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SINGLE PHASE NEUTRAL LINKED VIENNA RECTIFIER: A SOLUTION FOR THE MITIGATION OF VOLTAGE SAG IN ASD FED INDUCTION MOTOR

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ABSTRACT

The two primary reasons for using an adjustable speed drive (ASD) in industry are Process control and Energy conservation. However, voltage sags are the most important power quality problem facing many commercial and industrial customers. Voltage sag problem arise because of transients in supply voltage by the usage of heavy inductive loads. Therefore to improve the performance of the motor and drive, new controlling drives has to be implemented with the help of power electronics. The ride-through capability of the induction motor during voltage sag is taken into account that duration of the ride-through operation depends on the initial motor flux, speed level, rotor time constant, load torque and inertia. Also Inverter design mainly affects the motor performance. A new combination technique has been proposed for the mitigation of voltage sag on adjustable speed drive. Simulation results are illustrated for the proposed techniques. The simulation results are compared with the circuit in the combination of diode rectifier and normal inverter. It is highlighted that the waveform generated by the new technique is efficient with the reduction of the effect of voltage sag.

Keywords: adjustable speed drive, voltage sag, Z-source inverter, neutral linked vienna rectifier.

1. INTRODUCTION

AC Adjustable Speed Drives (ASDs) become very popular variable speed control drives used in industrial applications. These systems are fairly expensive but provide a higher degree of control over the operation and in many cases reduces the energy. ASD allow precise speed control of a standard induction motor and can result in significant energy savings and improved process control in many applications. Voltage sag represents one of the major power quality problems. The abnormal operating conditions such as heavily loading conditions, frequently starting of large induction motors and transmission system faults in electric system utility are considered the main reasons of voltage sag problem [1]. Reduction in RMS supply voltage between 0.1 and 0.9 per unit with duration of 0.5 cycles to 1min is called voltage sag. Voltage sags normally do not cause equipment damage but can easily disrupt the operation of sensitive loads such as electronic adjustable speed drives (ASDs) [1]. Sudden and sharp variation of current may cause triggering of protection system. Diverse torque peaks during motor's life can weaken motor's shaft and variations of speed damage the final product in different applications. A critical evaluation method over ASDs results that ASDs are very sensitive to voltage sags and swell [2] and the behavior of three phase AC ASDs during balanced and unbalanced sags also analyzed [3].

The Z-source inverter system employs a unique LC network in the DC link to reduce the voltage and current ripple and small capacitors on the AC side of the diode rectifier in the front end. By controlling the shoot through duty cycle, the Z-source can produce any desired output AC voltage, even greater than line voltage. It able to provide ride-through during voltage sags without any additional energy storage elements. Improves power factor, reliability reduces harmonic current and extends output voltage range [4, 5, 6]. The improved Z-source inverter with reduced Z-source capacitor voltage stress also provides the better ride through capability to the drive systems used in industry [7] and the design calculation of Z-source network also detailed in earlier research [8]. Vienna rectifier is a combination of a single phase AC/DC boost converter with a neutral link provides a new topology [9]. Technical and economical advantageous of this type of rectifier can briefly be noted as, low harmonic injection to the main, controlled output voltage, high efficiency, power factor improvement, high reliability, low voltage stress on power semiconductors [10].

Voltage sag problem will also occur in the DC link and hence it will affect inverter which is present in the back end of the ASD. Because of the voltage sag in the inverter, switching pattern problem will occur due to that it will affect the motor resulting in reduction of speed of the motor.

Voltage sag problem of power quality is improved by a Z-source inverter which can boost the output voltage and improve the ride through capability of the system. In order to reduce the voltage sag problem in DC link, it should be controlled in the front end itself [11]. It is expected that the efficiency of the system can be improved by using Vienna rectifier in the front end with neutral link connection and Z-source inverter as the back end.

2. DESIGN METHODOLOGY

A. ZSI and Vienna rectifier for ASD

Vienna rectifier is a single phase AC/DC boost converter from which the DC output is obtained across DC link capacitor. It is also used to prevent the rapid voltage change because of its split capacitor arrangements with the value double than normal rectifier. By controlling the

ARPN Journal of Engineering and Applied Sciences

shoot through duty cycle, the Z-source can produce any desired output AC voltage, even greater than the line voltage. As a result, the Z-source inverter system provides ride through capability during voltage sag, reduces line harmonics, improves power factor and reliability and extends output voltage range.

