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Modeling and Analysis of Shared/Common DC Bus Operation of AC Drives (Part I)

Ajith. H. Wijenayake
Rockwell Automation
Adv. Tech Labs
1201 S. Second Street
Milwaukee, WI 53154
(414) 382-5798

Tom Gilmore & Rich Lukaszewski
Rockwell Automation
Standard Drives
West Enterprise Drive
Mequon, WI 53092
(414) 242-8261 (414) 242-7155

Dale Anderson & Gary Waltersdorf
Rockwell Automation
Applications Engineering
West Enterprise Drive
Mequon, WI 53092
(414) 242 8419 (414) 242 8331

ABSTRACT- The Shared/Common bus operation of AC drives is becoming popular in many industrial applications due to it's advantages such as cost reduction, reduced space requirements, and improved reliability. Depending on the application requirements, there are presently two methods to interconnect DC buses of AC drives; Shared-bus and common-bus. Very little or no work has been done in analyzing the use of such system configurations in industrial applications. In a shared-bus configuration, complete drive units are connected through dc bus fuses to form a common bus. These schemes require individual devices for protection and control, and still may cause bus fuse failures due to poor coordination among each drive's DC bus precharge circuits consisting of different converter front ends, such as diode and SCR. During the normal motoring operation of such systems, the proper load sharing of input converters must also be ensured, not to cause any device failures or nuisance tripping by exceeding the front end converter ratings. This may also require additional hardware between positive and negative busses depending upon the precharge configurations. The common bus drive systems used in a coordinated system can also be beneficial to user by using regenerative energy of larger drives to supply the other small drives which are motoring. The reliability of such operations must be ensured by analyzing the system and properly selecting the bus fuse sizes. The other version of common bus configuration is the concept of one large converter supplying many inverters to reduce the number of supporting components. However, as the number of parallel drives increases it is difficult to select the proper device ratings by testing. Therefore, an analytical method to determine the way of connecting the system with right components is an essential to the system integrator. This paper analyzes the different shared/common bus configurations in precharging, motoring and regenerating, and addresses how to select the components, and connect the system together to ensure a trouble free operation, using PSpice simulations.

1.0 INTRODUCTION

The shared/common bus operation of AC drives are being employed in coordinated industrial drive systems due to the opportunities available in cost reduction of capital expenditures, commissioning and maintenance. Applications with few as two AC drives can benefit from shared/common bus operations. As the number of drives in the system increases, the complete analysis becomes very tedious, but becomes essential to ensure the trouble free operation. Typical applications of shared/common bus include motoring and regenerative applications such as centrifuges, winders, sawmill (Chip-n-Saw) , textiles(post spinning process) and test stands. Regenerative applications typically use a dc shunt brake to absorb the regenerative energy, although this energy can be used to supply other motoring loads in a shared bus configuration by connecting the DC buses through properly rated fuses. The common bus applications either have a regenerative converter or rely on a net motoring load, in which case the regenerative drive(s) will partly or fully supply the motoring loads. Figure 1 shows a two drive shared configuration in the form of block diagram. In shared/common bus applications the front end converters, which may consist of different type of configurations and pre-charge control schemes, are tied together at the capacitor nodes through bus fuses. The front end converters may consist of either diodes or thyristors, as shown in Figure 2.

In a diode front end converter, the pre-charge circuit may either be in series with the DC link capacitor bank or in series with the DC link inductance. In a thyristor front end the pre-charge is achieved by decreasing the firing angle gradually from 180 to 0 degrees, over a predetermined duration [1]. Therefore, when they are connected together, the system behavior during pre-charging, motoring and regenerating, is always adversely affected due to poor co-ordination of pre-charging control and converter configurations.

