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Simulation of Ride through Capability of Adjustable Speed Drive for Type A, Type D and Type F Voltage Sag and Swell using Cuk Converter

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Abstract

Voltage sag and swell are common in power systems. Adjustable speed drives are susceptible to these issues occurring due to faults in electric power systems. In this paper, an approach to provide a ride through with Cuk converter is explored. The proposed approach maintains the constant ASD dc bus voltage under sag and swells conditions. The simulation results are presented for the verification of the proposed Cuk converter topology.

Index Terms: ASD (Adjustable Speed Drive), Cuk converter, voltage sag, swell.

Introduction

A power-quality problem is an occurrence manifested in a non standard voltage, current or frequency deviation that results in a failure or miss operation of end-use equipment [1-2]. Power quality is a reliability issue driven by end users. There are three concerns firstly the characteristics of the utility power supply can have a detrimental effect on the performance of industrial equipment, secondly, harmonics produced by the industrial equipment, such as rectifiers or adjustable speed drives (ASD) can have a detrimental effect on the reliability of the plant's electrical distribution system, the equipment it feeds, and on the utility system and lastly the characteristics of the current and voltage produced by ASDs can cause motor problems.

The situation of poor power electric quality is more evident in countries with a weaker power grid such as India, African countries, and other developing countries, than in the industrialized world. Nevertheless, the problem is of significance also in countries with a strong power grid [3].

Although there are number of power quality problems such as transients, interruption, sag/under voltage, swell/over voltage, waveform distortion, voltage fluctuations and frequency variations; voltage sag is a major reason for ASDs shutdown [4].

Voltage sag (dip) is a reduction between 10 and 90% in root - mean- square (rms) voltage, with duration between 0.5 cycles and 1 min [5]. It is generally caused by a short circuit or over load in the utility system. Typically voltage sag duration ranges from 0.5 to 30 cycles, and its depth depends on the power system distribution and the proximity to the fault site. For simplicity purposes, the sag is considered to be rectangular. Then it can be characterized by duration, depth, and the voltage point on wave when the sag begins [6].

Adjustable Speed Drives (ASDs) are one of the most sensitive loads to voltage sags because transient voltages cause nuisance tripping events. In [7], it is pointed out that tripping may occur due to several causes:

- dc-bus under voltage (controller or protection trip)
- increased ac currents during the sag or the post sag (over current trip or fuse blowing);
- drop of speed or torque variations.

The tolerance of an ASD to voltage sags depends on the characteristic of the voltage sag. Seven different types of voltage sags, classified as A, B, C, D, E, F and G may come upon the terminal of an ASD as a result of symmetrical and asymmetrical faults. The voltage sags are classified according to the number of phases affected and the phase displacement, which are associated to the fault type. Table 1 presents the categories of voltage sag according to the fault types [8]. Fig.1. shows the phasor diagram and equations of various types of voltage sags.

There are number of approaches that can help to the susceptibility of ASDs to electric power disturbances. A variety of energy storage technologies are candidates for providing the needed full power ASD ride through under sags and swell.

Battery Back-up systems, super capacitors, motor-generator sets, fly-wheel energy storage systems, super conducting magnetic energy storage (SMES) fuel cells and Boost converters are some examples of these technologies [9-11].

In this paper, an approach to achieve ride-through for ASD's under sag and swell condition with Cuk converter is presented. If the Cuk converter absence in the circuit, the dc bus voltage will decreases. So the performance of three phase Induction motor gets affected. If sag/under voltage, swell/over voltage occur in the circuit the Cuk converter provides the ride through capability. Hence the performance of the machine does not get affected.

The simulations are carried out for a circuit without Cuk converter and the circuit with type A, type D and type F sags and swell conditions with Cuk converter.

Table 1: The categories of voltage sags

Voltage Types	Fault Type						
	3ϕ	1ϕ		2ϕ		2ϕ-G	
	Voltage Sag categories						
Phase	*A*	*B*	*C*	*D*	*E*	*F*	*G*
Line	*A*	C^*	*D*	*C*	*F*	*G*	*F*

