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Voltage Sag Mitigation in a Three-Phase Induction Motor using DSTATCOM and DVR

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Voltage sag in distribution system is one of the most frequently occurring power quality problem, There are many solutions to mitigate voltage sag. This paper describes one such technique to mitigate voltage sag occurring during the starting of three-phase induction motor by using power electronic devices called Dynamic Voltage Restorer (DVR) and Distribution Static Compensator (DSTATCOM). This paper is organized with a brief introduction of voltage sag and its characteristics, structure and control principles of DSTATCOM and DVR. The performance of both DSTATCOM and DVR to mitigate voltage sag caused by starting of three phase induction motor is observed and compared. The simulation models of both the devices are analyzed and results are shown.

Keywords: *Voltage sag, three-phase induction motor, Dynamic voltage restorer (DVR), Distribution Static compensator (DSTATCOM), Starting current.*

1.0 INTRODUCTION

One of the most common power quality problems in distribution system is voltage sag. Voltage sag is a rms reduction in ac voltage at power frequency, for duration from a half-cycle to a few seconds [1]. Magnitude and duration are its two significant characteristics. Figure. 1 shows magnitude and duration of voltage sag. Voltage sag occurs in distribution system due to two main causes.

(i) Line to ground fault

(ii) Starting of motor

Line to ground fault results into voltage sag of short duration (approximately 10 ms) and small magnitude (equal to 10%). In other case during motor starting, voltage sag is of smaller magnitude and long duration up to 600ms.

Some solutions for voltage sag compensation have been presented earlier: shunt injection of reactive current and series injection of voltage. Devaraju *et al.* [2], in their paper, have discussed about modeling of custom power devices to mitigate power quality problems. The authors A.F. Huweg S.M. Bashi and N. Mariun [3] have discussed modeling of STATCOM to improve voltage sag due to starting of high power induction motor.

This paper focuses on voltage sag caused during starting of three-phase induction motor. The large inrush of starting current in induction motor results in voltage sag, which in turn causes speed reduction and torque oscillations.

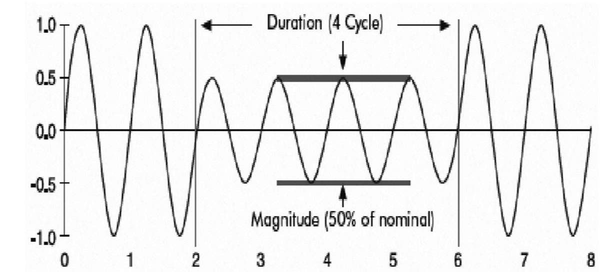

FIG. 1 VOLTAGE SAG MAGNITUDE AND DURATION

At present, a wide range of very flexible controllers are available to mitigate voltage sag. Among these,

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the distribution static compensator (DSTATCOM) and the dynamic voltage restorer (DVR) are most effective controllers, both of them are based on the VSC principle. DVR injects series voltage to the system, whereas DSTATCOM injects shunt current. For this, DVR is connected in series with the system,whereas DSTATCOM connected in shunt.

2.0 BASIC CONFIGURATION OF DISTRIBUTION STATIC COMPENSATOR (DSTATCOM)

The Distribution a Static Compensator (DSTATCOM) is, shunt connected power electronics based device. It is connected near the load at the distribution systems. The basic electronic block of the DSTATCOM is the voltage Source Converter (VSC) that converts an input DC voltage into a three-phase AC output voltage at fundamental frequency [4].

Basically, DSTATCOM consists of a Voltage Source Converter (VSC), a DC capacitor for energy storage, a coupling transformer and associated control circuits. The coupling transformer leakage inductances function as coupling reactors. The main purpose of the coupling reactors is to filter out the harmonic current components of the pulsating output voltage of the power converters. The AC voltage difference across the leakage inductance produces reactive power exchange between the DSTATCOM and the system. Figure 2 shows the schematic representation of the DSTATCOM.

