Voltage Sag Ride-Through for Adjustable Speed Drives in Industrial Systems

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Abstract: This paper is aimed at providing power/energy to the Adjustable speed drives during unsymmetrical voltage sag conditions by using supercapacitor as an energy storage system. The energy storage device will inject energy at the time of voltage sag and keep the ASDs in operation and hence avoid stoppage of the process in the processing industries. This method will be economical as compared to the existing methods and can be used as a retrofit in the existing industrial ASDs. Boost converter along with supercapacitor as an energy storage device has been used as the hardware to compensate the DC-link voltage because of its simplicity and cheap price. Based on the proposed topology, simulation model in MATLAB 7.5 (Sim Power Block set) has been developed for voltage unbalance conditions with supercapacitor as an energy storage device. The designed control technique is modelled, simulated and successfully implemented in the laboratory. The extensive simulation results supported by experimental results were provided to validate the proposed system.

Keywords: Voltage sag; Supercapacitor; Adjustable speed drives; Power quality; Ride-through

I. INTRODUCTION

The application of adjustable-speed drives (ASD's) in commercial and industrial facilities is increasing due to improved efficiency, energy savings, and uninterrupted process control. However, ASD's are often susceptible to voltage disturbances, such as sags, swells, transients (due to capacitor switching), and momentary interruptions (outages). Electric power quality relates to non-standard voltage, current or frequency deviation that results in failure or misoperation of end-user equipment. According to survey reports, voltage sags of 10%–30% below nominal for 3–30-cycle durations account for the majority of power system disturbances, and are the major cause of industry process disruptions [1-5].

Voltage sags because of balanced three-phase faults or power failure results in the reduction of the voltage on the DC-Link that is proportional to the AC source voltage. This type of voltage sag is the most severe. The under-voltage or over current protection on the DC-Link may trip the ASD's. There are three major negative effects that unbalanced input voltages can have on ASD's. First, unbalanced voltages can create significant input current unbalances that stress the diode bridge rectifiers and input protective devices such as fuses, contactors and circuit breakers. Second, unbalanced voltages typically inject a second harmonic voltage component onto the DC-Link voltage that increases the electrical stresses on the DC-Link choke inductor (if used) and the DC-Link electrolytic capacitors, potentially shortening the capacitor lifetime. Third, voltage unbalances can give rise to ripple torque of magnitude double the fundamental frequency in the ASD's induction machine which increases the mechanical and thermal stresses.[6-7]

II. NATIONAL AND INTERNATIONAL STATUS REVIEW

The review carried out clearly indicates that power shortages in India have had significant negative impacts, in the short term, on the national value added (GDP), and, in the long term, on the growth rate of value added (GDP). At the aggregate level, power consumers in India face power shortages to the tune of 12.6% in peak power (kVA) availability and 7.5% in energy (kWh) availability, it is clear that India's GDP and GDP growth rate will continue to be adversely affected in future [7-9].

In India no comprehensive technique is followed in this context and merely uneconomical solution like providing full rated uninterrupted power supplies are used. Till date, the use of ASDs is quite less, which is otherwise necessary for energy conservation and efficiency. Once the proportion of ASDs is higher than it will be necessary to study the impact of power quality disturbances on these drives.

As per the International Status Review, it is observed that the modern industrial process equipments such as "Adjustable Speed Drives" are often susceptible to power fluctuations and interruptions. The adverse effect of symmetrical faults and its ride-through capabilities has been reported in the literature. To design Adjustable Speed Drives which may 'ride-through' during power supply disturbances is a challenging research work [8-10].

III. EXISTING RIDE-THROUGH TOPOLOGIES

Voltage sag can cause most of its damage to equipment and circuit protection devices when it is cleared. At this point, large voltage and current transients are present, as the system returns to normal. The DC-Link voltage is low (due to the preceding sag), and once full AC voltage is available, the DC-Link capacitor will draw a large recharge current. Pre-charging circuits to reduce initial current when the ASD's are first switched on are normally timed out. This recharging current may even be sufficient to burn out the diodes in the rectifier if the incoming circuit protection does not trip first.

There are many different types of mitigation techniques available to control or mitigate the effect of voltage sags on ASD's. They are based on software control, hardware (such as increasing the DC-Link capacitor size), or a combination (such as a boost converter) [11, 12].

The different ride-through topologies require energy storage devices injecting power at the DC-Link during voltage sags as described in the literature are as follows:

- Adding capacitors across the DC-Link
- Load inertia
- Variable-torque loads variable-torque loads
- Battery backup
- Flywheel and motor-generator (M/G) combination
- Superconducting Magnetic Energy Storage (SMES)

- Supercapacitor

IV. MAIN OBJECTIVE AND PROPOSED TOPOLOGY

The objective of this section is to investigate the performance of an ASD's under three-phase unsymmetrical fault leading to balanced and unbalanced voltage sag at PCC. The proposed topology is designed by using supercapacitor as energy storage device along with boost converter across DC-Link as a ride-through alternative for ASD's.

The performance of ASD's under unsymmetrical fault conditions has been simulated using MATLAB Simulink Power System Block set tool box. The functional block diagram is shown in Figure 1. A three-phase programmable voltage source feeds the power bus to PCC through series impedance (taken as resistance of 0.1 ohm assuming the length of line to be very small). Two independent feeders are connected at this PCC bus; one feeds the ASD's and the other is connected to the load. The faults are created at the load feeder to study the impact of voltage sags on the ASD's connected at the same PCC. The shunt impedance method has been used to generate voltage sags. At the time of faults the fault current flows through the impedance leading to a voltage drop across it, thereby causing voltage sags at PCC.

The ASD's used is a scalar controlled induction motor of specifications 5 H.P, 415 volts (L-L), 3- Phase, 4 Poles, 50 Hz, 1444 rpm and is having a supercapacitors as an energy storage device at DC-Link. A buck-boost DC-DC converter converts the output of the connected energy storage device to the desired DC-Link voltage.