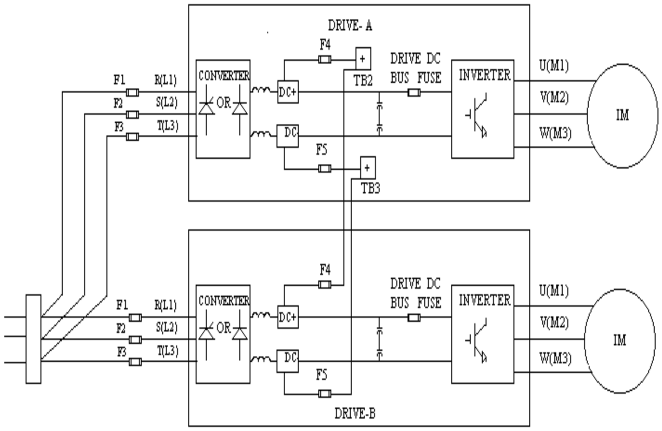

Figure 1. Two drive shared DC bus configuration.

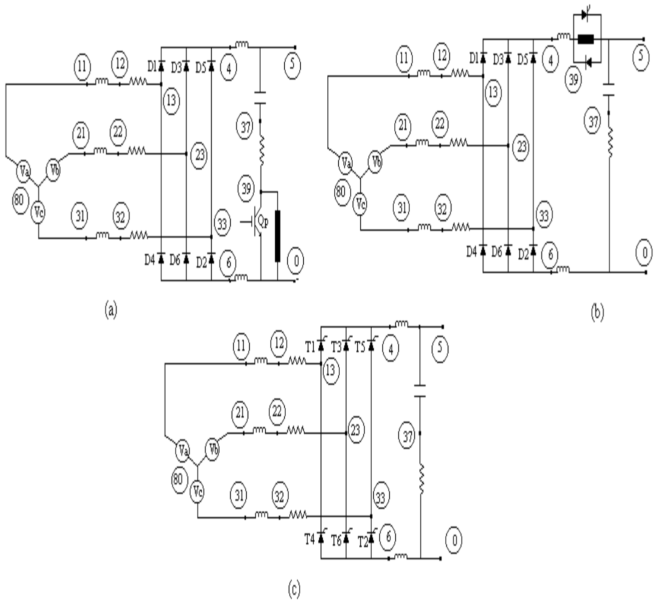

Figure 2. Front end converter models with pre-charge circuits.

This makes it very difficult to develop a set of general guidelines for shared/common bus applications. Therefore, it is a must that one analyzes each shared/common bus configuration on individual basis to study the possible current levels during all modes of operation, and then select the components and connect the system, based on such values. Otherwise, there is a significant risk of misapplication of drives that could result in drive damage or frequent system failures.

2.0 MODELING OF FRONT END CONVERTER AND PRE-CHARGE OPERATION

In diode front end, the pre-charge control is simulated using a voltage controlled switch, and with SCR front end it is simulated using the fact that during pre-charge, the SCR's gate pulse frequency, whose value depends on pre-charge duration, is constant , but differs from the utility frequency. Since the device forward voltage drop and other parasitic characteristics have a dominant effect on the current sharing between the converters, it is essential that the main power devices in the front end converters are modeled accurately to reflect the actual conditions. In a shared bus system, any of the above converters with different pre-charging schemes and pre-charge intervals, may be connected together, except type (a) to type (c). This configuration causes current surges through diode front end and bus fuses due to thyristor converter's uncontrolled pre-charging through diode front end. Figure 3 and Figure 4 show the typical pre-charging wave forms for a diode front end and a thyristor front end.

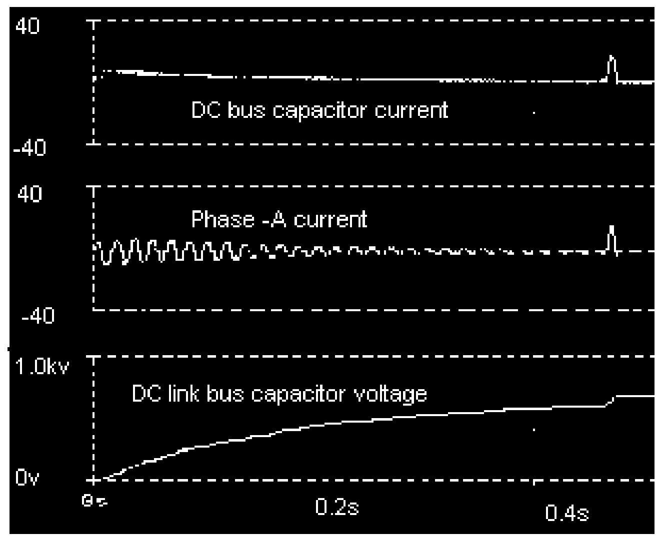

Figure 3. Typical pre-charge wave forms for a diode converter.

