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Comparative Study of Various Adjustable Speed Drives during Voltage Sag

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ABSTRACT

This Paper compares the sensitivity of various adjustable speed drives to voltage sag for the process control applications. Three phase voltage sag of type B caused due to SLG fault is considered and four topologies of ASD's are compared in this paper. The comparison is done especially in speed, voltage, current and torque of the ASDs. Diode rectifier without z source inverter, diode rectifier with z source inverter, single phase two leg Vienna rectifier and single phase neutral linked Vienna with z source inverter are compared and the best one is highlighted. The circuits of various ASD's are simulated using Matlab /Simulink.

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1. INTRODUCTION

Adjustable Speed Drives (ASD) systems are widely used due to their improved efficiency, availability and reliability they offer. In the past years due to better electronics components and topology the performance of ASD's has improved. The ASD's provide benefits such as improved process control, energy savings, simple maintenance and automated diagnostic [1]. However, ASD's are much sensitive to power quality disturbances such as voltage sag, swell, transients and momentry interruptions [2-3]. Voltage sags are one of the most important power quality problem in ASD [4]. A voltage sag is a momentry decrease os 10% - 90% in the RMS voltage magnitude for a duration from 0.5 cycles to 1 minute [9]. Voltage sag of type B due to single line to ground fault (SLG) is the most frequently occurred voltage sag [2]. In the electric motors speed loss, peak current and torques are the major effect produced by voltage sags [5]. Hence, the ASD's must be compatible to withstand the voltages a disturbance [6].

The existing topologies to achieve ride through during voltage sags are adding more capacitors to the DC bus, ride through using load inertia [1]. Adding more capacitors to the DC bus is a simple and rugged method but it's cost is high and a large cabinet space is required [7]. The load inertia maintains the DC bus voltage to a specified value for few seconds that does not exceed 20% [7]. The nonlinear loads in ASD's inject harmonics and result in reduced power factor. The active power filters improve the distorted power factor [14].The ride through capability of ASD's can be increased by the use square-wave SVC [15].

A boost converter between the rectifier and the Dc-link capacitors can be used to maintain the Dc bus voltage during voltage sag [8]. Even though this method provides ride through with lower cost, it fails during outages [1]. The diode rectifier can be replaced with an PWM rectifier in order to provide ride through up to 50% sag but it also fails during outages [1]. Vienna rectifier is a boost type three level converter [10]. Single phase neutral linked Vienna rectifier is a combination of a single phase AC/DC boost converter and a neutral link [11]. The neutral in the Dc bus doubles the voltage and acts as a voltage doubler [12]. This modified topology of Vienna rectifier has n advantage of low harmonic injection, controlled output voltage and power factor improvement [10]. The Dc link also gets affected by the voltage sag and hence the back end inverter will be affected. Due to this the switching pattern of the inverter will get affected, which leads to reduction of speed in the motor. To overcome this problem Z source inverter can be connected at the backened of the ASD. The Z source inverter can boost or buck the dc bus voltage to a desired output voltage [13].

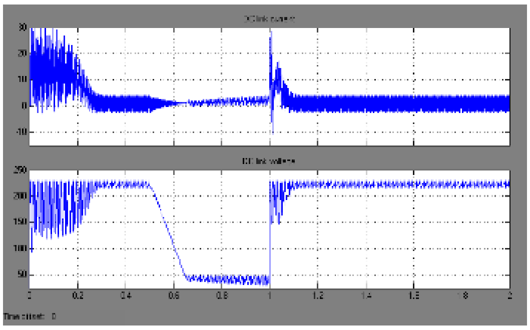
2. COMPARISON OF ASD

The Core idea of this paper is to make out a comparison between various ASD topologies during voltage sag which differ from one another in terms of its performances and internal composure. Four topologies say, diode rectifier with and without z source inverter, single phase two leg Vienna rectifier and single phase neutral linked Vienna rectifier with z source inverter are compared based on Dc link voltage, rotor and stator current, RMS AC output voltage, speed and electromagnetic torque during voltage sag condition.