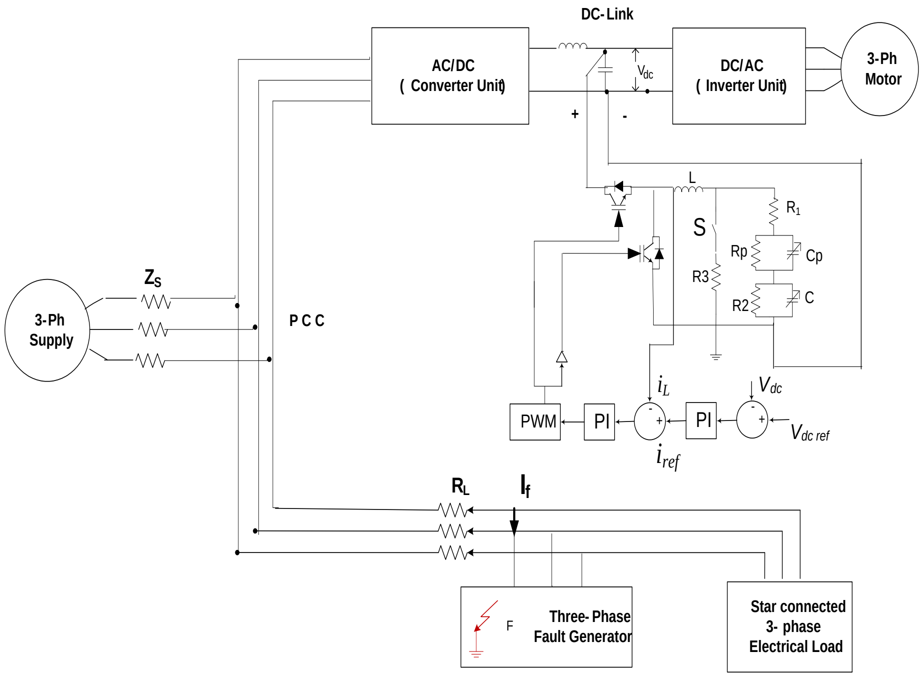


Figure 1. Block Diagram of Proposed Technique.

The hardware set up is shown in Figure 2. It consists of:

a) *AC/DC converter section: This unit consists of uncontrolled three- phase diode bride rectifier.*

b) *DC/AC inverter unit: This unit consists of MOSFET based inverter.*

c) *Energy Storage Devices: The device is a supercapacitor bank of 12V modules. This 12V DC is converted to 220 V DC (for experimental purpose) with the help of buck-boost converter*

d) *Voltage Sag Generator Unit: The various types of faults were created in the lab using shunt impedance method by actually grounding/shorting the line terminals in order to represent the true voltage sag conditions as shown in Figure 1.*

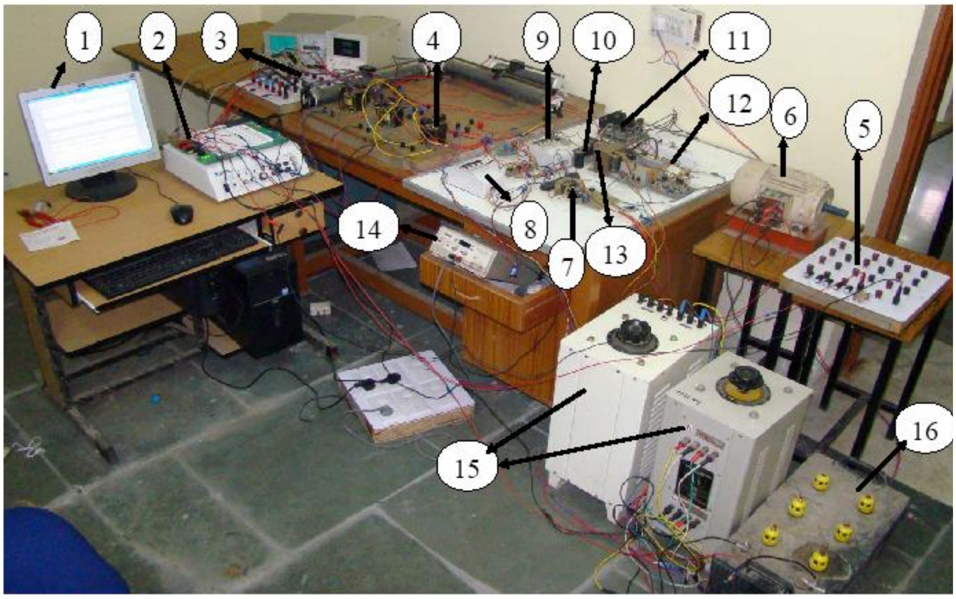


Figure 2. View of Designed Hardware.