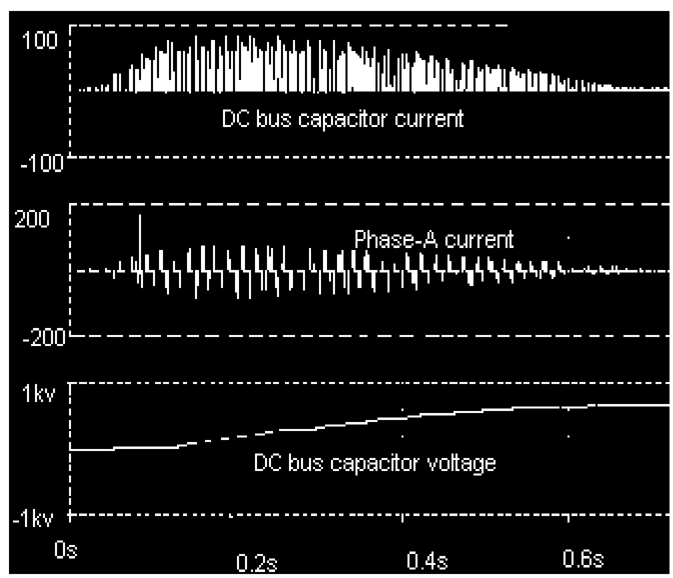

Figure 4. Typical pre-charge wave forms for a SCR converter

The current pulse which occurs towards the end (Figure 3), is due to pre-charge resistor cut-off. In this study the parallel operation of a 7.5 HP and a 125 HP drives with diode front ends, and a 7.5HP diode front end drive with a 125HP SCR front end drive, are analyzed.

3.0 PARALLEL OPERATION OF 7.5 HP AND 125 HP DRIVES WITH DIODE FRONT ENDS

3.1 *Analysis During Pre-charging*

Parallel operation during pre-charging, with different pre-charge times, must be analyzed to ensure that the small drive's power diode and capacitor RMS ratings are not exceeded, and to determine the maximum bus fuse currents, and circulating currents if there is any. Figure 5 shows the precharging and bus fuse currents, and DC link voltages. Figure 6 shows the how the smaller drive's line currents are increased due to current sharing tendency.

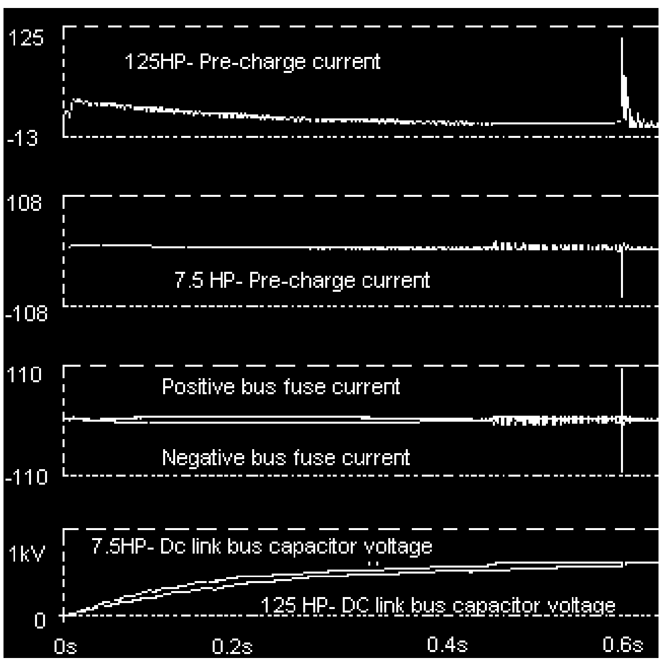

Figure 5. DC link voltage, bus fuse and dc bus capacitor current

Figure 7. Shows the effect due to difference in pre-charge duration. The event is characterized by two current surges in the fuse, and additional ripple current in small drive's bus capacitor. The current surges which occur due to the pre-charge transient flow through bus fuses, and they are very much higher than the current which would have occurred if the drives were operating independently. If there are many drives with the same pre-charge time, then the current surge would be much larger due to the coincidence of the each transient.