3. COMPARISON OF PARAMETERS

3.1. Comparison of DC Link

The DC link parameters such as the voltage and the current are monitored for different rectifiers and the observed readings are criticized after through study. The DC link voltage of the diode rectifier without Z-source decreases to 50 Volts as in Figure 1(a) and stays there for a while before saturating around 235 V, the diode rectifier with Z-source shows an improvement by staying by a little bit time lesser than the previous one at the 50 V range before going into saturation around 235V as in Figure 1(b). The single phase two leg Vienna rectifier stays at the 125V for a small time then it recovers. The Z source neutral linked-Vienna rectifier produces more accurate voltage by recovering immediately. Thus the Z source neutral linked Vienna rectifier is highlighted in terms of DC link voltage and current.



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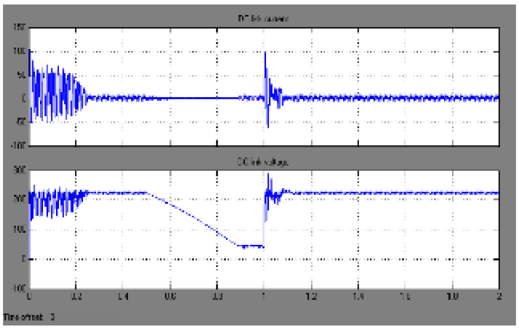

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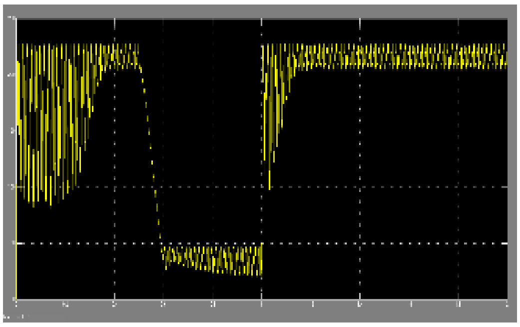

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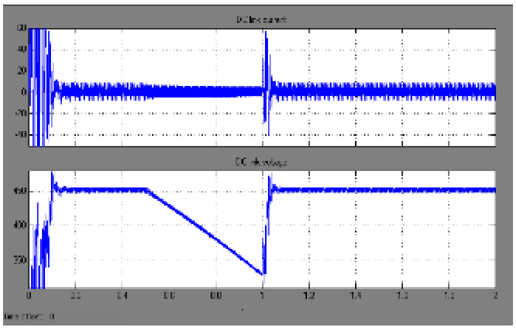


(d)

Figure 1. Comparison of output voltage: (a) Diode rectifier without Z-source; (b) Diode rectifier with Z-source; (c) Single phase two leg Vienna rectifier with Z-source (d) Z-source Neutral linked Vienna

Table 1. Dc Link Voltage & Distortion Table

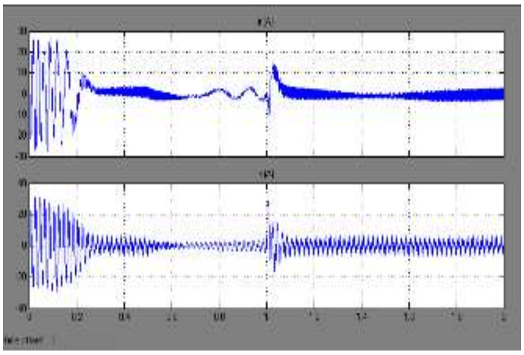
Asd's With Different Rectifiers	Duration of Distortion (s)	Lowest Voltage Reached (v)
Diode rectifier without Z-source	0.5-1.0	40
Diode rectifier with Z-source	0.5-1.0	50
Single phase two leg Vienna rectifier	0.5-1.0	125
Z source neutral linked Vienna rectifier	0.5-1.0	315

The Table 1 tabulated above provides a detailed report on the performance of the various ASD's in terms of lowest voltage attained and duration of distortion. The analysis is to obtain an ASD with less duration of distortion and the ability of the ASD to maintain it rated voltage during the conditions at which the voltage sag occurs.

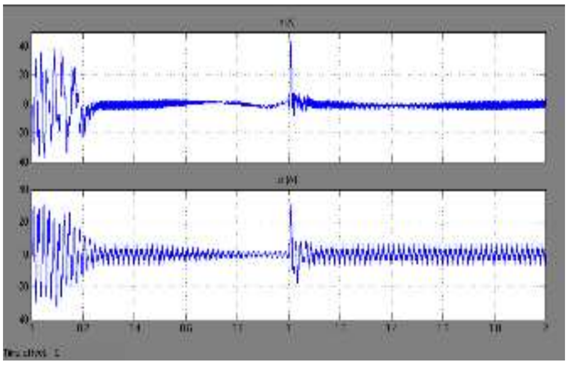
The different parameters noted during the operation of various ASD's are noted down and the results shows the Z sourceVienna rectifier fed ASD is the novel choice as it is showing better output and stability at the conditions that induces voltage sag in the power system. From the table is it confirmed that the Z source Vienna is providing the inverter a good operating voltage to outperform other rectifier fed ASD's also the time required for the Z source Vienna fed ASD is very less that is it is around 0.8-1s this recovery time is comparably good over others.