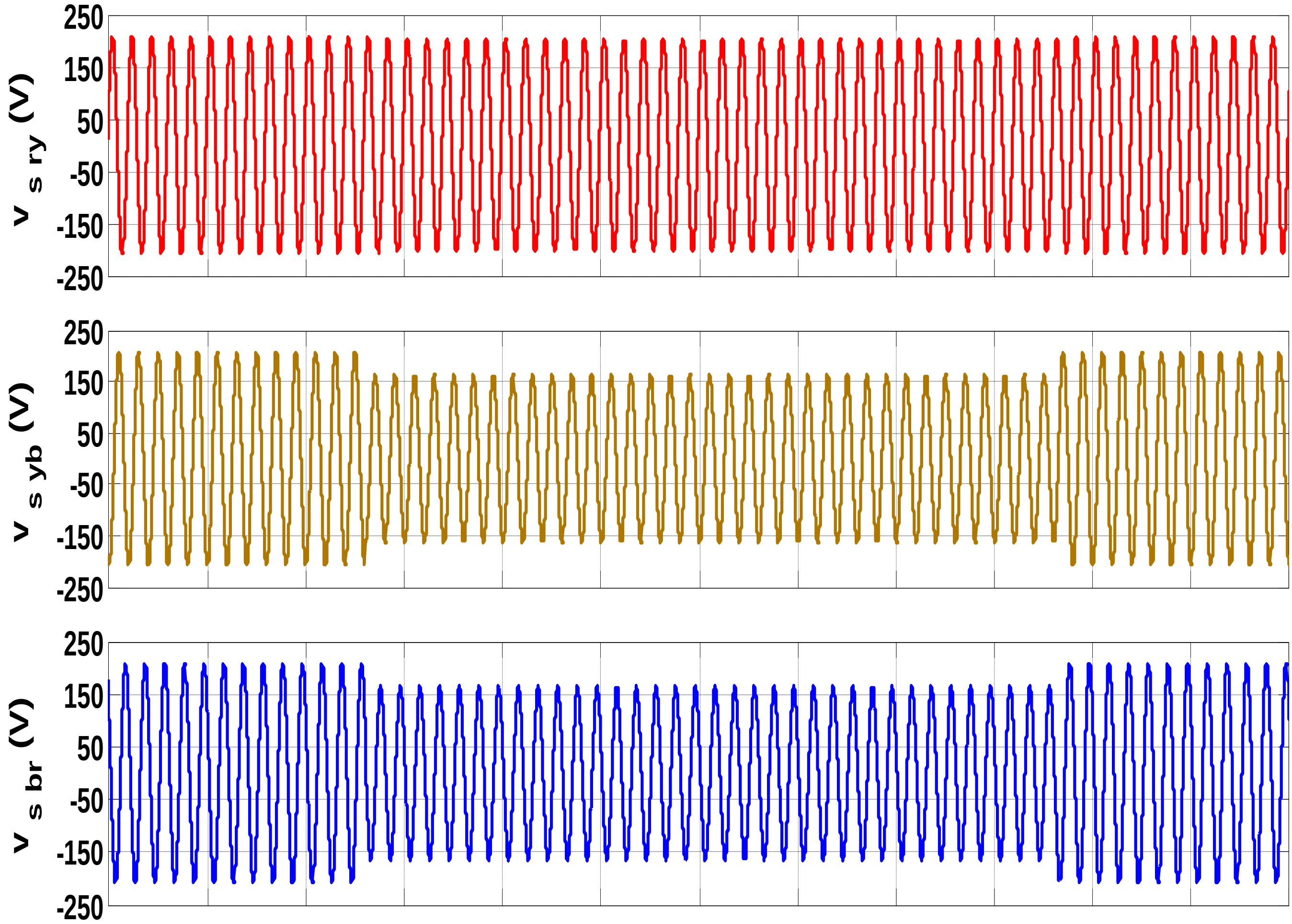
1. Waveform in LabVIEW
2. DAQ board
3. DC isolation circuit
4. Isolation transformer
5. Supercapacitor
6. 3-phase induction motor
7. Sag generator
8. 3-phase supply
9. AC/DC converter section
10. Capacitor bank(DC- link)
11. Adjustable speed drives
12. Boost converter
13. DC- link
14. Function generator
15. 3-phase Auto transformer
16. Battery

V. RESULT AND DISCUSSION

This section gives the performance of ASDs during unsymmetrical (single line to ground-Type-B) fault with and without supercapacitor as an energy storage devices across DC-Link to provide ride-through. At the terminals of three-phase motor observations are also taken to check the effect of various power quality disturbances. The performances of ASD have been simulated in MATLAB and the same was verified by experimental results.

A. *Performance of ASDs during Single Line to Ground (Type-B) Fault without Ride-Through*

The simulation and hardware results for single line to ground fault are shown in Figure 3 to Figure 6. The single line to ground fault was simulated where the three-phase source voltage amplitude drops to a value of about 40% of the pre-event voltage during 1.86 to 2.56 sec about 35 cycles as shown in Figure3 and 4. After the event, voltage returns back to pre sag voltage. During the fault period the three-phase uncontrolled rectifier operates in single phase operation and draws almost, the double current which may actuate the over load protection and trips the ASDs. During the voltage sag the DC-Link voltage drops from 205V to 195 V which is well above the threshold setting at the DC-Link. The DC-Link voltage shows the voltage ripples of twice the fundamental frequency. The electromagnetic torque (T_e) and the speed (w_r) of the Induction motor drops slightly as shown in Figure 5 and Figure 6. The effective motor current during the fault period increases so as to maintain the desired torque as shown in Figure 5 and Figure 6.