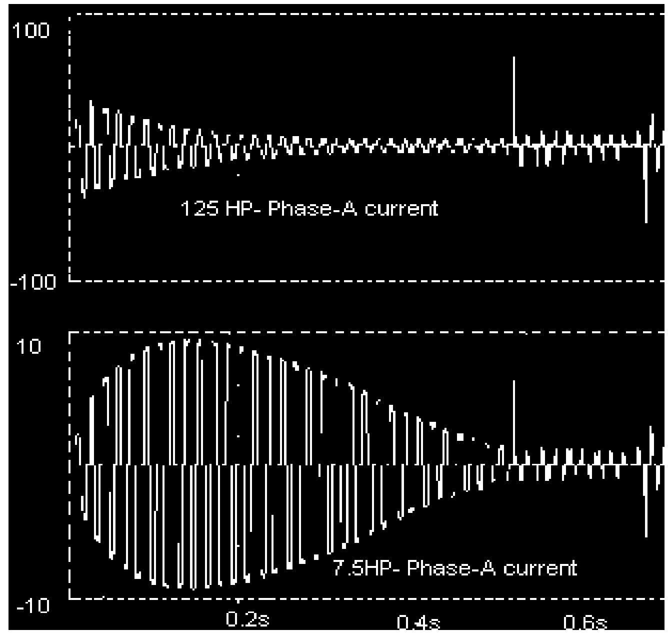

Figure 6. Phase-A line currents.

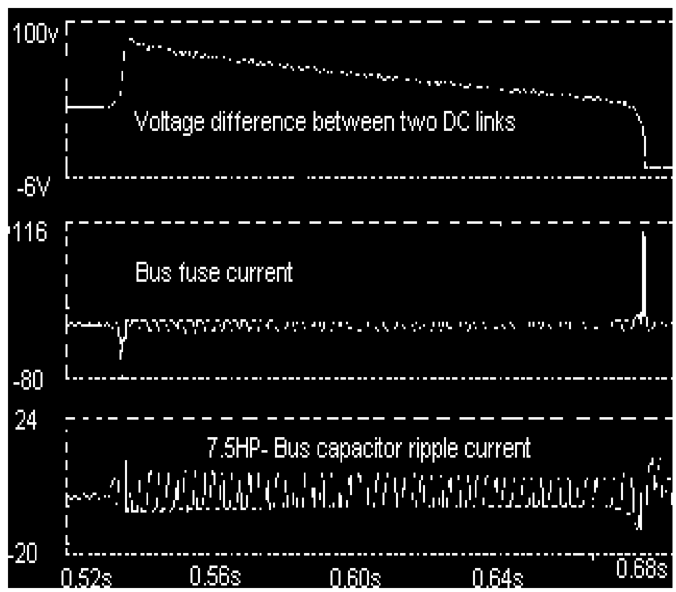

Figure 7 Effect due to different pre-charge times

If there are many drives with different pre-charge time, then this event would occur between each transient until all the drives are pre-charged. The cumulative effect of this event may cause additional bus capacitor heating and excessive diode currents in smaller drives, during frequent power ups. For the simulated case, the current surge has a peak magnitude of 106 Amps and a duration of about 3ms. Therefore, the bus fuses should be rated to exceed the equivalent I^2t value of the surge. Table 1. Shows the comparison among the device stresses during independent and parallel operation of the drives in pre-charge mode. In 7.5 HP drive there are about 100% increase in diode current and about 26% increase in capacitor RMS current, while the bigger drive shows a reduction of about 24% and 19% in diode and capacitor currents respectively. Although these increments lie within the smaller drives ratings, they may exceed the device ratings, depending on the number of drives connected in parallel or on the size of the bigger drive.

TABLE 1.
DEVICE STRESSES IN INDEPENDENT AND PARALLEL PRE-CHARGING.