3.2. Comparison of Rotor and Stator Current

The rotor current and the stator current are the two main parameters that are taken into consideration for comparison. In this case almost all the ASD's are undergoing a small distortion as shown in the graphs Figure 2(a), (b), (c) & (d) and at the end of 1 second then they are coming back and stabilizing.



(a)



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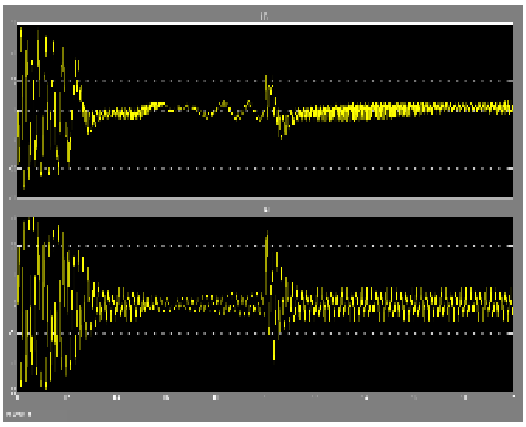

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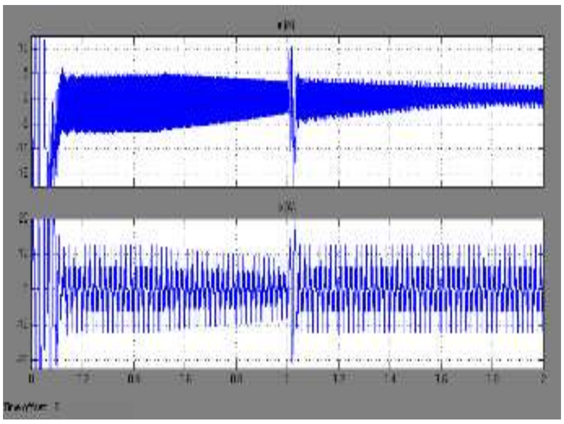


(d)