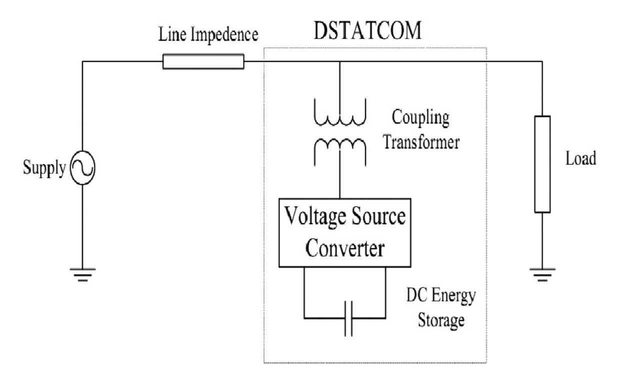


FIG. 2 SCHEMATIC DIAGRAM OF DSTATCOM

The main objective of VSC is to convert the DC voltage across the capacitor into a set of 3-phase AC output voltage. These voltages are in phase and coupled with the AC system through the coupling reactor. The effective control of active and reactive power exchanges between the DSTATCOM and the AC system can be achieved with the suitable adjustment of the phase and voltage magnitude of the DSTATCOM output voltage.

2.1 Operation OF DSTATCOM

The operation of the DSTATCOM is as follows:

- When the voltage magnitude of AC system is above the DSTATCOM output voltage, the current flows through the transformer reactance from the AC system to the DSTATCOM, resulting in the device absorbing reactive power (inductive).
- Otherwise, if the voltage magnitude of the DSTATCOM output voltage is above the AC system voltage, the current flows from the DSTATCOM to the AC system, resulting in the device generating reactive power (capacitive).
- If the voltage magnitudes of the DSTATCOM and the AC system are equal, the reactive current is zero and the DSTATCOM does not generate/absorb reactive power.

The DSTATCOM can supply real power to the power system if it has a DC source or energy storage device on its DC side. This can be accomplished by adjusting the phase angle of the DSTATCOM terminals and the phase angle of AC power system. The DSTATCOM absorbs real power from the AC power system when phase angle of AC power system leads the VSC phase angle. It supplies real power to the AC power system when the phase angle of AC power system lags VSC phase angle [5].

2.2 Reactive Power Control Using DSTATCOM

The principle of reactive power control by using DSTATCOM is that the amount of reactive power (capacitive or inductive) exchange between the DSTATCOM and the system can be adjusted by controlling the magnitude of DSTATCOM output voltage with respect to that of system voltage [6].The reactive power supplied by the DSTATCOM is given by equation (1).

$$Q = \frac{V_{DSTACOM} - V_S}{X} \times VS....... \quad (1)$$

where Q = reactive power;

$V_{DSTATCOM}$ = magnitude of DSTATCOM output voltage.

V_S = magnitude of system voltage;

X = Equivalent impedance between DSTATCOM and the system.

When Q is positive, the DSTATCOM supplies reactive power to the system. On the other hand, DSTATCOM absorbs reactive power from the system when Q is negative.

3.0 BASIC CONFIGURATION OF DYNAMIC VOLTAGE RESTORER (DVR)

A Dynamic Voltage Restorer (DVR) is a series device that generates an AC voltage and injects it in series with the supply voltage through an injection transformer to compensate the voltage sag. The injected voltage and load current determine the power injection of the DVR. The DVR provides a three-phase independently-controlled voltage source, whose voltage vector (magnitude and angle) adds to the source voltage to restore the load voltage to pre-sag conditions.

The power circuit of the DVR is shown in Figure 3. The DVR consists of mainly a three-phase Voltage Source PWM inverter, coupling transformer, passive filter and energy storage unit [7]. The DVR employs the same blocks as the DSTATCOM, but in this application the coupling transformer is connected in series with the AC system.

