-swell condition

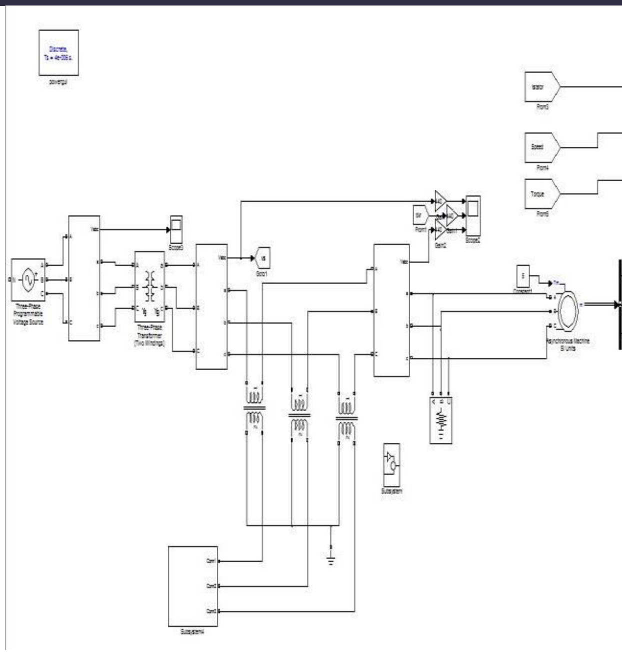


Fig 12 Simulink daigaram of proposed system with sag Condition applied in Induction Motor Drive

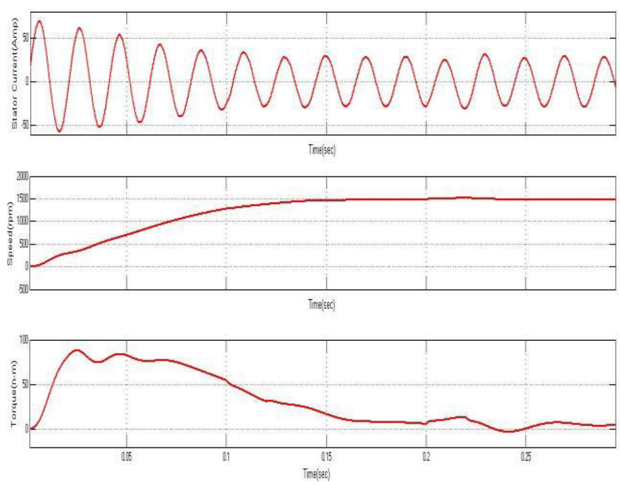
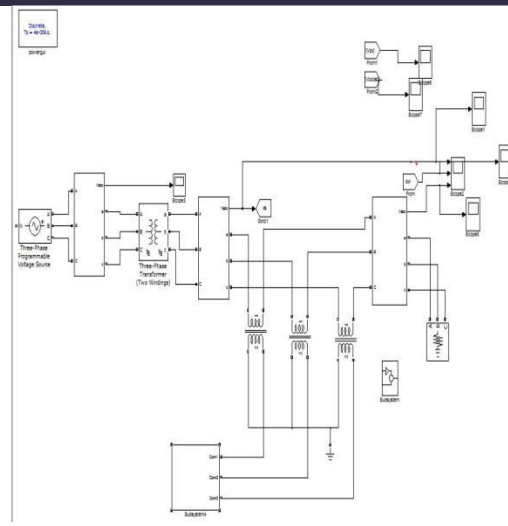
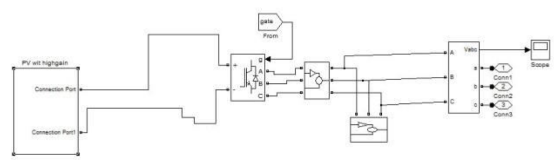


Fig 13 Simulation wave form of proposed system of Induction Motor Charcteristics



(a)



(b)

Fig 14 Simulink daigaram of proposed system with sag Condition applied With PV Cell

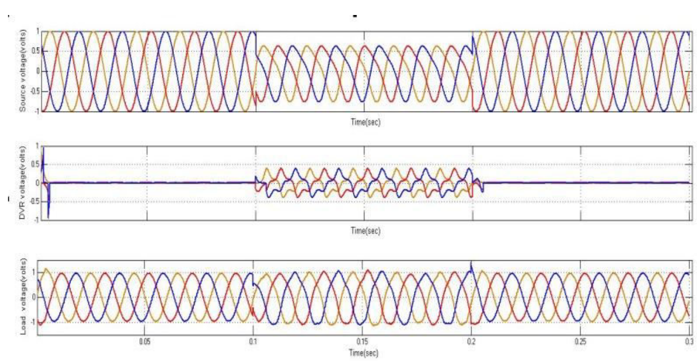


Fig. 15 Simulation Wave forms of load voltages by DVR with sag condition with PV Cell (a) source Voltages, (b) DVR Voltages and (c)Load Voltages

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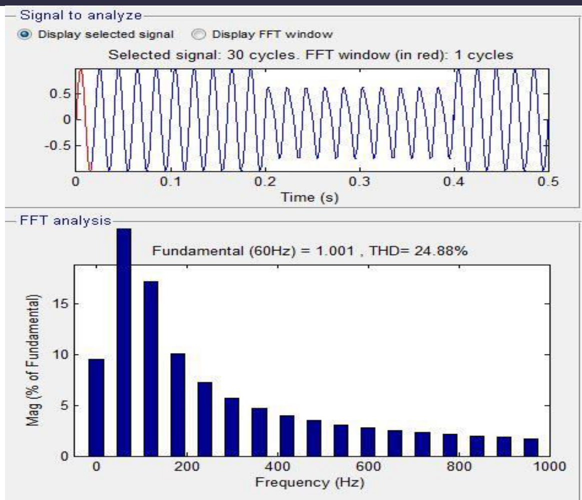

Fig 16 FFT analysis Load voltage of proposed system with PV Cell in sag condition

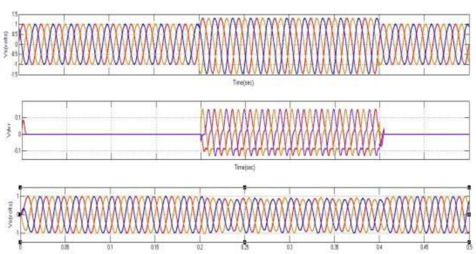

Fig. 17 Simulation Wave forms of load voltages by DVR with sag condition with PV Cell (a) source Voltages, (b) DVR Voltages and (c)Load Voltages

(6) CONCLUSION

In this paper, a DC-link voltage control algorithm based DVR, specially designed for uncontrolled rectifier fed ASD is developed using dq0 stationary reference frame. This control technique continuously monitors DC-link voltage of ASD and maintains it to the reference value, such that the ASD performance should not alter. From the simulation study, DVR based on the proposed control technique is used to mitigate voltage related PQD like source harmonics, unbalanced, sag and swell occurred on PCC. Hence, the operation of ASD is not affected, as the variation in DC-link voltage, stator current, electromagnetic torque and rotor speed are nearly negligible.

Furthermore, the proposed technique allows the speed of the motor to remain in its permissible limit during any PQD, which is a critical factor in continuous process operation. Moreover, from the simulation results, DVR is also capable to mitigate voltage harmonics generated by non-linear load like ASD. The proposed control algorithm is working effectively by maintaining constant DC-link voltage of ASD when PQD occurred on PCC as well as it is able to suppress the harmonics generated by ASD

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