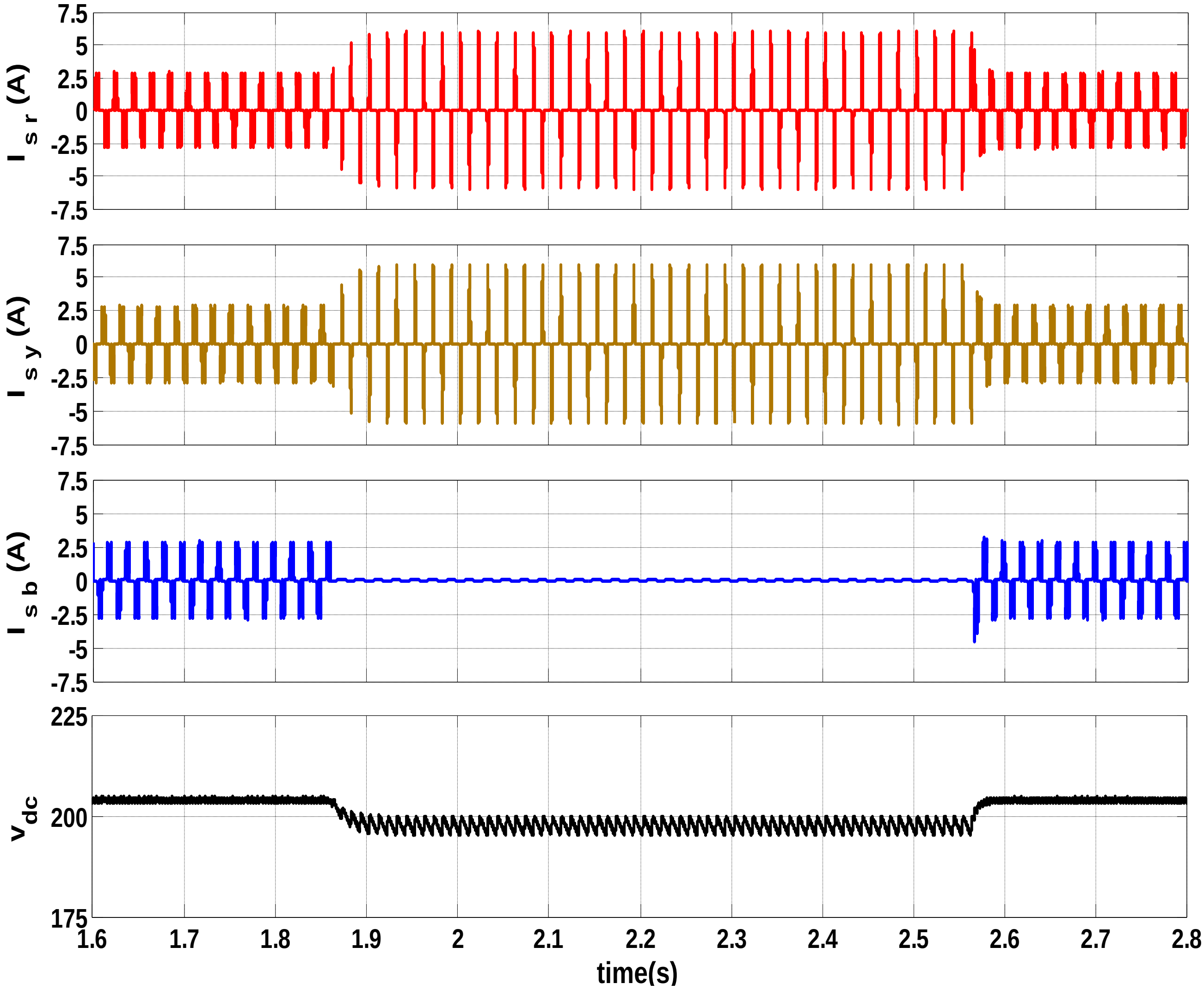


Figure 3. Simulation results showing three-phase source voltages, currents and DC-Link voltage during SLG fault (Type-B) without any ride-through.

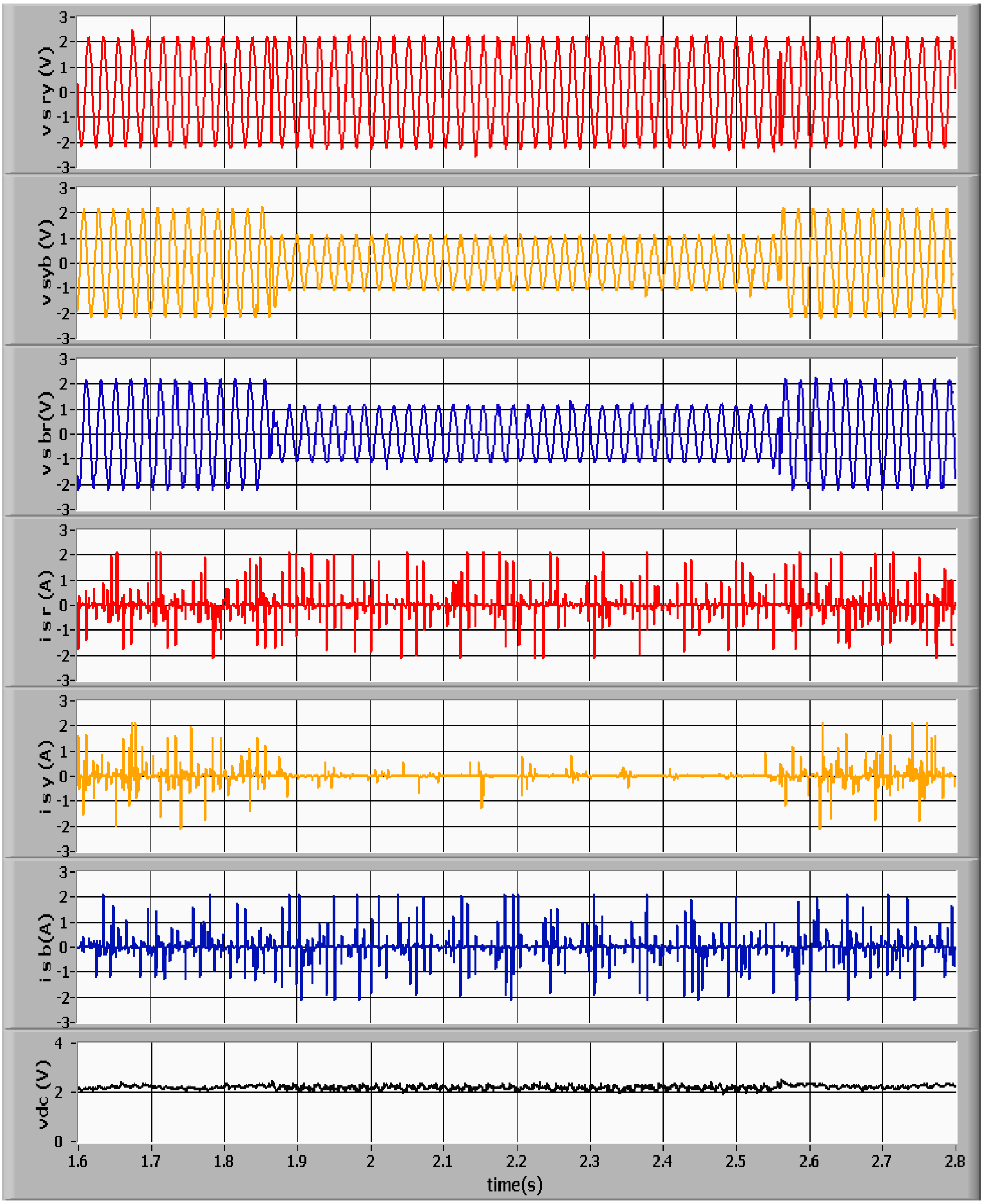


Figure 4. Experimental Results showing three-phase source voltages, currents and DC-Link voltage during SLG fault (Type-B) without any ride-through. Voltage scale: 100 V per division. Current scale: 2.25 A per division. DC-Link Voltage scale: 100 V per division.