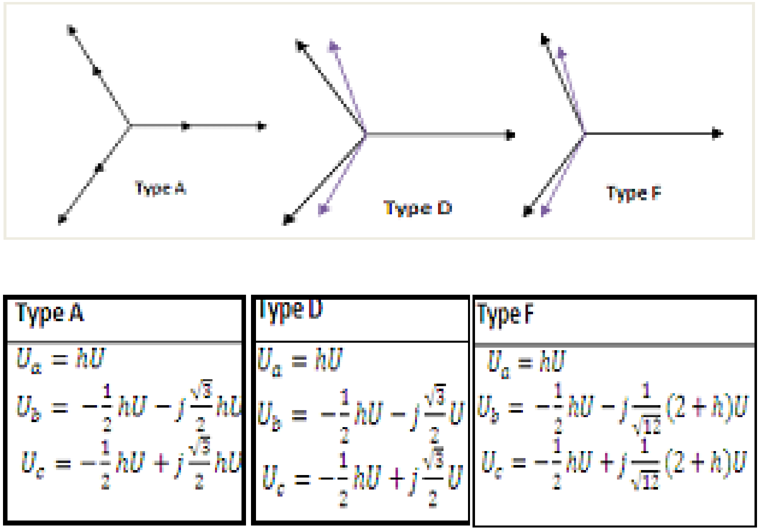

Figure 1: Classification of voltage dips

Proposed ride-through topology

In conventional, ASDs' unit consists of three basic parts as shown in Fig.2.The rectifier converts the fixed frequency AC input voltage to DC voltage. The inverter switches the rectified DC voltage to an adjustable frequency AC output voltage; it may also control output current, if required. The DC link connects the rectifier to the inverter and may also contain an inductor as well as a capacitor.

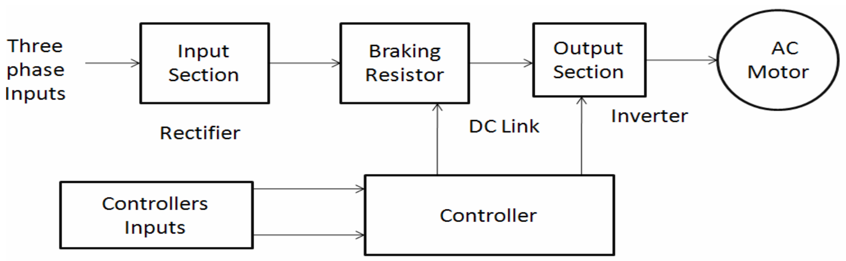

Figure 2: Block diagram of conventional ASD

In Fig.3, the proposed ride-through topology using Cuk converter for adjustable speed drive is shown, which has been directly connected across a dc link to maintain the voltage level constant under power quality disturbance such as sag and swell. Hence the motor performance does not get affected due to voltage sag and swell.

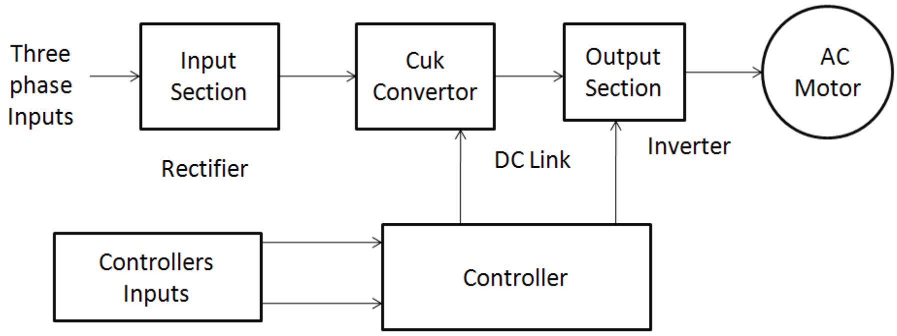

Figure 3: Block diagram of ASD with Cuk converter

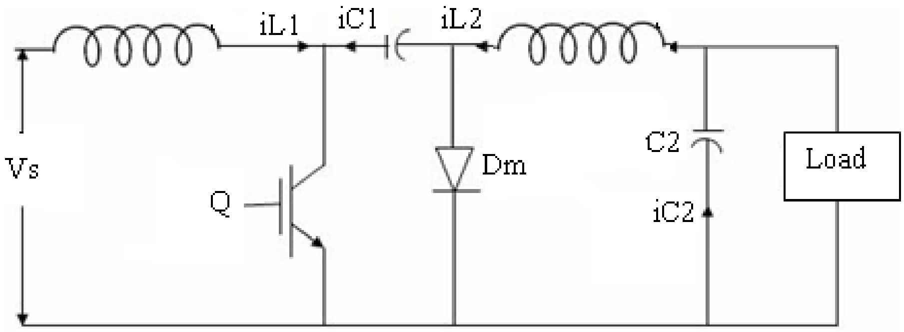

Figure 4: Circuit diagram for Cuk converter topology

Similar to buck-boost regulator, the Cuk regulator provides output voltage is less than or greater than the input voltage. But the output voltage polarity is opposite to that of the input voltage. This topology circuit diagram is shown in Fig.4. When the input voltage is turned on and transistor Q_1 is switched off, diode D_m is forward biased and capacitor C_1 is charged through L_1, Dm and the input supply V_s.