B. Design calculation of ZSI and DC link capacitor

From the circuit of Z network we found that, shoot through (To) and non shoot through (T1) state timings are the important factor to find the voltage across inductor and capacitor of the Z network. It gives the equation to find the maximum DC link voltage across the Dc link capacitor [12],

$$Vi=Vc-VL = 2Vc-Vo= T/ (T1-To) X (B X Vo) \quad (1)$$

Where B is the Boost factor resulting from shoot through state.

The output peak phase voltage can be expressed as

$$VAC = M X B X (Vo/2) \quad (2)$$

and BB = M X B = (0 to ∞) where BB is the appropriate buck-boost factor.

The average current through the inductor equals to that through the diode, which is IL = P/Vin (3)

IL = 0.75 X 10^3/230 = 3.26 A.

The maximum current through the inductor occurs when the maximum shoot-through happens, which causes maximum ripple current. In this design, 30% (60% peak to peak) current ripple through the inductors during maximum power operation was chosen. Therefore, the allowed ripple current is 30% and the maximum current through the inductor is 3.26 A. the maximum operating voltage applied is 400V.

1/ (1-2Do) = 400/230, Do = 0.2125

For a switching frequency of 10 kHz, the shoot-through time per cycle is 21.25µs. The capacitor voltage during that condition is:
Vc= 230 X (1-Do)/ (1-2Do) = 315V.

$$\Delta IL= ToVc/L => L= ToVc/\Delta IL \quad (4)$$

To keep the current ripple less than 30%
(0.978≈1A),

L = (21.25 X 10^-6 X 315)/ (0.978) = 6.8 mH

During shoot-through, the capacitor charges the inductors, and the current through the capacitor equals to the current through the inductor. Therefore, the voltage ripple across the capacitors can be roughly calculated by:

$$\Delta Vc = (Iav x T0) / C \quad (5)$$

To limit the capacitor voltage ripple to 0.015 %at peak power, the required capacitance is:

C = (3.26 X 21.25 X 10^-6)/ (315 X 0.015 %) = 1026.29µF ≈ 1000 µF.

The DC link capacitor value is calculated by using Mill man's equation assuming the ripple factor value as 0.2 and resistance of load 1000Ω,

$$ro= 1/(4\sqrt{3}FCR) \quad (6)$$

C is approximately 1000 µF but for Vienna rectifier that value should be two times of the normal Dc link capacitor when it is used as split capacitor. So here we consider the split capacitor value as 2000 µF.

3. PROPOSED NEUTRAL LINKED VIENNA RECTIFIER COMBINED ZSI FED ASD

Vienna rectifier is a combination of a boost DC/DC converter series with a single phase rectifier provides a new topology. It's a single-phase; single-switch rectifier. It can be seen as a diode bridge rectifier with an integrated boost converter. The Vienna rectifier is useful wherever six switch converters are used for achieving sinusoidal mains current and controlled output voltage, when no energy feedback from load into the mains is required. The Vienna rectifier comprises a semiconductor switch in each phase leg of 1- phase Diode Bridge. It is a highly efficient method of high current, single-phase AC/DC conversion and is very useful for achieving unity power factor correction.