Configuration	Id (RMS)	Ic (RMS)
7.5 HP only	2.66	4.20
125 HP only	13.63	17.56
7.5/125 Parallel		
7.5 HP	5.20	5.30
125 Hp	10.34	14.22

3.2 Analysis During Motoring and Regeneration

3.2.1Pspice Modeling of Inverter and Induction Motor

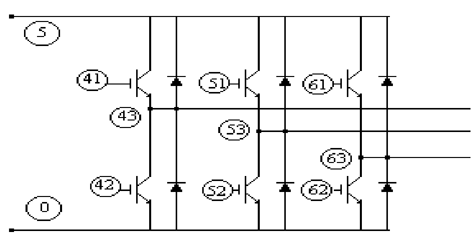

Figure 8. PWM inverter main power devices model.

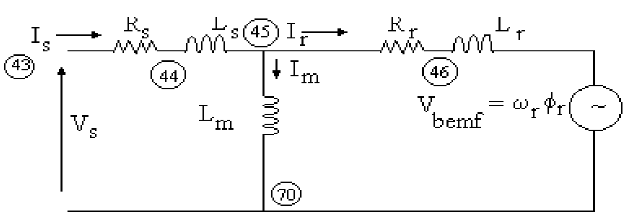

Figure 9. Phase- A of induction motor model.

Figure 8 and Figure 9 show the equivalent Pspice inverter and motor model used. The dead time required for the upper and lower power devices is obtained by off-setting the two triangular carrier waves with respect to each other [2]. In the Pspice program, in addition to the parameters shown in Figure 9, efficiency, power factor angle, rated voltage and frequency , and the motor loading factor should be included in order to facilitate for the determination of the equivalent back EMF and hence the equivalent per phase diagram for volts/Hz operation of the motor.

3.2.2 Analysis during Motoring and Regenerating

Using 7.5 HP and 125 HP induction motor parameters, the shared bus system was simulated when both drives were supplying the full load for motoring , and when 125 HP was regenerating and 7.5 HP was motoring. Figure 10 shows the 5 HP drive's currents and positive bus fuse current, while Figure 11 shows the same for the 125 HP drive during parallel operation. Table 2 shows the complete data for different modes of operations. This shows that the 7.5 HP drive's DC bus capacitor current is increased beyond the rated values in motoring and regenerating modes, resulting in high fuse currents. This can be solved by connecting back-to-back diode in series with positive and negative fuses, as shown in Figure 12. This will reduce the currents to lower levels, during all modes of operation, as shown in last two rows of Table 2, and in Figure 13.

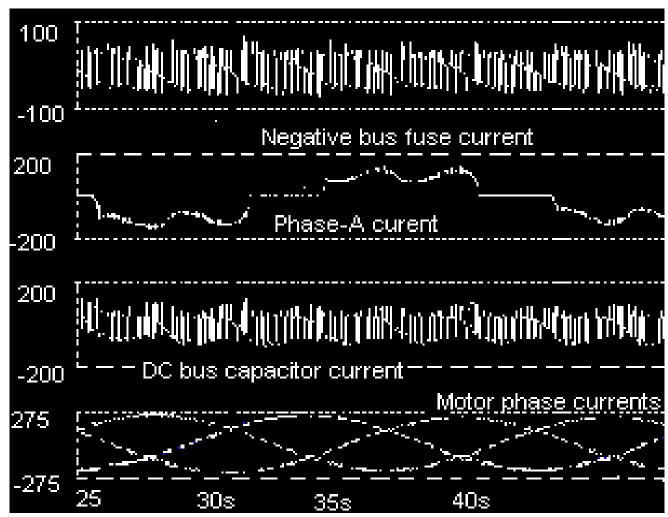

Figure 10. 7.5 HP Drive's currents and positive bus fuse currents.