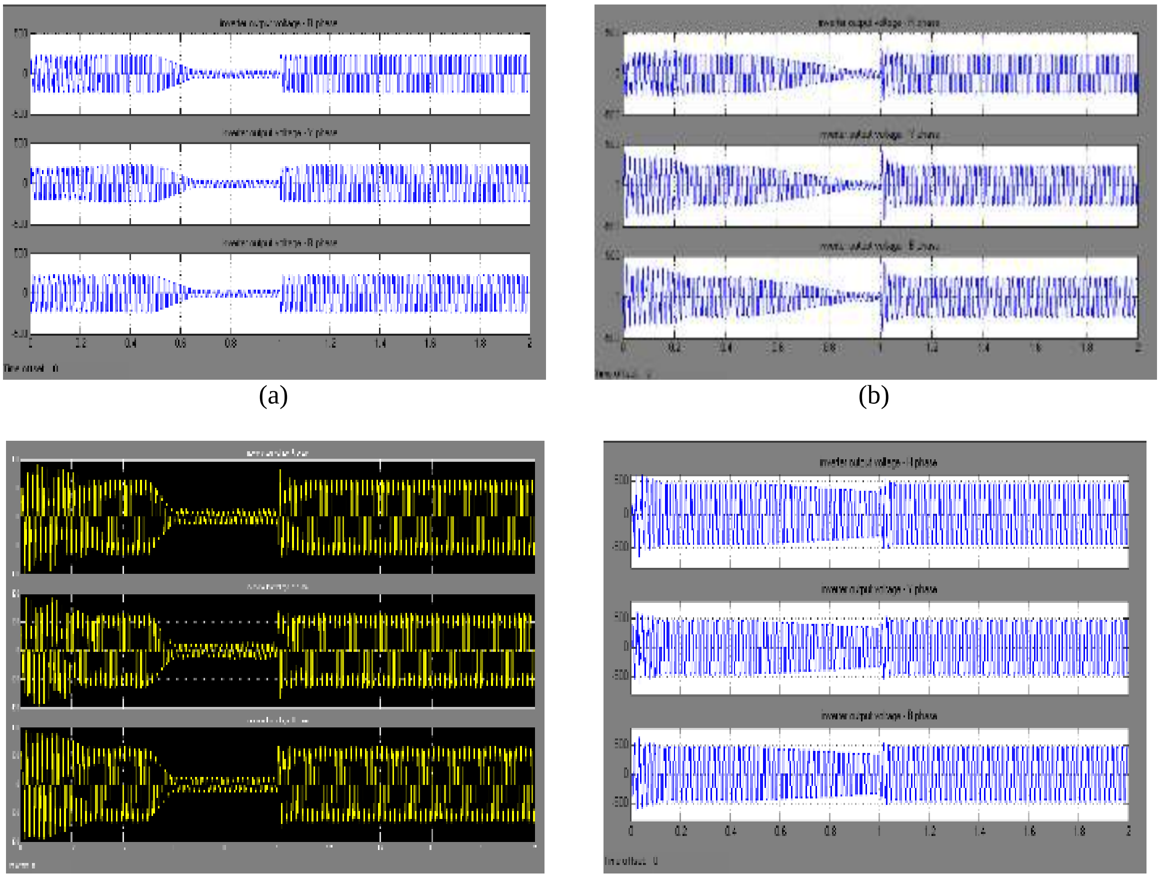
Figure 2. Comparison of rotor and stator current delivered by various ASD's employing: (a) Diode rectifier without Z-source; (b) Diode rectifier with Z-source; (c) Single phase two leg Vienna rectifier; (e) Z source Neutral linked Vienna rectifier

Table 2. Rotor, Stator Current Distortion Table

Asd's With Different Rectifiers	Duration of Distortion (s)
Diode rectifier without Z-source	1.0-1.07
Diode rectifier with Z-source	1.0-1.06
Single phase two leg Vienna rectifier	0.3-1.0
Z source neutral linked Vienna rectifier	-

3.3. Comparison of Output Voltage

The stability of an electric system depends on the its capacity to deliver voltage at its output constantly irrespective of the load connected, provided the current absorbed by the load shouldn't be higher than the capacity of the system. Now the three phase output voltage of five different Adjustable speed drives are compared.



(a) (b)

(c) (d)

Figure 3. Comparison of Output voltages of different ASD's employs: (a) Diode rectifier without Z-source (b) Diode rectifier with Z-source; (c) Single phase two leg Vienna rectifier; (e) Z- source Neutral linked Vienna rectifier

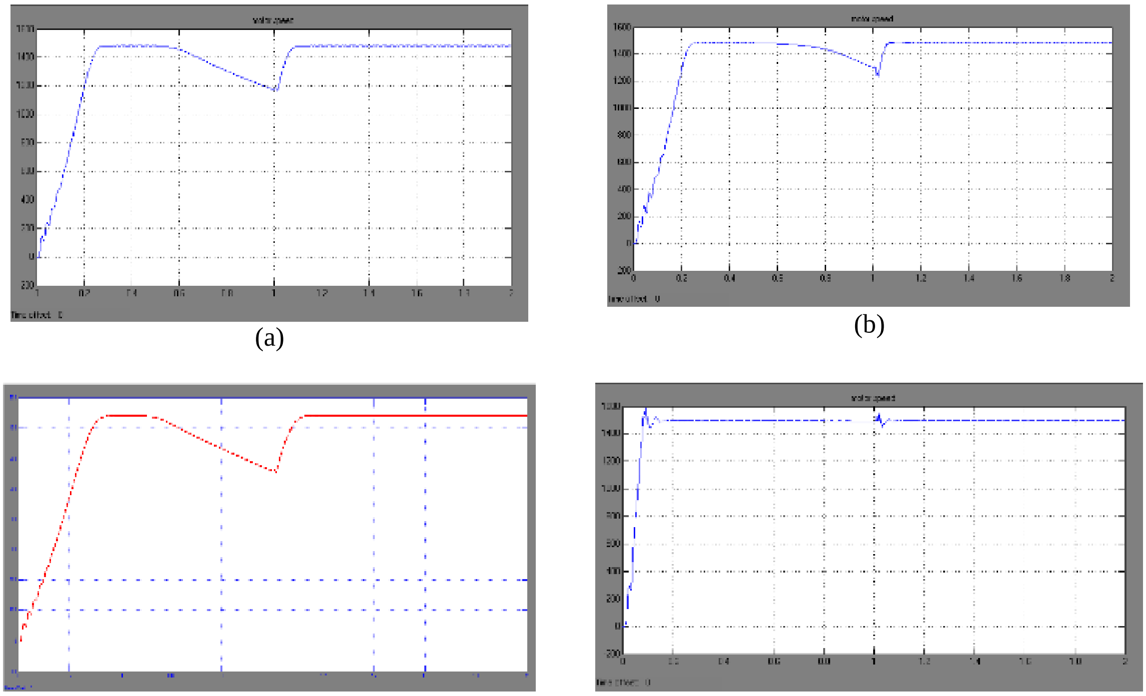
Table 3. Output Voltage Distortion Table