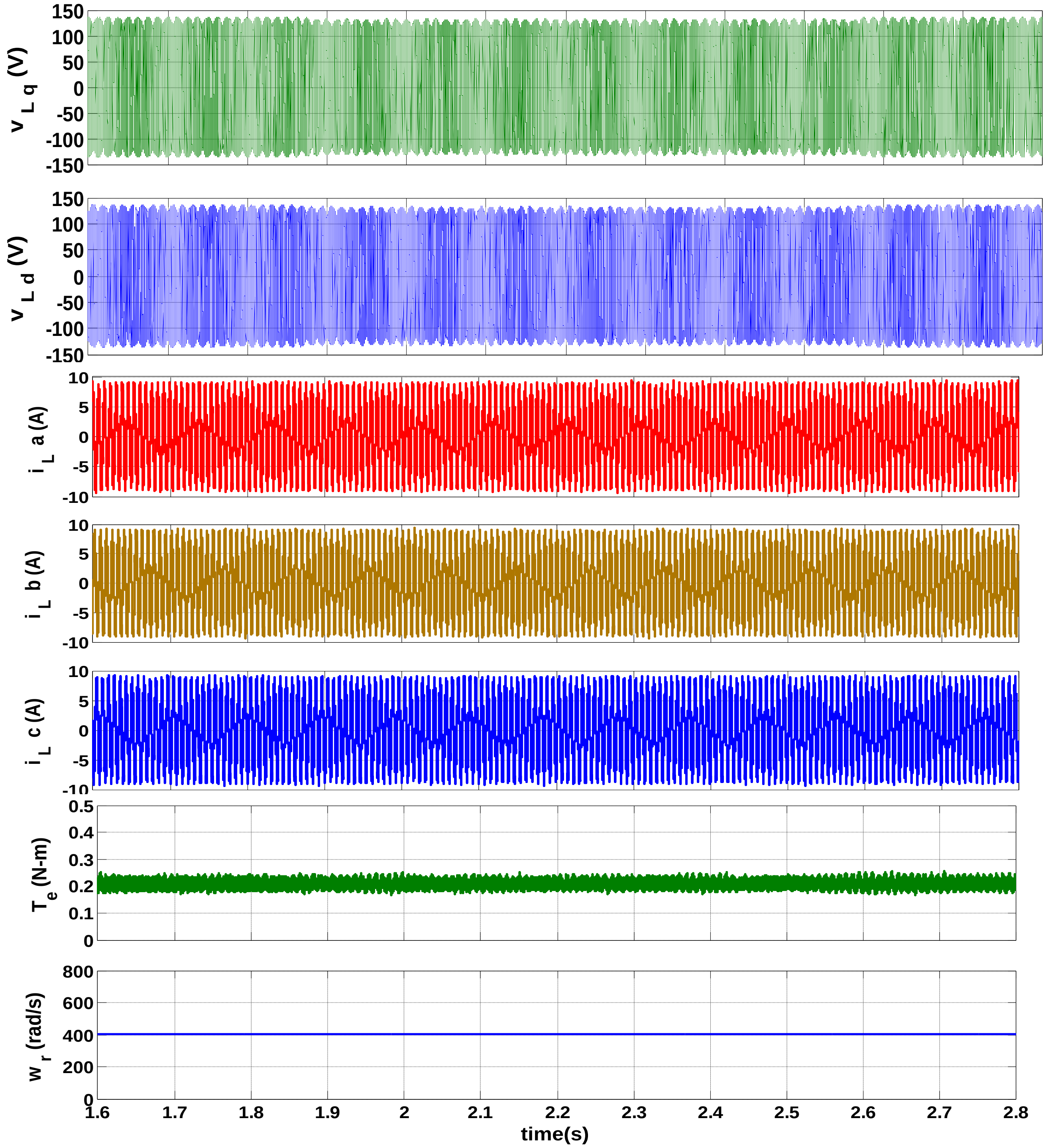


Figure 5. Simulation results showing stator voltages in d-q frame, three-phase stator Currents, electromagnetic torque and rotor speed during SLG without anyride-through.

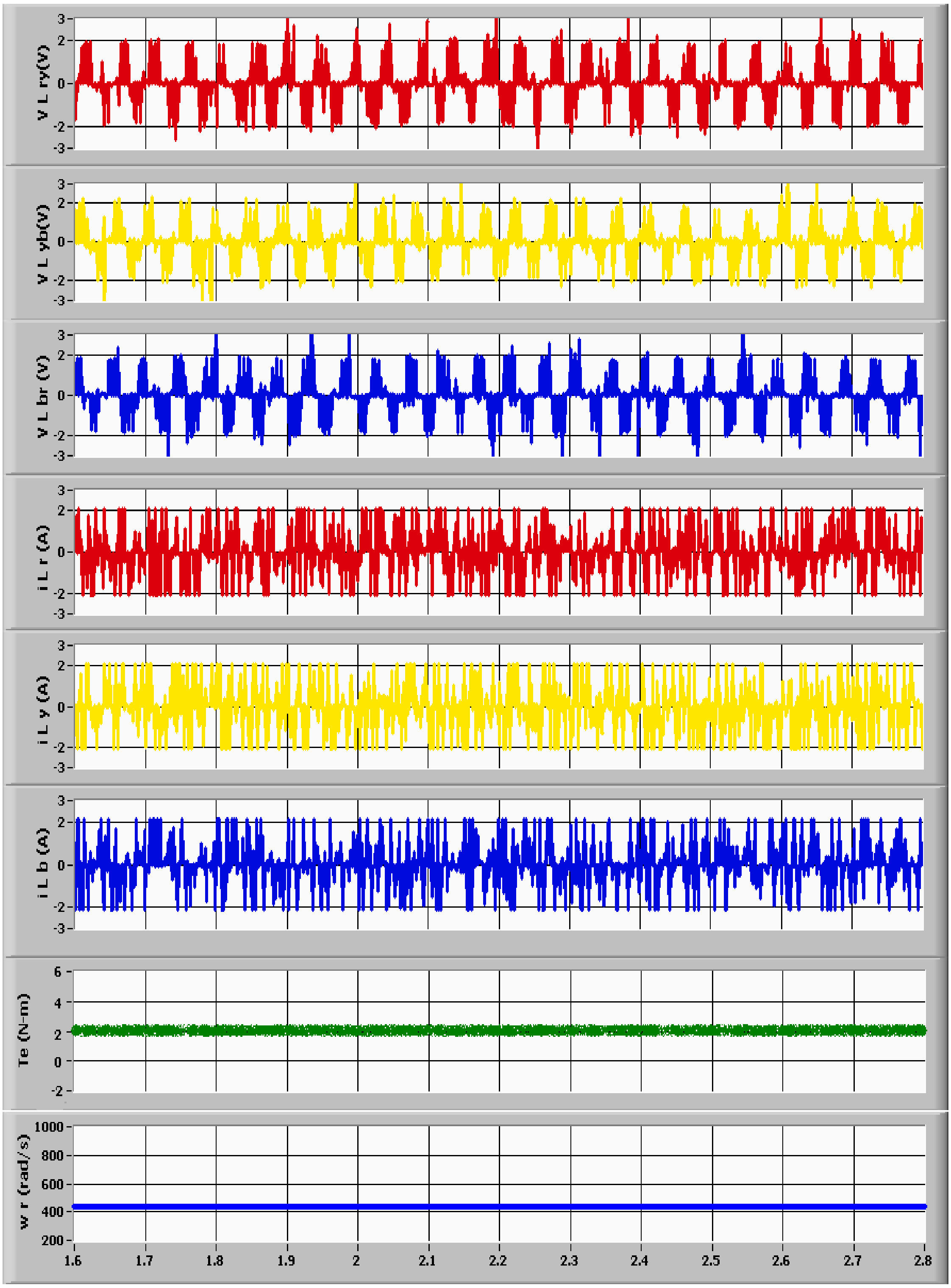


Figure 6. Experimental results showing three phase stator voltages, three-phase stator currents electromagnetic torque and rotor speed during SLG fault without providing any ride-through. Stator voltage scale: 100 V per division. Load current scale: 10 A per division. Electromagnetic Torque scale: 1 N-m per division. Rotor Speed scale: 1 rad/s per division.