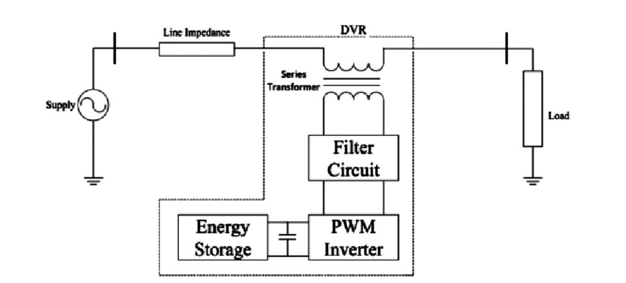


FIG. 3 SCHEMATIC DIAGRAM OF DVR

The voltage source-controlled PWM inverter generates a three-phase AC output voltage, which is controllable in phase and magnitude. These voltages are injected into the ac distribution system in order to maintain the load voltage at the desired voltage reference. Filter circuit eliminates the harmonics presented in the inverter output voltage and produces pure sinusoidal AC voltage.

3.1. Control Scheme OF DVR

The block diagram of the proposed controller for the DVR is shown in Figure 4. In the control circuit, comparator subtracts rms value of load voltage from reference rms voltage and generates error signal.

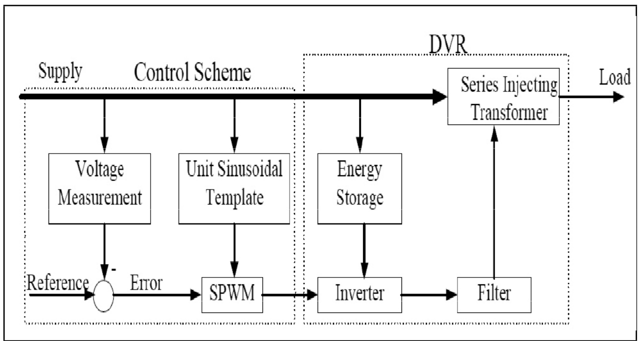


FIG. 4 THE BLOCK DIAGRAM OF THE PROPOSED CONTROLLER FOR THE DVR

The sinusoidal PWM scheme is used here to control the inverter. In SPWM, pulses are generated by comparing high -frequency triangular (carrier) signal, with sinusoidal signal which is generated by multiplying unit magnitude sine wave with error generated by comparator.