ASD's With Different Rectifiers	Duration of Distortion (s)
Normal rectifier without Z-source	0.65-1.0
Normal rectifier with Z-source	0.2-1.0
Single phase two leg Vienna rectifier with Z-source	0.57-1.0
Z source neutral linked Vienna rectifier	-

Like the way analyzed the previous data of rotor and stator current a table has been formed in that various data regarding the output voltage of five different ASD's are analyzed and are categorized in a scale that varies from LOW to HIGH which proportionate that performance of the ASD's from Poor to Good. From the graph we are getting an impression of various performances particularly the graph Figure 3(e) shows the excellent performances of ASD with single phase neutral linked Vienna rectifier and Z-source inverter. Whereas the ASD's that employs diode rectifier Figure 3(a) and single phase two leg Vienna rectifier Figure 3(c) are not up to the mark.

3.4. Comparison of Speed

Now coming into the main picture the speed of the motors are measured after connecting it with different ASD's and its variations are analyzed by noting the speed at different time.



(a) (b) (c) (d)

Figure 4. Comparison of Speed: (a) Diode rectifier without Z-source; (b) Diode rectifier with Z-source (b) Single phase two leg Vienna rectifier with Z-source inverter (d) Single phase neutral linked Vienna rectifier with Z-source inverter

The speed variation of motor by the use of different rectifiers is tabulated along with the distortion duration in the Table 4.

Table 4. Speed Table

ASD's With Different Rectifiers	Duration of Distortion (s)	Lowest Speed (rpm)
Normal rectifier without Z-source	0.5-1.05	<1200
Normal rectifier with Z-source	0.6-1.05	1250
Single phase two leg Vienna rectifier	0.5-1.1	1100
Z-source neutral linked Vienna rectifier	-	1450

As we inspire from the graph and the Table, ASD's that uses Z-source neutral linked Vienna rectifiers in Figure 4(d) are good in terms of the distortion in speed. But the other ASD's have not produced the desirable results. The ASD employing diode rectifier without Z-Source Figure 4(a) and the ASD with single phase two leg Vienna rectifier Figure 4(c) are producing huge distortion with higher settling time of around 0.6s and these two are making the machine to reach a speed of as below as 1100 rpm instead of which affects greatly the process in the industries.

3.5. Comparison of Electromagnetic Torque

The ultimate aim of any motor will be to produce the rated torque at the output at constant speed, as the torque requirement varies from one application to the other and its requirement will vary time to time since it depends on the type of load being connected at the shaft of the motor. Also it is quite different from other parameters like as voltage, current, speed that has been discussed earlier. The value of the torque depends on the value of the stator current.