The circuit operation can be divided into two modes. Mode1 begins when transistor Q_1 is turned on. The current through inductor L_1 rises. At the same time, the voltage of capacitor C_1 reverse biases diode D_m and turns it off. The capacitor C_1 discharges its energy to the circuit formed by C_1, C_2, the load and L_2. Mode 2 begins when transistor Q_1 is turned off. The capacitor C_1 is charged from the input supply and the energy stored in the inductorL_2 is transferred to the load. The diode D_m and transistor Q_1 provide a synchronous switching action. The capacitor C_1 is the medium for transferring energy from the source to the load.

Design

Output voltage $V_{dc} = \frac{DV_{in}}{1-D}$ (1)

Boost Inductor$L_i = \frac{DV_{in}}{f_s \Delta I L_i}$ (2)

Intermediate Capacitor $C_1 = \frac{D}{R f_s \Delta V_{C_1} / V_0}$ (3)

Output filter inductor $L_0 = \frac{(1-D)V_0}{f_s \Delta I_{L_0}}$ (4)

Output filter Capacitor $C_0 = \frac{I_{av}}{2\omega \Delta V_0}$ (5)

For 1.5KW, 400V, 3.7A, f_s =25 KHz, VD=0.5V, ΔI_{Li}= 1.5A, I_0 = 4A, ΔV_o= 5V, design parameters are calculated on the basis of above equations as L_1=L_2=12.5mH, C_1=400µF, C_2=5µF

Problem formulation

ASDs' are often susceptible to voltage disturbances, such as voltage sags and swell during balanced and unbalanced conditions. The above said power quality problems are the major cause of ASDs' industry process disruptions. Depending upon the characteristics of the disturbance, the ASD's controlled process may be momentarily interrupted or permanently tripped out. To avoid such circumstances, ASD's have been provided a ride through topology or an external energy backup during fault conditions. An energy storage device like battery, capacitor, super-capacitors, superconducting magnetic energy storage, load inertia, boost converter, buck-boost converter, Cuk converter, flywheels, fuel cell etc have to be connected across DC-link to maintain the required voltage level. In this paper, the objective is to investigate the methods to enhance adjustable speed induction motor drive tolerance to voltage sags through the addition of Cuk converter by keeping the DC link voltage level as constant. In this topology, the Cuk converter is directly connected across the DC link to maintain its level constant at any abnormal condition of voltage sag and swell.

Voltage dips at the terminals of the equipment can be classified into seven types. This classification is obtained from different fault types and taking into account transformer configuration and star or delta connection of the load. In this paper, voltage dips type A, type D and type F are discussed. Voltage sags, classified as type A, are the most severe ones as they cause the larger amount of energy withdraw from the dc bus, and are more likely to trip the adjustable speed drives (ASD) under voltage protection. The asymmetric voltage sags usually have at least one line supply voltage which keeps the dc link voltage above the under voltage protection level. Nevertheless, voltage sag type A is the least severe as far as the over current level is concerned. On the other hand, voltage sags type D, caused by two-phase faults, are accountable for the most severe sags as far as over current are concerned and the least severe as for the dc bus under voltage threshold level.