B. *Performance of ASDs during Single Line to Ground (Type-B) Fault with supercapacitor as Ride-Through alternative*

The simulation and hardware results, shown from Figure 7 to Figure 8 under unsymmetrical fault condition, are an example of voltage sag of Type-B (Line to Ground Fault) with supercapacitor as a ride-through capability connected across DC-Link through Boost Converter. A supercapacitor bank of 5 F, 13.5 V (25F, 2.7V , 5 Nos. connected in series) The amplitude drops to a value of about 75% of the pre-event voltage during 2.05 to 2.58 sec about 27 cycles. The compensation provided by the supercapacitor bank is much faster as compared to other energy storage devices. The motor side three-phase voltages, currents, electromagnetic torque and rotor speed are also shown in Figure9 and Figure 10. The result shows the improvement in the current being drawn by the rectifier. A supercapacitor bank is able to provide required ride-through.

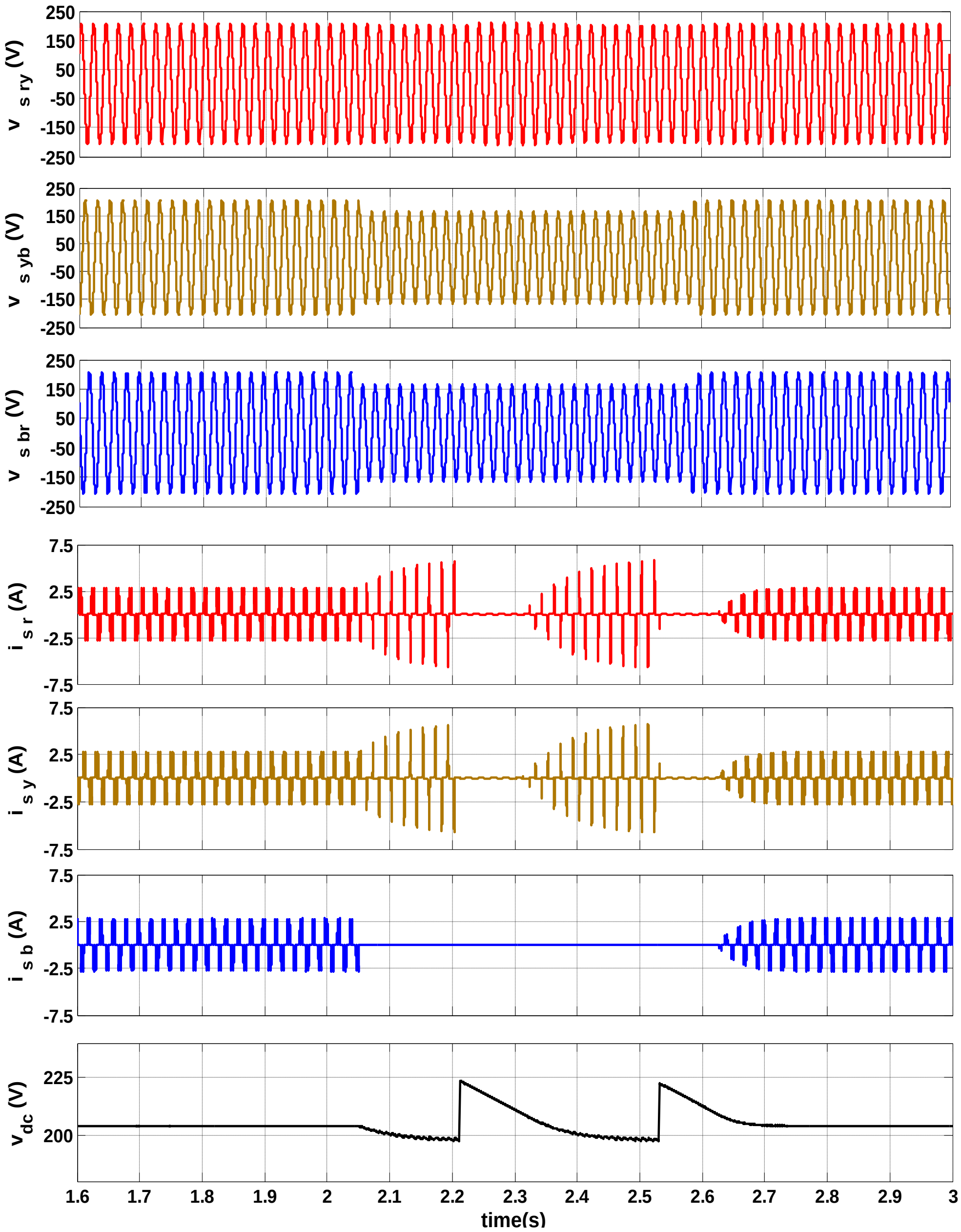


Figure 7. Simulation results showing three-phase source voltages, currents and DC-Link voltage during SLG fault(Type-B) with supercapacitor as ride-through alternative.