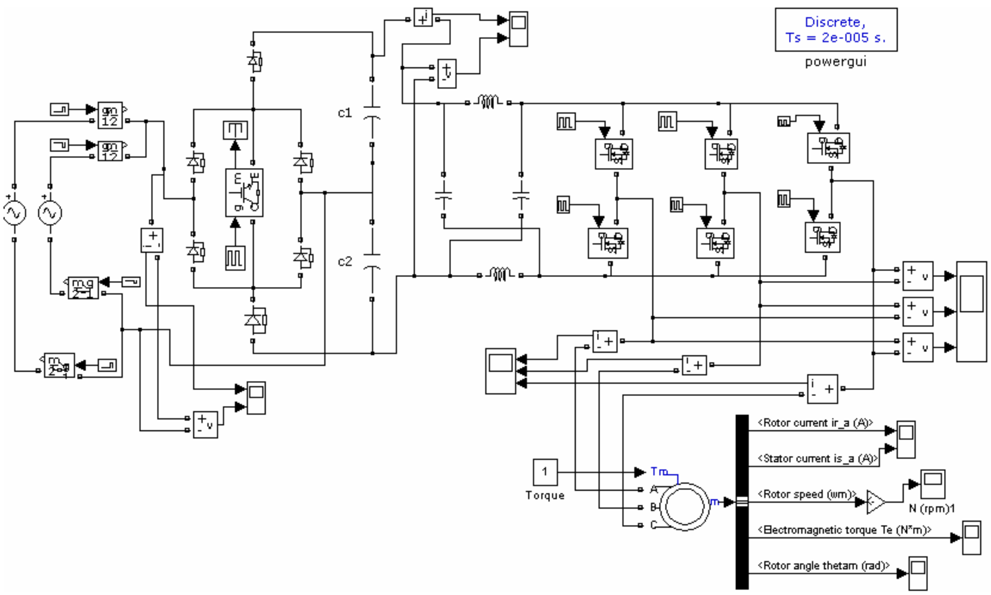

Figure-1. Circuit diagram of neutral linked Vienna rectifier combined Z- source inverter fed induction motor.

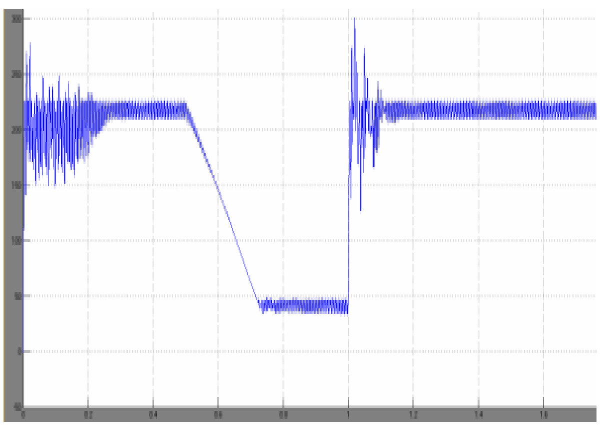

Figure-2. DC link capacitor voltage of normal rectifier.

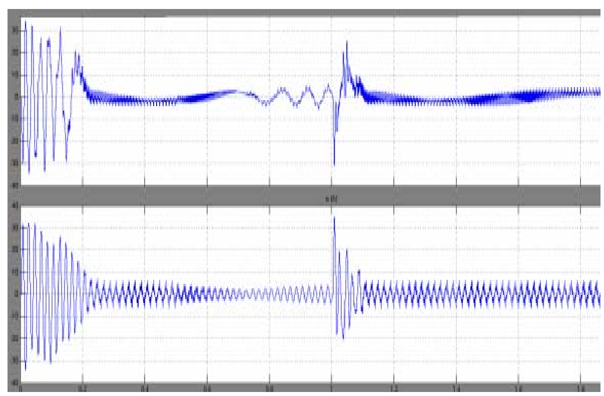

Figure-4. Rotor and stator current waveforms of normal rectifier and inverter fed IM.

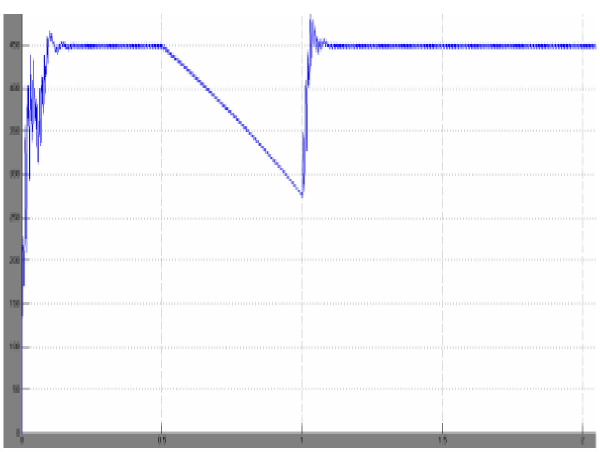

Figure-3. DC link capacitor voltage of Vienna rectifier.