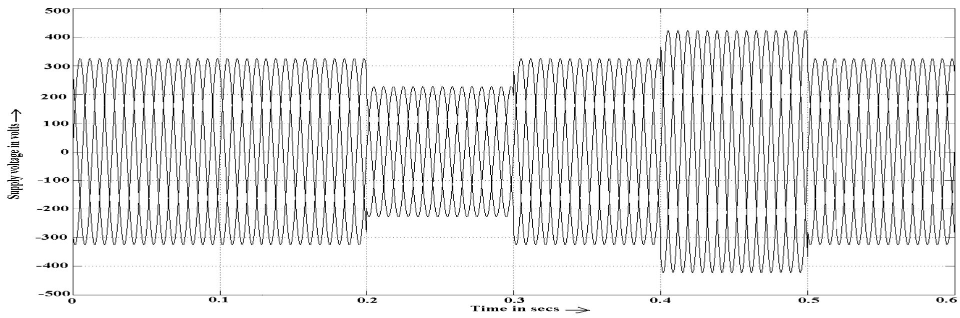

Figure 5: Three phase supply voltage with type-A dip and swell

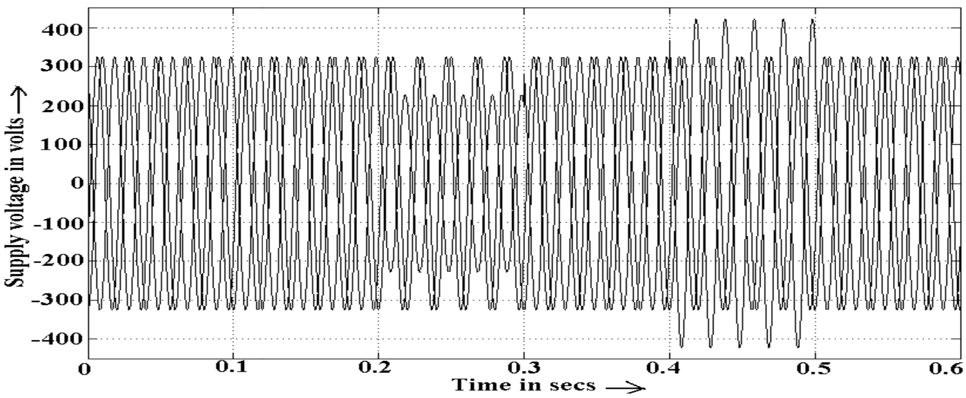

Figure 6: Three phase supply voltage with type-D dip and swell

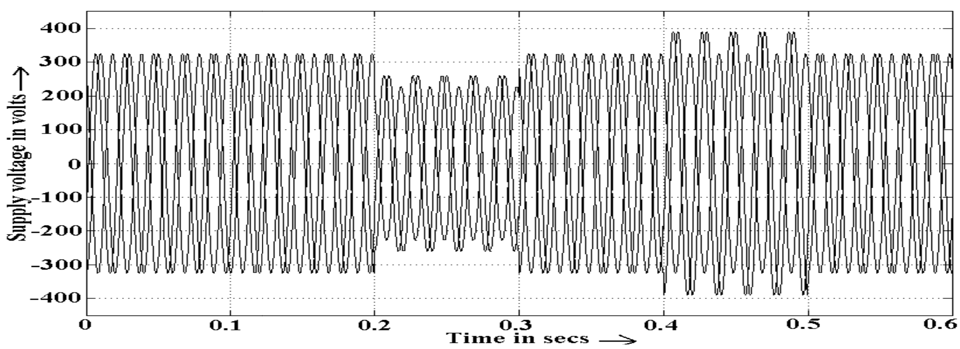

Figure 7: Three phase supply voltage with type-F dip and swell

Fig.5, Fig.6, and Fig.7 shows the simulation result of three phase supply voltage with type A, D and F voltage sags on adjustable speed drives (ASD) respectively.

Here sag occurs between 0.2 and 0.3 seconds and swell occurs between 0.4 and 0.5 seconds.

Results and discussion

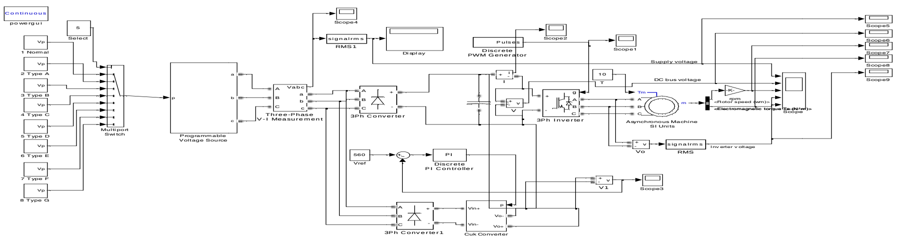

Figure 8: Simulink model for type-A dip on ASD with Cuk converter

The Simulink model Fig.8, shows that type-A dip is created on the 3-phase AC supply of the adjustable speed drive which is fed to the diode rectifier. The output voltage of the DC-link is below the under voltage protection. At that time the Cuk converter starts to boost the DC-bus voltage to maintain the constant voltage level. As a result the induction motor speed and torque are constant. The rating of the three phase induction motor is 1.5KW, 400V, 3.7A.

The Simulation results of dc bus voltage, speed and torque under type A dip are shown. Fig.5. shows the simulation reult of supply voltage drop with type A dip and swell condition. Fig.9, Fig.10 and Fig.11 shows the simulation result of dc bus voltage, speed and torque under type A dip and swell without Cuk converter. If the Cuk converter is not included in the circuit the performance of the machine gets affected. Here the dc bus voltage is not constant. So speed and torque are not constant. It is clearly shown in the simulation result.