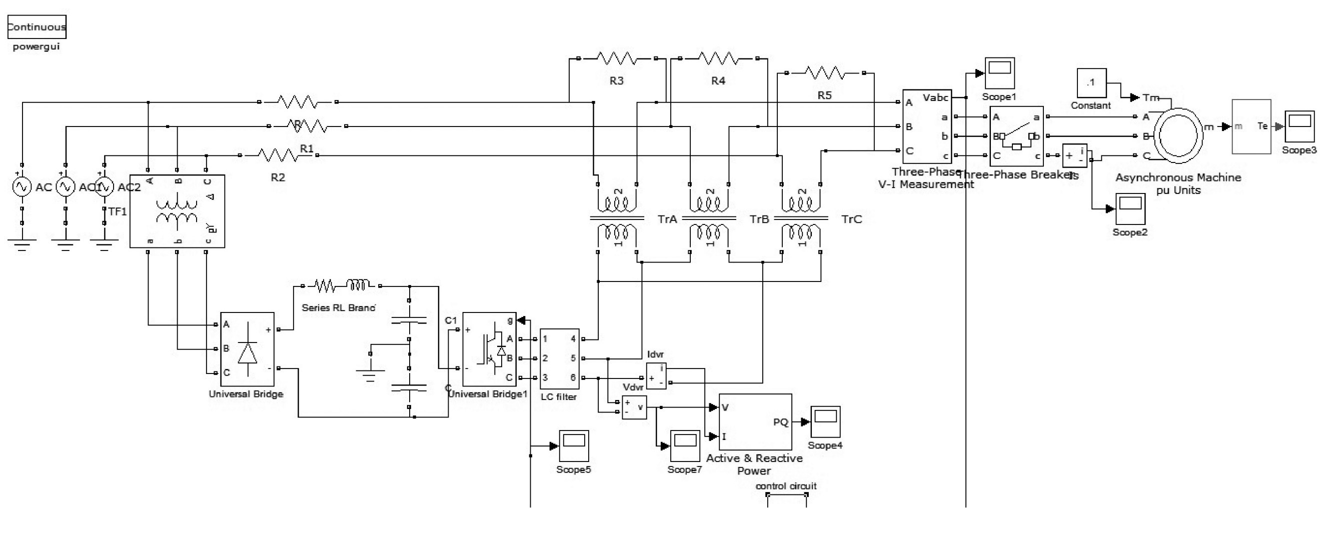


FIG. 5 MATLAB/Simulink model of DSTATCOM with 3-phase induction motor

The unit magnitude sine wave has been taken from the supply with the help of unit sinusoidal template. The inverter in this study is a six-pulse inverter and the thyristors used are chosen to be of type Integrated Gate Bipolar Transistors (IGBT) for their fast response and robust operation.

The line voltage is rectified and the DC energy is stored in large capacitor banks. The SPWM inverter takes input DC voltage from these capacitor banks. The filter circuit purifies inverter output and this filtered voltage is injected into the system through series transformers. Here, three single-phase injection transformers are used to inject the required voltage to the system at the load terminals.

4.0 SIMULINK MODEL OF DSTATCOM WITH INDUCTION MOTOR

The simulink model of DSTATCOM [8] with a 3-phase induction motor is shown in Figure 5. The standard values of system parameters are incorporated in Table 1. The line and source impedance are assumed to be purely resistive. a Three-phase CB is used for direct online starting of induction motor. In the proposed model, a capacitor is used as a DC source to supply the DC voltage to the inverter. An uncontrolled six diodes-based rectifier is used to keep the capacitor charged to the required level. The firing pulses for thyristorized converter are generated by synchronized six-pulse generator. Coupling transformers are used to couple the DSTATCOM to the supply lines.

TABLE 1

SYSTEM PARAMETERS

Sl. No.	System parameters	Standards
1	Line voltage	415 V (rms)
2	Line resistance	2 Ω
3	Load	415 V, 5 kW, 3-ph,4-pole IM

5.0 SIMULINK MODEL OF DVR WITH INDUCTION MOTOR

The simulink model of DVR with a 3-phase induction motor is shown in Figure 6. Here, the required energy for compensation of load voltage during sag can be taken from the supply line through a rectifier and a capacitor. The firing pulses for PWM inverter are generated by control circuit which was discussed earlier in Section 3.1.