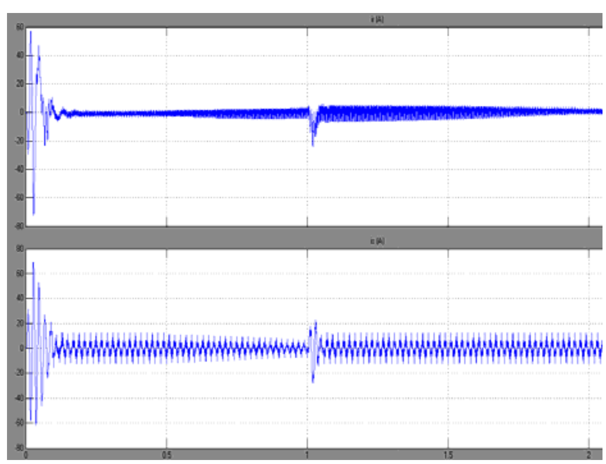

Figure-5. Rotor and stator currents of neutral linked Vienna rectifier and Z source inverter fed IM.

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The circuit diagram of adjustable speed drive in combination of Neutral linked Vienna rectifier and Z-source inverter under sag condition (approximated sag produced in the input supply side) which was shown in the Figure-1. Single phase AC voltage is the source for the Vienna rectifier and the output of the Vienna rectifier is the input for the Z-source inverter. The three phases induction motor which was connected to the Z-source inverter without LC filter.

4. EXPERIMENTAL RESULTS

The results are compared, shows Figure-2, which explains the DC link output voltage for normal rectifier under sag condition. It depicts voltage level during both normal and sag. Under sag the voltage lying at less than 50. Figure-3 shows the DC link voltage, which proves that the neutral link provides the voltage double that of the normal rectifier. Therefore during sag period the DC link voltage is considerably nominal to 280V which would not affect the performance of the motor and only minimum variation in the speed of the motor. Waveforms comparisons are shown in Table-1 and Figure-6.

Table-1. Result analysis of the waveform.

During voltage sag	Normal system	Neutral linked Vienna system
Stator and rotor currents	Ir oscillating in between zero and it disturbs the speed of the motor	Is varies from 12A - 6A during sag, but provides stable condition
Rotor speed	1490-980 rpm	1490-1470 rpm
DC link voltage	Reduced to 50V and stays up to 4 seconds. That gives reduction in motor speed	450V-275V, this value of reduction won't affect the motor speed maximum

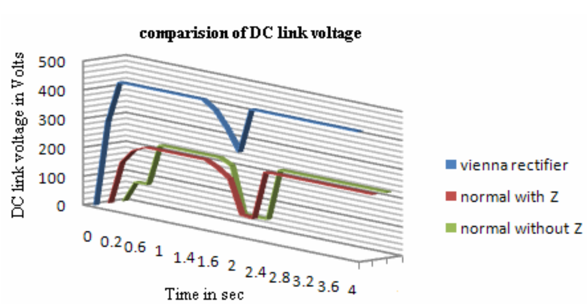

Figure-6. Comparison wave form of DC link capacitor voltage.

5. CONCLUSIONS

The simulation results are analyzed for the combination of neutral linked Vienna rectifier with Z-source inverter. This output is compared with the circuit in the combination of diode rectifier and Z source inverter as well as with diode rectifier and normal inverter. In case of diode rectifier the switching losses tends to be low but output voltage is lesser than the input voltage applied. While in case of controlled rectifier the switching losses are high which results in higher EMI losses. Also the output voltage can be controlled only till the input voltage. When Vienna rectifier is used the output voltage is almost twice the input voltage. Vienna rectifier also improves the power factor considerably. In both the other cases, motor speed reduced rapidly during sag. This affects the drive and in turn, the process stops, but this power quality problem can be resolved by the new combination of Single phase Neutral linked Vienna rectifier with Z-source inverter provides double the voltage than normal system across Dc link capacitor and proves the better performance of the motor even at sag conditions.

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ARPN Journal of Engineering and Applied Sciences

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