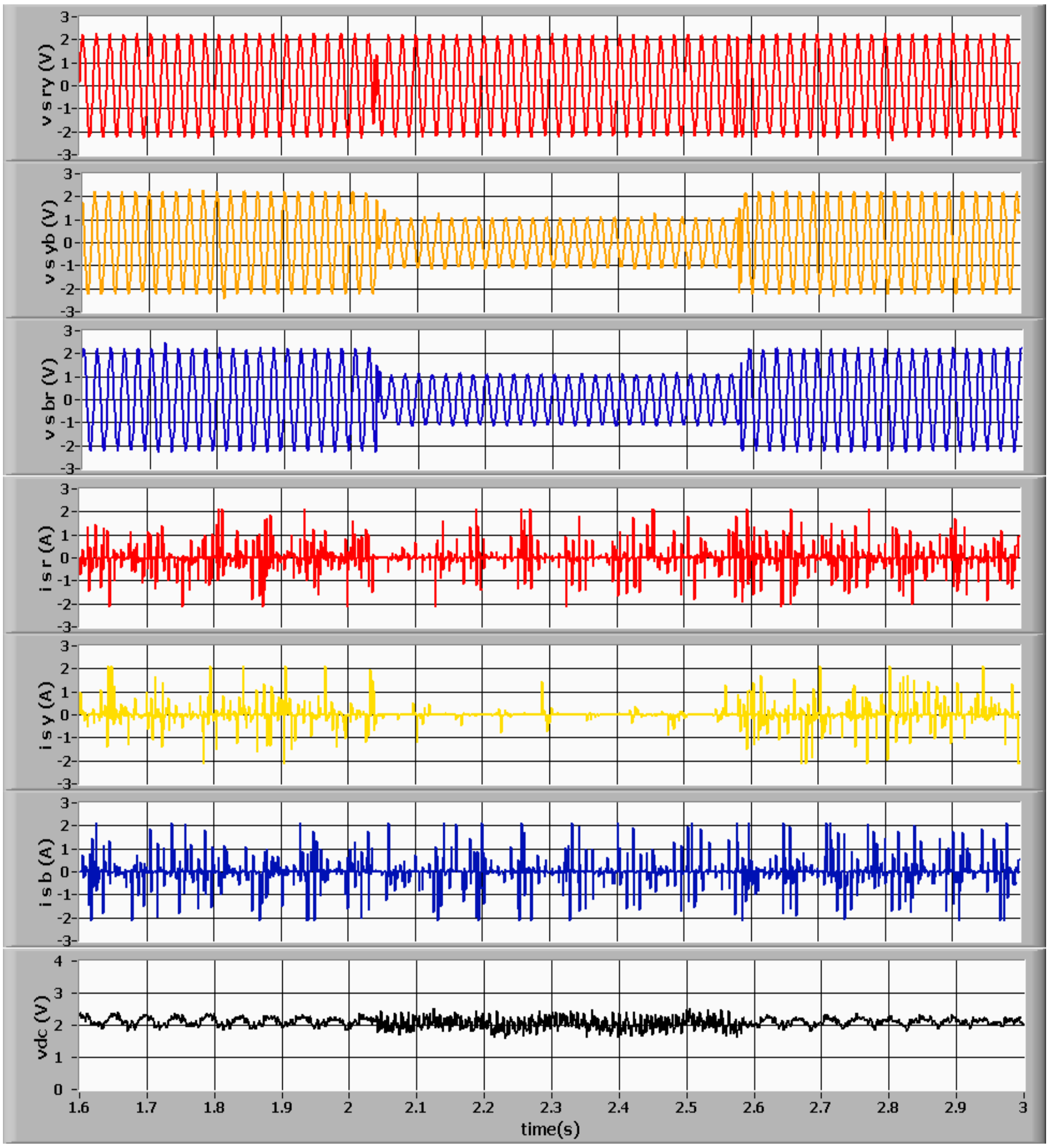


Figure 8. Experimental results showing three-phase source voltages, currents and DC-Link voltage during SLG fault(Type-B) with supercapacitor as ride-through alternative. Voltage scale: 100 V per division. Current scale: 2.25 A per division. DC-Link Voltage scale: 100 V per division.