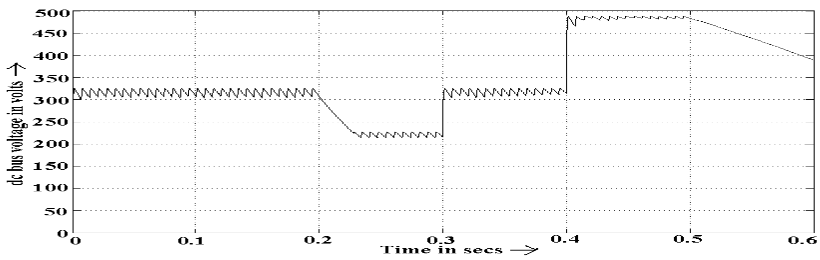

Figure 9: DC bus voltage for type-A dip on ASD without Cuk converter

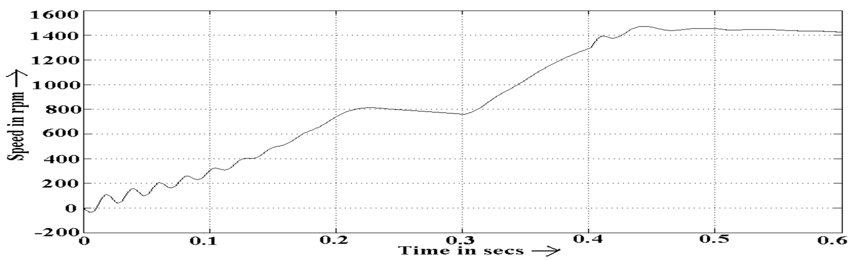

Figure 10: Speed of IM for type A dip on ASD without Cuk converter

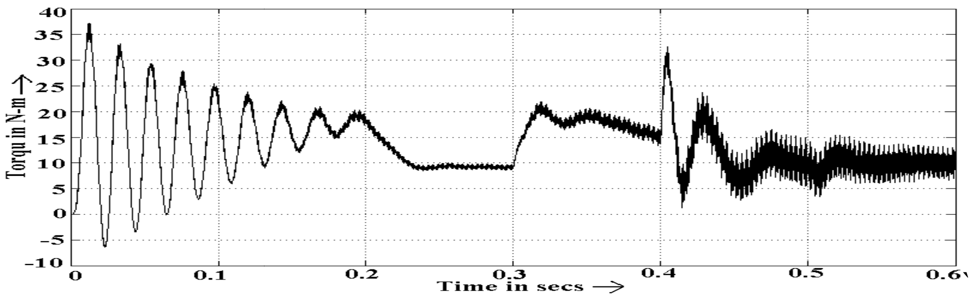

Figure 11: Torque of IM for type A dip on ASD without Cuk converter

Fig.12 shows the simulation reults of dc bus voltage drop with type A dip on ASD with Cuk converter. Fig.13 and Fig.14 shows the simulation result of speed and torque under type A dip with Cuk converter. Due to the presence of Cuk converter Vdc,speed and torque are constant. Fig.15, Fig.16 and Fig.17 shows the simulation result of dc bus voltage, speed and torque under type D dip without Cuk converter. Due to the presence of Cuk converter the performance gets affected. Fig.18 shows the simulation reults of dc bus voltage drop under type D dip on ASD with Cuk converter. Here Vdc is constant. Fig.19 and Fig.20 shows the simulation result of speed and torque under type D dip with Cuk converter.