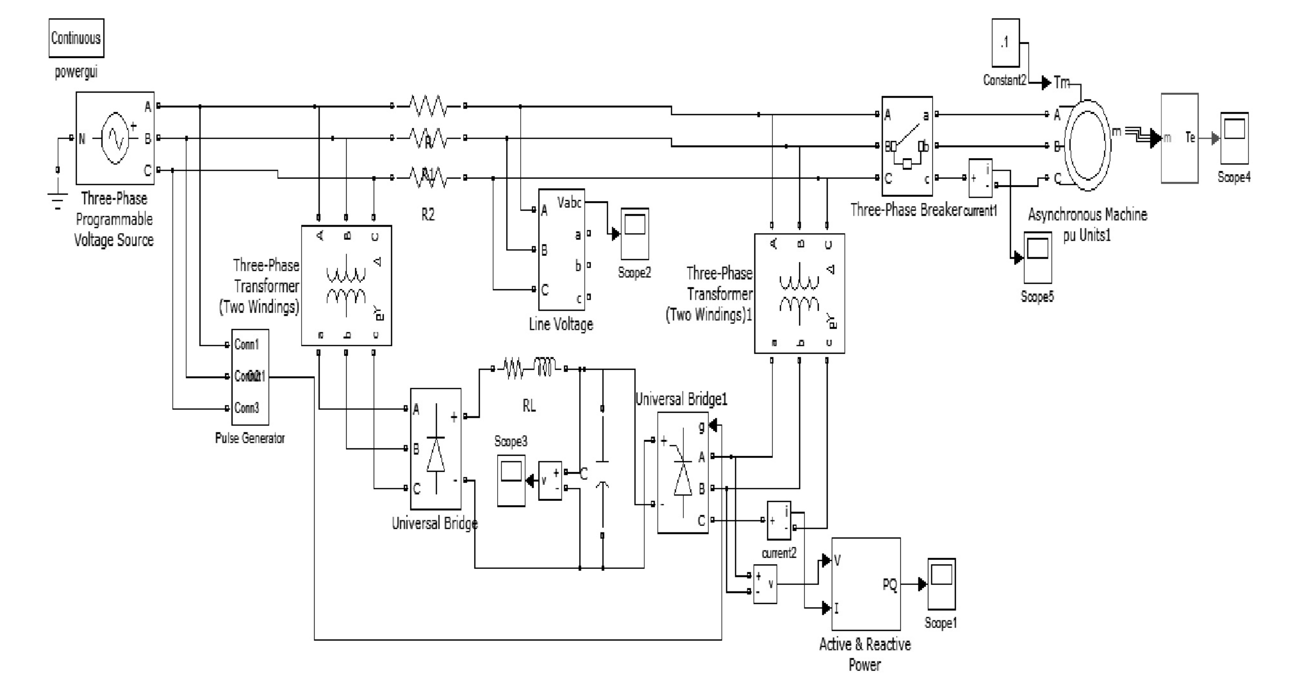
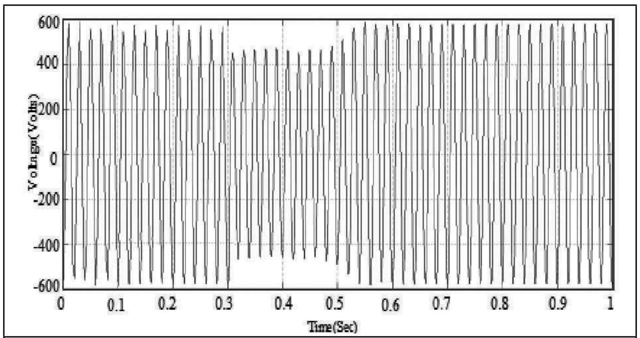


FIG. 6 MATLAB/SIMULINK MODEL OF A DVR WITH 3-PHASE INDUCTION MOTOR

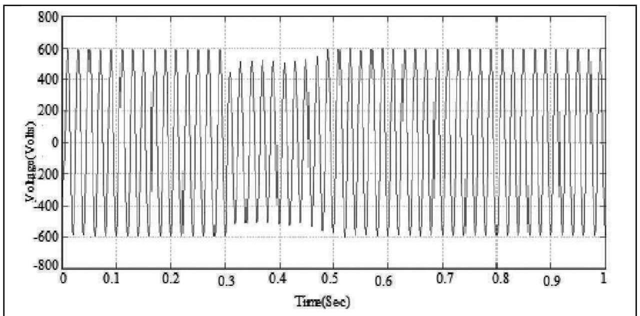
6.0 SIMULATION RESULTS

Initially, the 3-phase, 5 kW, 415 V, 50 Hz, 4-pole, squirrel cage induction motor performance is observed and then it is operated with DSTATCOM and DVR. The CB is set initially open and it is closed at 0.3 sec.