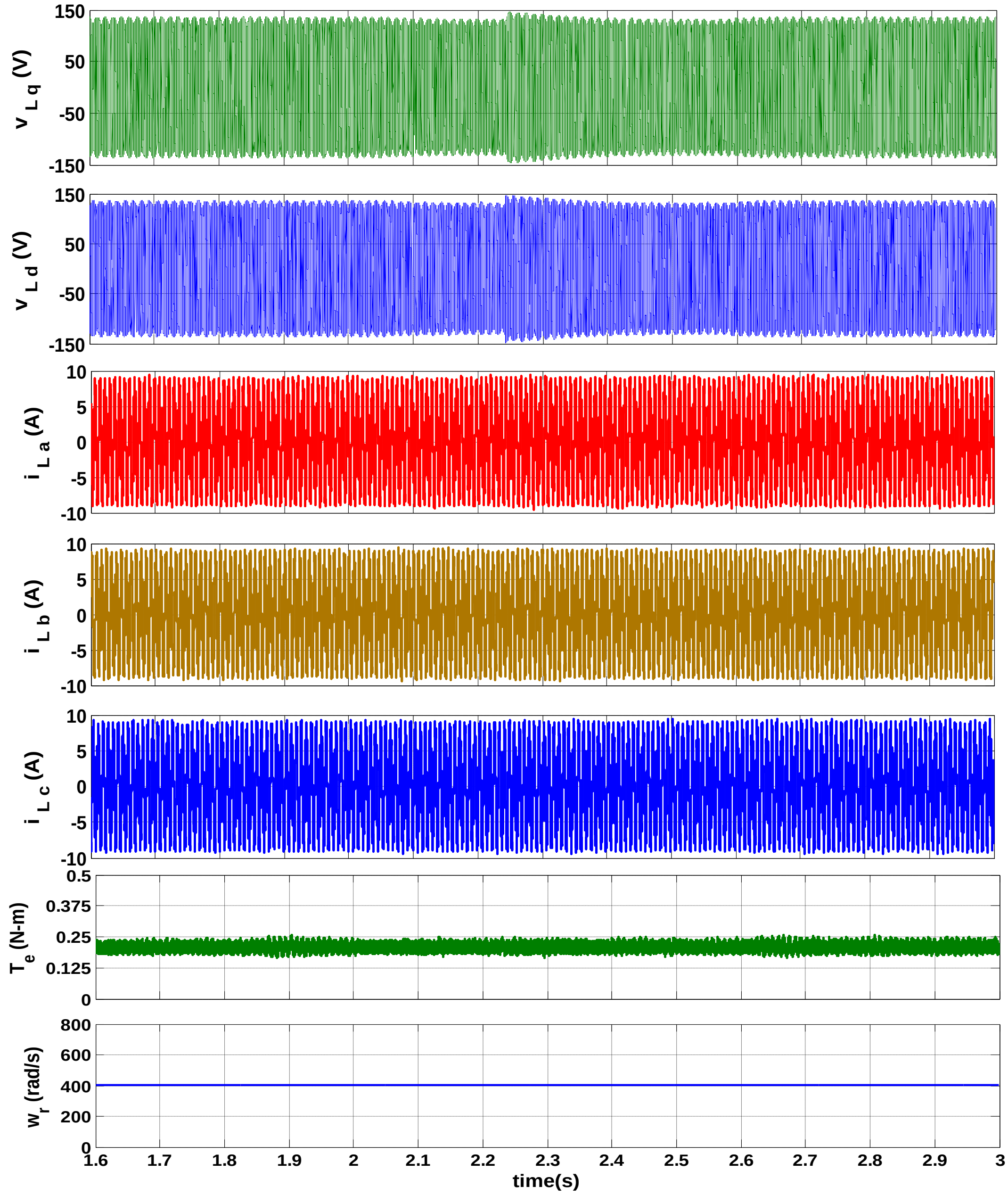


Figure 9. Simulation results showing stator voltages in d-q frame, three-phase stator currents, electromagnetic torque and rotor speed during SLG fault (Type-B) with supercapacitor as ride-through alternative

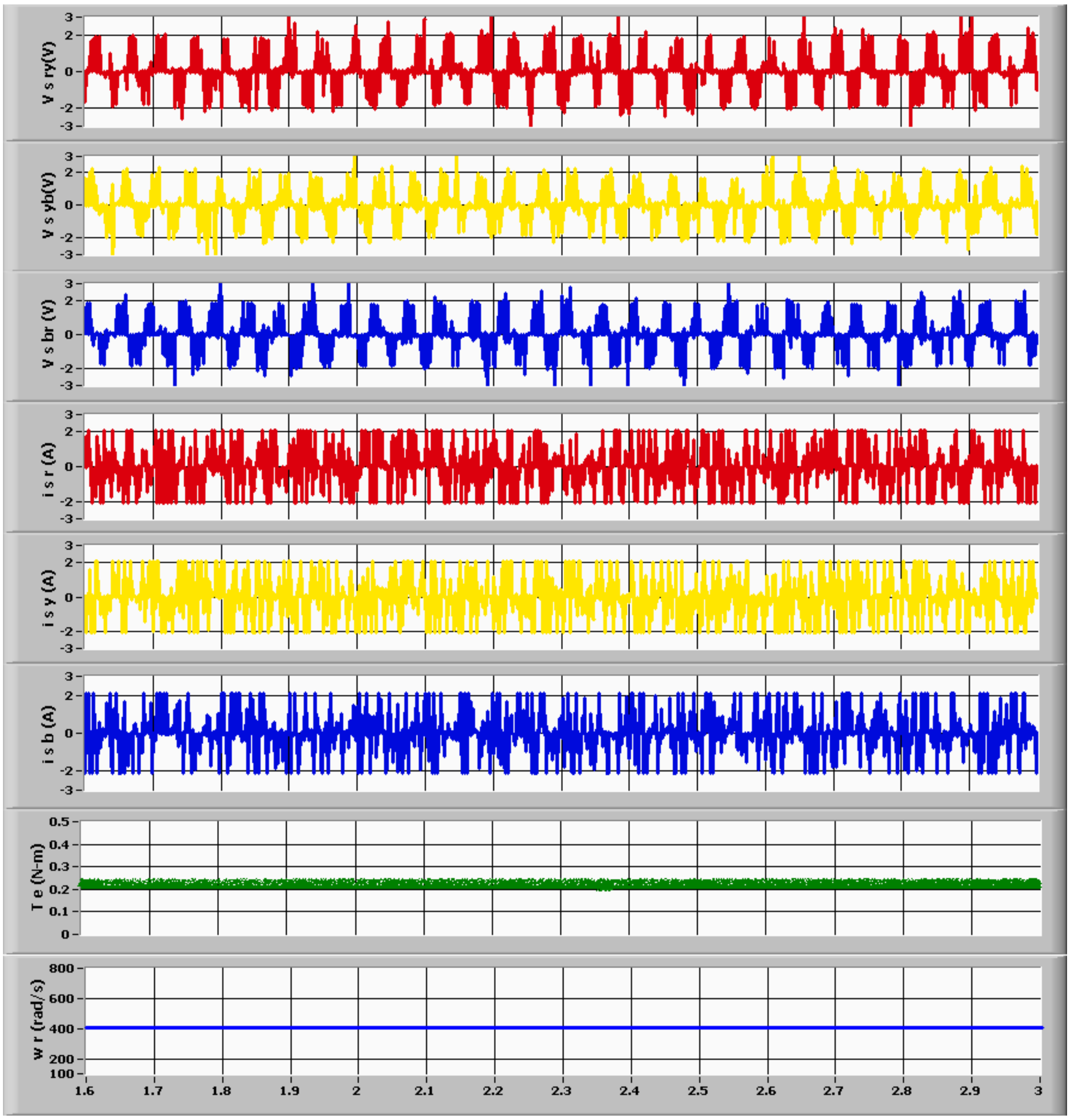


Figure 10. Experimental results showing three phase stator voltages, three-phase stator currents, electromagnetic torque and rotor speed during SLG fault (Type-B) with supercapacitor as ride-through alternative. Stator voltage scale: 100 V per division. Load current scale: 10 A per division. Electromagnetic Torque scale: 1 N-m per division. Rotor Speed scale: 1 rad/s per division.

VI. CONCLUSION AND FUTURE WORK

The proposed topology is capable of providing ride- through during unsymmetrical voltage sags so as to avoid the nuisance tripping of the ASD's. The effectiveness of the proposed topology has been verified by means of simulations based on MATLAB and experimental results obtained on a laboratory prototype. From the results it is clear that the supercapacitor's dynamic response is fast enough to respond to the load transient requirements and avoid the affects of the various power quality disturbances on the adjustable speed drives. The supercapacitor maintains the DC-Link voltage thereby reduces the input inrush current. Based on the results the performance of these energy storage systems for the above objective shall be compared and recommendations shall be given to employ these for different processing industries. This will have economic benefits in these industries.

Based on the above, the impact of other power quality issues on the process industries like food and beverages, paper, textile etc shall be studied and investigated through experiment work/simulation.

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