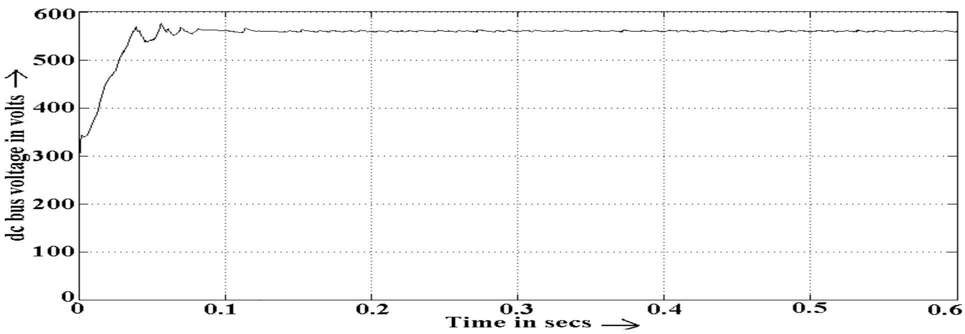

Figure 13: Speed of IM for type-A dip on ASD with Cuk converter

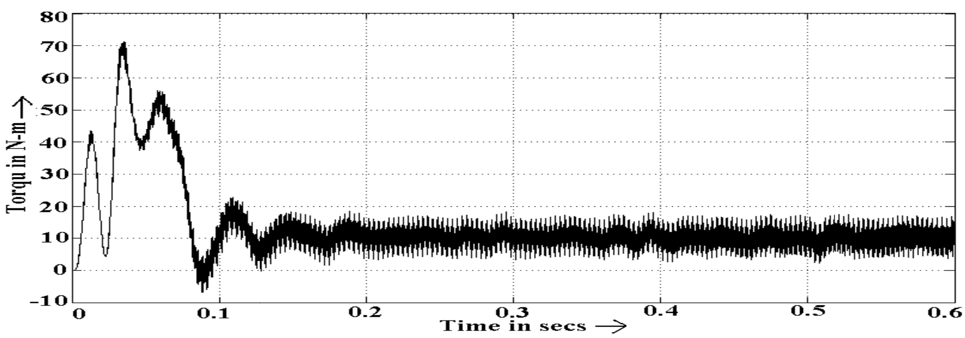

Figure 14: Torque of IM for type-A dip on ASD with Cuk converter

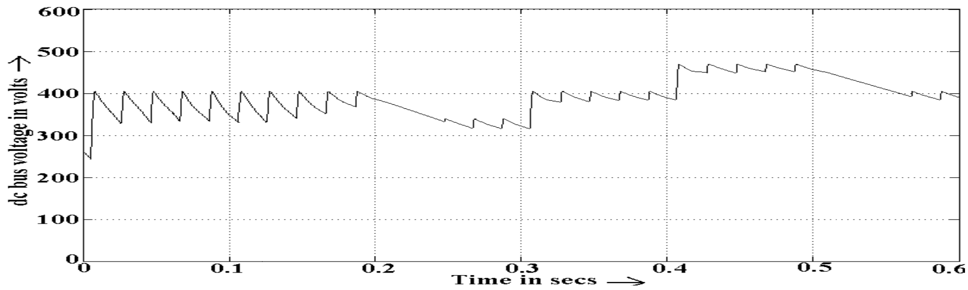

Figure 15: DC bus voltage for type-D dips on ASD without Cuk converter

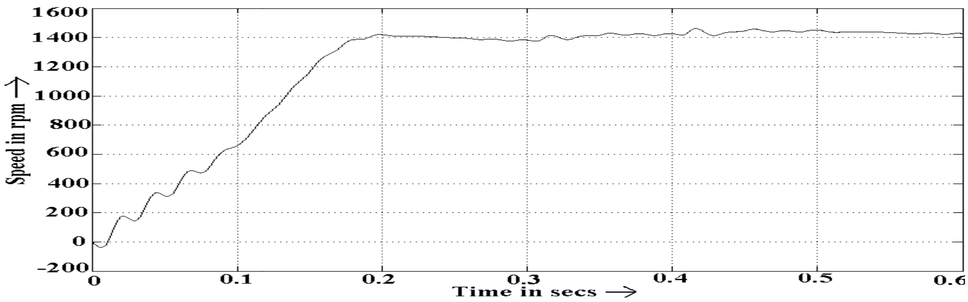

Figure 16: Speed of IM for type-D dip on ASD without Cuk converter

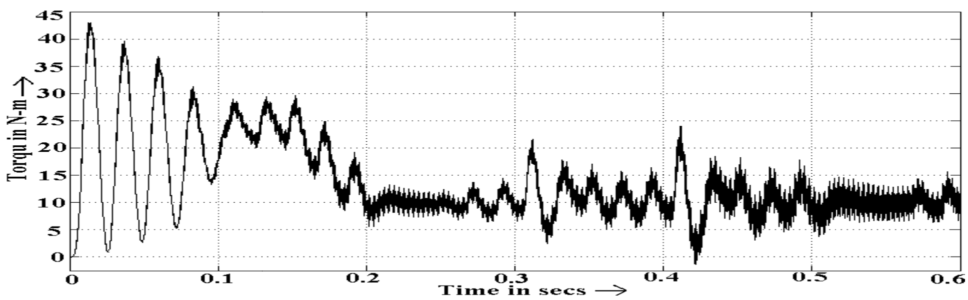

Figure 17: Torque of IM for type-D dip on ASD without Cuk converter

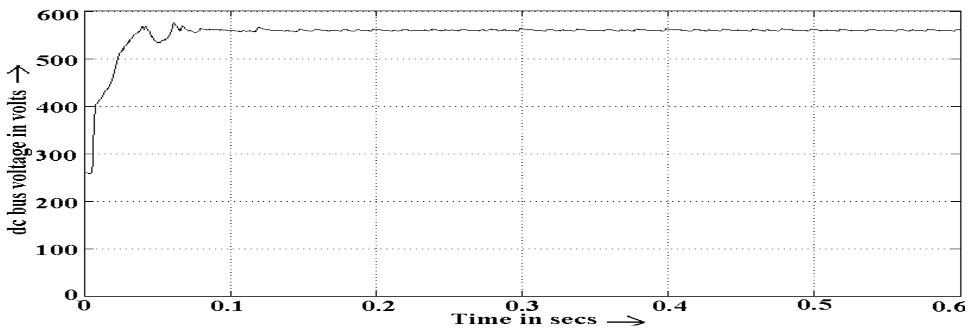

Figure 18: DC bus voltage for type-D dips on ASD with Cuk converter