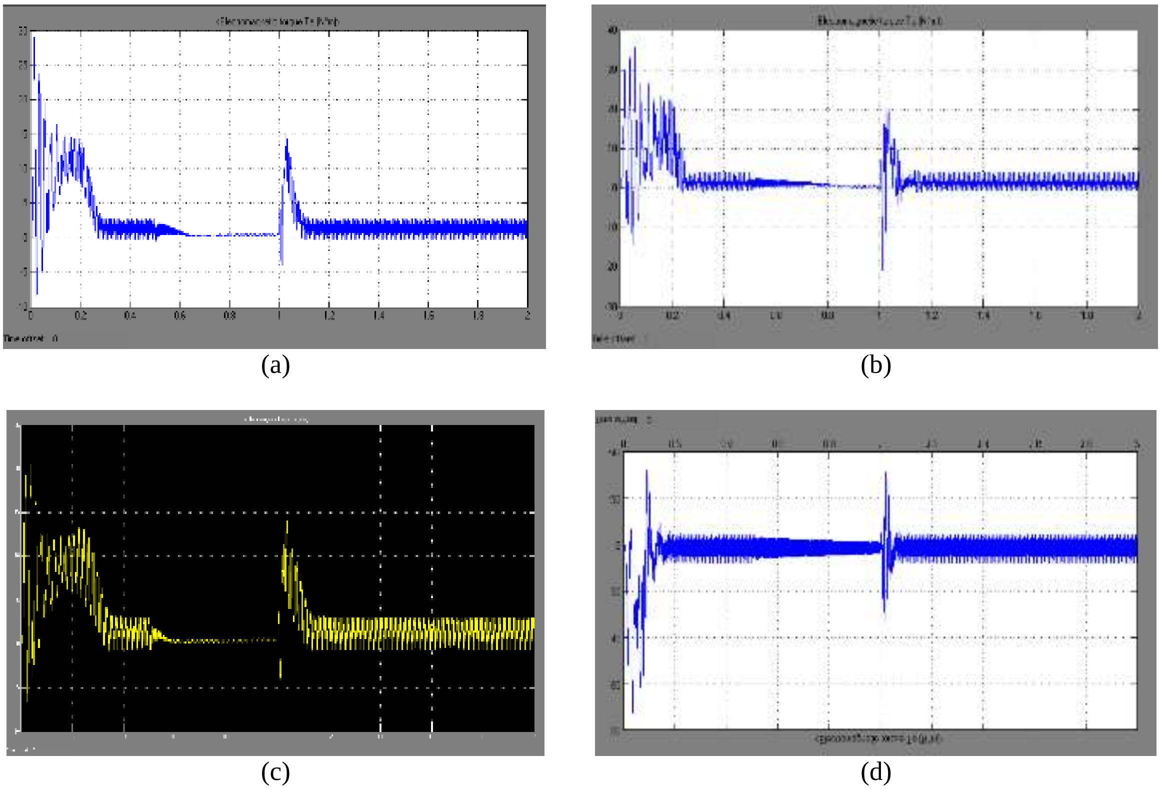


Figure 5. Comparison of Electromagnetic Torque: (a) Normal rectifier without Z-source; (b) Normal rectifier with Z-source; (c) Single phase two leg Vienna rectifier with Z source inverter (d) Z- source neutral linked Vienna rectifier

The drive should have the capacity to handle any load without variation in speed or torque. In the quest of finding out the most suitable drive for this purpose we are again going to compare five different drives. The settling time of these Adjustable Speed Drives in terms of electromagnetic torque is tabulated in the Table 5.

Table 5. Electromagnetic Torque Distortion Table

ASD's with different rectifiers	Duration of distortion (s)
Normal rectifier without Z-source	1-1.07
Normal rectifier with Z-source	1-1.13
Single phase two leg Vienna rectifier	1-1.1
Z source neutral linked Vienna rectifier	1-1.05

After the simulation of electromagnetic torques of various drives, the data collected are tabulated in Table 5 and are compared for duration of electromagnetic torque distortion. In this area also the best performers of the previous comparisons are providing the excellent results as compared to the other ASD's i.e. Z source neutral linked Vienna rectifiers Figure 5(d) is producing the desired results. Whereas the other ASD's with Diode rectifier without Z-source Figure 5(a) and other are not performing well.

4. ASD WITH Z- SOURCE NEUTRAL LINKED VIENNA RECTIFIER

After discussing the performance of various drives in different area such as DC Link, Rotor and Stator Voltage & current, Output Voltage, Speed and Electromagnetic Torque we came to the conclusion that the ASD with Z source Vienna rectifier outperforms all other competitor. Since the internal structure of the ASD that employs the Z source Vienna rectifier proves better performance amongst the four topologies Figure 6 is taken for interpretation.