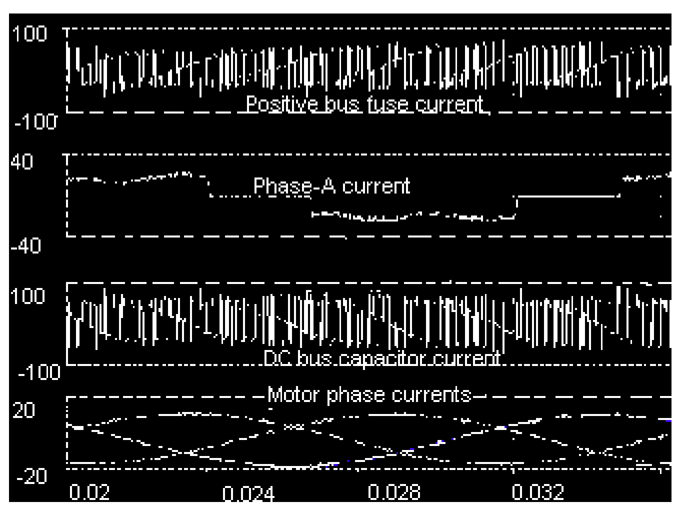

Figure 11. 125 HP Drive's currents and negative bus fuse current.

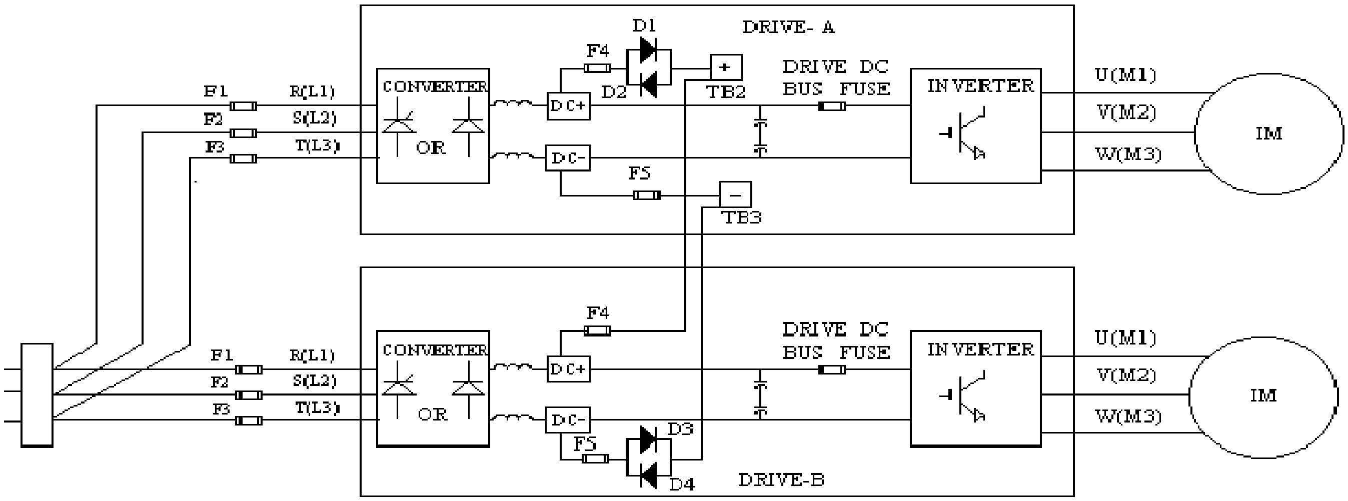

Figure 12. DC bus shared drive system via back-to-back diode connection.