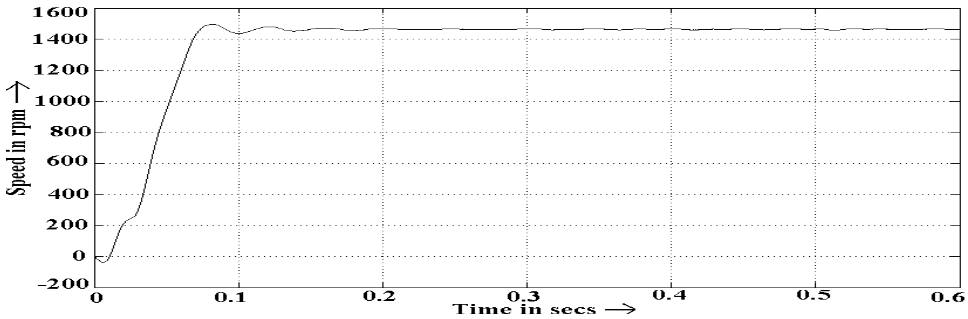

Figure 19: Speed of IM for type-D dip on ASD with Cuk converter

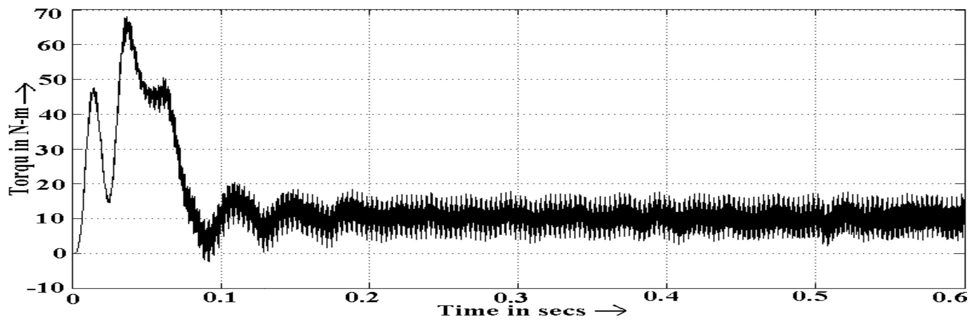

Figure 20: Torque of IM for type-D dip on ASD with Cuk converter

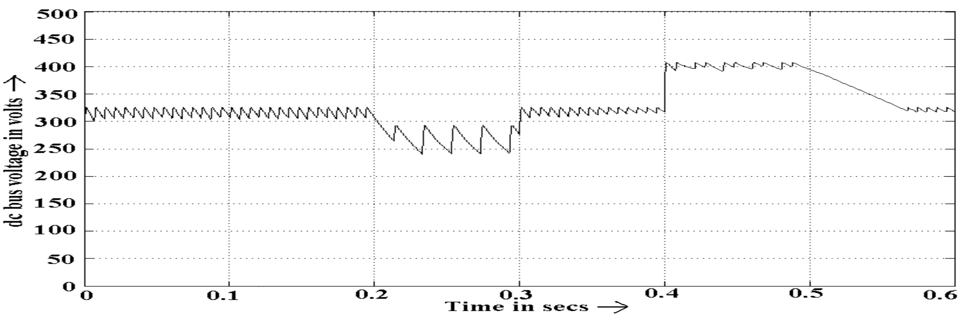

Figure 21: DC bus voltage for type-F dips on ASD without Cuk converter

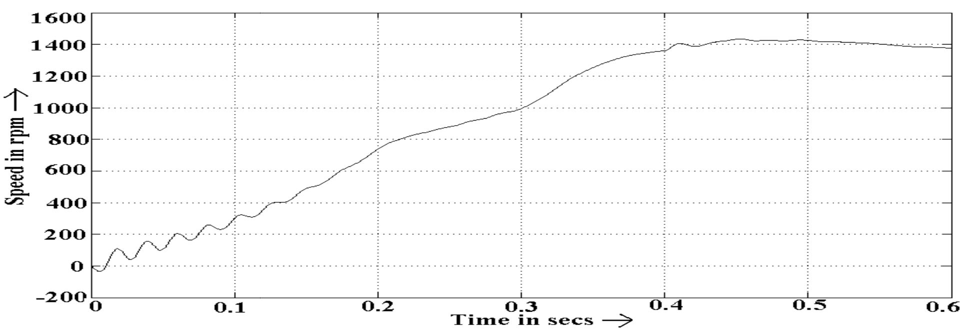

Figure 22: Speed of IM for type-F dip on ASD without Cuk converter

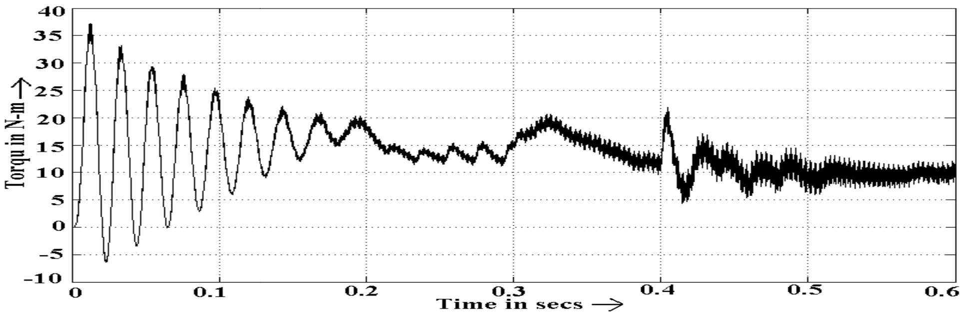

Figure 23: Torque of IM for type-F dip on ASD without Cuk Converter

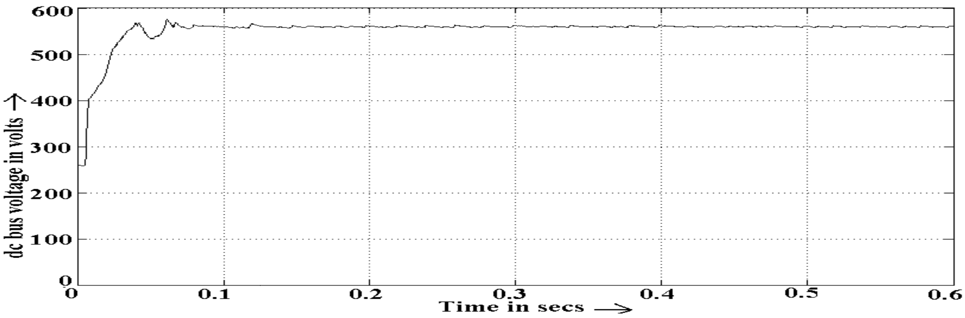

Figure 24: DC bus voltage for type-F dip on ASD with Cuk converter

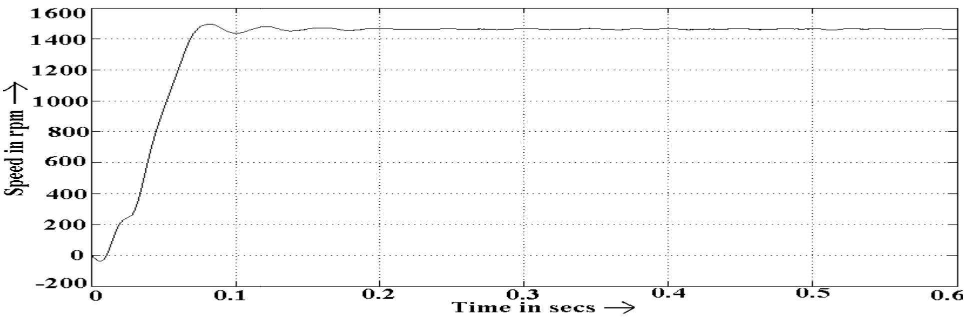