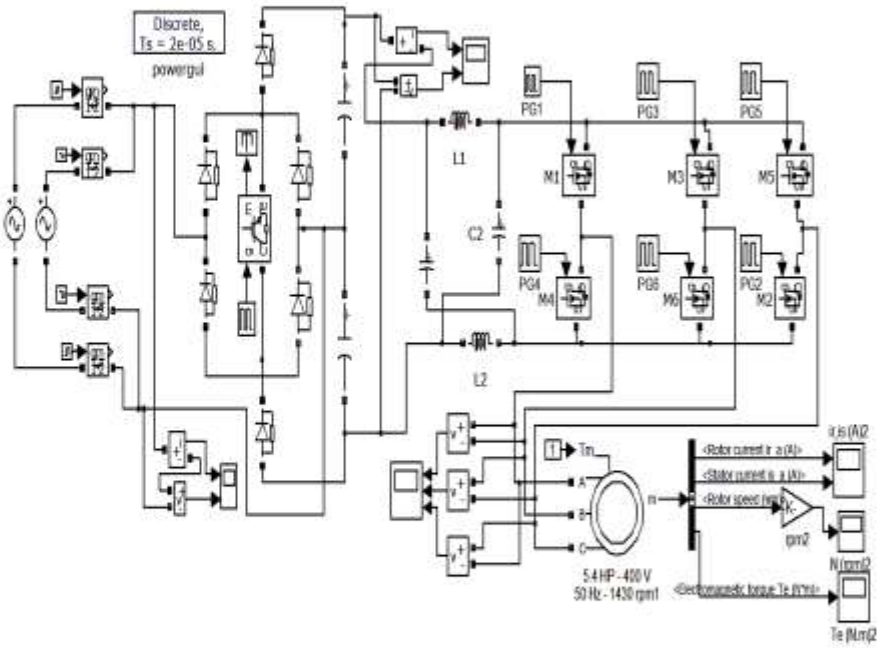


Figure 6. ASD with Z source neutral linked Vienna rectifier

Table 6. Parameters Considered For Comparison And Results

Parameters	Duration of Distortion (s)	Lowest Value reached
DC Link Voltage	0.5-1.0	100 (V)
Rotor and Stator current	-	-
Output Voltage	-	-
Speed	-	1500 (rpm)
Electromagnetic Torque	1-1.05	-

Z source Vienna rectifier is the configuration with four diodes and a power electronic controlled switch. In case of single phase rectification, connected in such a way that it can reduce the voltage stress across the power electronic rectifying switch and can produce a good operating voltage for the inverter that has to be connected with the rectifier. The various parameters discussed corresponding to ASD are tabulated in Table 6. That is for various parameters the distortion level and the lowest value reached are tabulated and discussed. The use of Z source Vienna rectifier the voltage at the output almost doubles the voltage at the DC link. So it provides a better solution to minimize voltage sag due to various reasons by providing the inverter a better operating voltage. Also the recovery time of this ASD is much better when comparing it with other ASD as 0.8 to 1s faster than others. So the Z source Vienna fed ASD find its application quiet impressive in the process control application in industrial sector. This ASD can be used for controlling different types of motors especially for the controlling of induction machine.

5. RESULTS AND DISCUSSION

The results of Diode rectifier without Z-source and with Z-source inverter proves that during voltage sag the dc link voltage is very low (40V-50V) to sustain the motor in running condition. The single phase two leg Vienna rectifier produces 125V during voltage sag condition which is a slightly improved condition when compared with diode rectifiers. The single phase neutral linked Vienna rectifier with Z-source inverter produces the required dc link voltage (315 V) for the continous operation of the induction motor.This topology of adjustable speed drive with single phase neutral linked inverter with Z-source inverter proves the satisfactory results during voltage sag condition.

6. CONCLUSION

This paper examines a comparative study on the performance of four topologies of Adjustable Speed Drives. ASD's with the combination of following, Diode rectifier without Z- source inverter, Diode rectifier with Z- source inverter, Single phase two leg Vienna rectifier and Z-source neutral linked Vienna rectifier using Mat lab/Simulink are compared. Performance parameters of ASD such as DC link voltage, rotor and stator current, motor speed and electromagnetic torque was investigated for the four different topologies. It is noticeable that the ASD with Z- source neutral linked Vienna rectifier proves better performance by producing higher DC link voltage and lesser variation in speed during voltage sag when compared to the other three topologies discussed in this paper. Thus this ASD system with Z source inverter and neutral linked Vienna rectifier improves the voltage sag problem in induction motor with faster response.

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