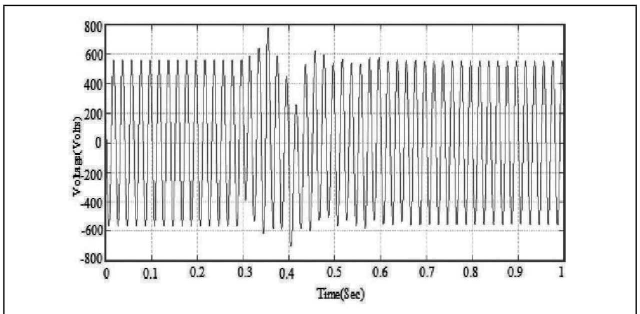
Figure 7 shows the line voltage of the induction motor without any controller and with proposed controllers. It can be observed that with DSTATCOM and DVR the depth and duration of voltage sag are reduced. On comparing the line voltage of system with DSTATCOM and DVR, it is determined that DVR is giving better performance.



(a)



(b)

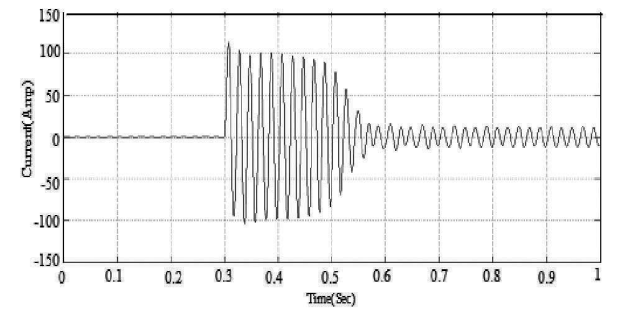


(c)

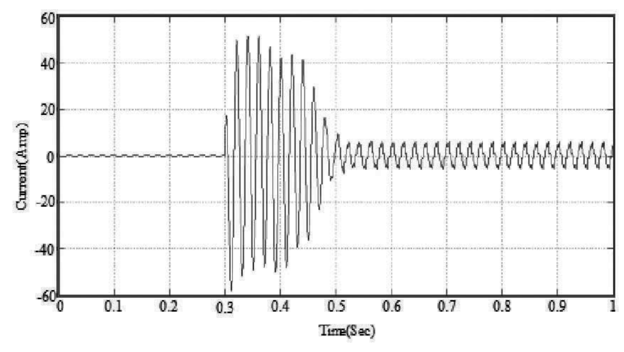
FIG. 7 LINEVOLTAGE(A)WITHOUTANYCONTROLLER (B) WITH DSTATCOM (C) WITH DVR

Figure 8 shows variation of induction motor stator current without and with controllers. From Figure 8(a) it is observed that when induction motor is started without any controller,its stabilization period is prolonged i.e. current takes more time to achieve steady state. Figures 8(b) and 8(c) shows the motor current with DSTATCOM and DVR. From these figures it is seen that induction motor starting duration is reduced, i.e. in this case, current takes much less time to stabilize.

Figure 9 shows variation of induction motor torque without and with controllers. Figure 8(a) shows that when induction motor is started without any controller, in this case the electromagnetic torque developed by the motor at starting is less. Figures 9(b) and 9(c) shows the motor torque with DSTATCOM and DVR. From these figures it is seen that when induction motor is started with DSTATCOM and DVR, the electromagnetic torque developed by the motor at starting is higher. Comparatively, the starting



(a)