Figure 25: Speed of IM for type-F dip on ASD with Cuk converter

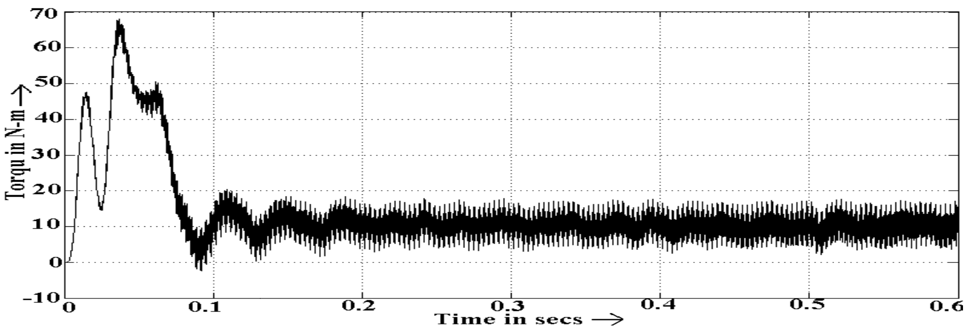

Figure 26: Torque of IM for type-F dip on ASD with Cuk converter

Conclusion

The simulations were carried out to mitigate type A, type D and type F voltage dips and swell using Cuk converter. The Cuk converter has provided a recovery and the performance of the ASD DC-bus voltage get improved under type A, type D and type F voltage dips. From these results, it is concluded that the Cuk converter is fast enough to respond to the abnormal conditions during voltage dips and swell on the adjustable speed drive.

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