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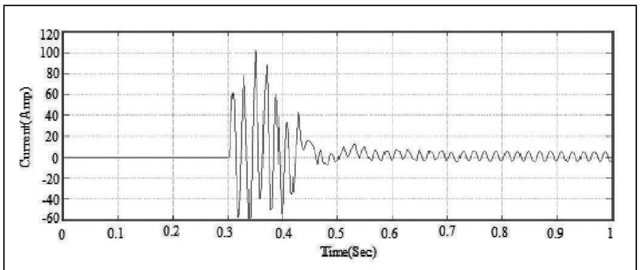
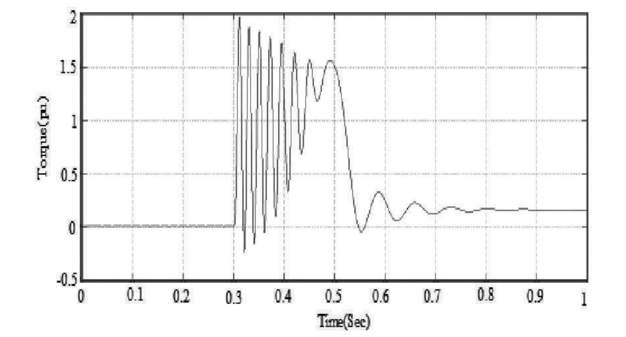
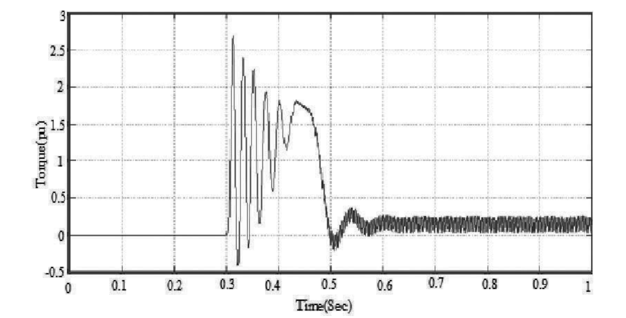


(c)

FIG. 8 INDUCTION MOTOR STATOR CURRENT (A) WITHOUT ANY CONTROLLER (B) WITH DSTATCOM (C) WITH DVR



(a)



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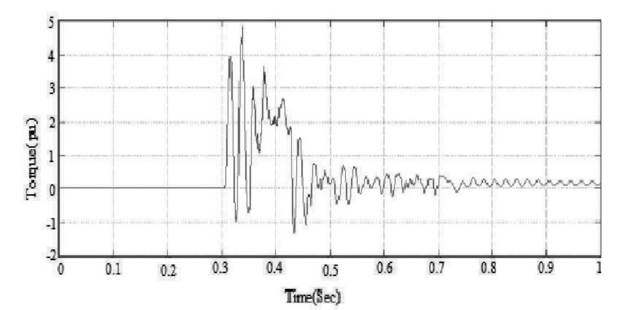

(c)

FIG. 9 INDUCTION MOTOR TORQUE (A) WITHOUT ANY CONTROLLER (B) WITH DSTATCOM (C) WITH DVR

TABLE 2				
OBSERVATIONS				
Sr. No.	**Parameters**	**Without any controller**	**With DSTATCOM**	**With DVR**
1	Sag magnitude	12%	6%	3 to 4%
2	Sag duration	0.25 sec	0.2 sec	0.1 sec
3	Starting current	100 A (peak)	50 A (peak)	60 A (peak)
4	Starting torque	1.8 p.u.	2.7 p.u.	4 p.u.

torque of the induction motor with DVR is higher than DSTATCOM. When induction motor is operating with control devices, the simulation results showing oscillations in electromagnetic torque in the steady state are caused by the power electronics converter. The comparative results regarding the above-mentioned simulation results are incorporated in Table 2.

7.0 CONCLUSIONS

Through this paper ,a basic configuration and principle of two power electronic converters DSTATCOM and DVR used for voltage sag mitigation are studied. Simulation models of DSTATCOM and DVR to compensate voltage sag occurring during starting of three-phase squirrel cage induction motor are presented.

The performance of three-phase induction motor is observed with and without controllers. In all three cases ,line voltage, stator current and torque developed by induction motor are recorded. The results obtained in all the three cases are compared and analyzed.

The analysis of results shows reduction, in magnitude and duration of voltage sag. The starting current is stabilized in short duration and also motor starting torque is increased with control devices. On comparing the performance of DSTATCOM and DVR to mitigate voltage sag, it is determined that DVR is giving better performance.

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