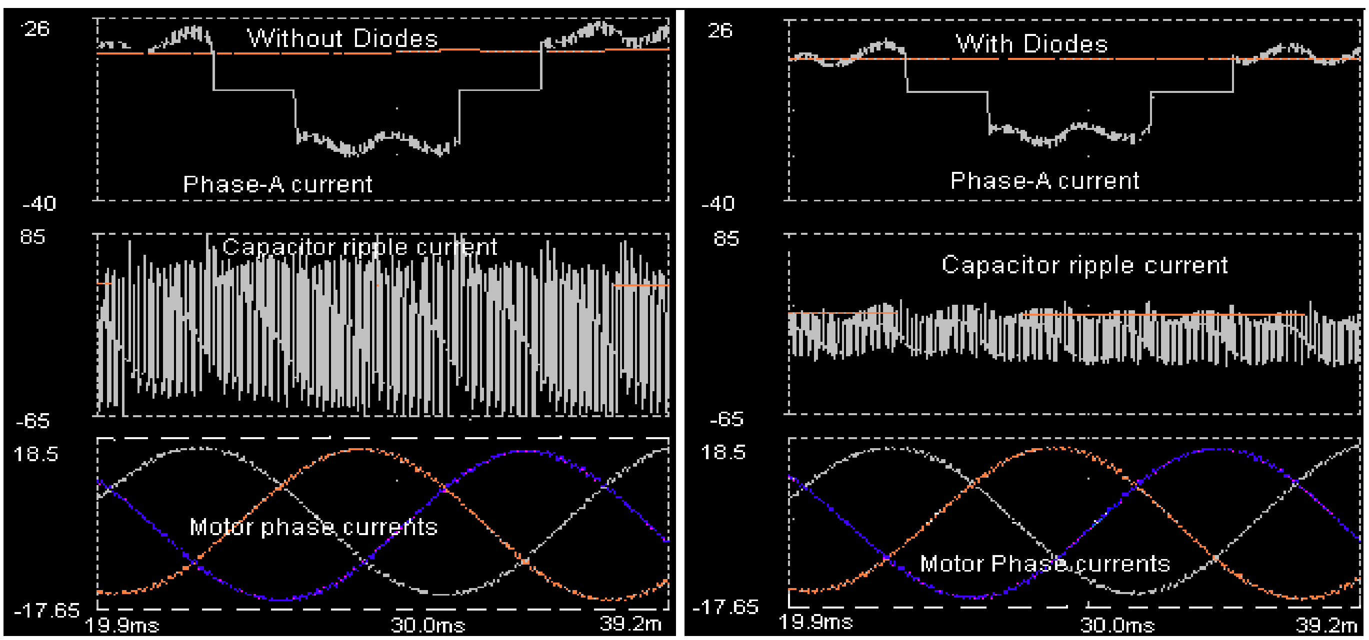

Figure 13. Smaller drive's capacitor and diode currents for the same motor currents with and without back to back diodes.

3.3 Parallel Operation of 7.5 HP Diode Front End Drive and 125 HP Thyristor Front End Drive

Parallel operation of type (b) diode front end with SCR front end is also possible since the pre-charge resistor can control the thyristor front end charging current, which flows through diodes. Table 3. Shows the simulated data for three modes of operation for this configuration. In this parallel operation, a large amount of 125 HP load current is fed through the diode front end and bus fuses, due to higher forward drop of the power thyristors, as shown in Table 3. This could be avoided by connecting the busses via back to back diodes.

TABLE 2.
CURRENTS DURING INDEPENDENT AND PARALLEL OPERATION OF TWO DIODE FRONT END DRIVES.

System Configuration	Im (RMS)	Ic (RMS)	Id (RMS)	Ifuse (RMS)
7.5HP only (motoring)	12.42		7.5	N/A
125HPonly (motoring)	165.4	90.65	100	N/A
7.5/125 Parallel				
7.5 HP Motoring	12.42	43.75	13.75	36
125 Motoring	165.4	78.125	106.25	36
7.5 Motoring	12.42	44.44	00	44
125 Regenerating	165.4	84.44	00	44
7.5/125 Parallel +Diodes				
7.5 Motoring	12.57	16.88	11.55	11.11
125 Motoring	167	97.00	100.00	11.11

4.0 FUTURE PLANS TO BE COMPLETED

Future work will include the validation of simulated data with experimental data to verify the accuracy of the modeling and the results. This will include two, three and four shared bus systems consists of different configurations (part II).

5.0 CONCLUSIONS

The Shared/Common bus operation of AC drives is becoming popular in many industrial applications due to it's advantages such as cost reduction, reduced space requirements, and improved reliability. However, due to their poor coordination of their converter sections, during pre-charge as well as during motoring and regeneration, the rectifier sections of the drives may not share current well. This also results in a unexpected high current through the bus fuses . Also , when there are many drives connected in parallel, additional circulating current may occur between drives. Therefore, before connecting busses together, exact analysis of the system is recommended to ensure the proper operation of the system under all modes of operation. The type of analysis described in this paper becomes very attractive in such system studies, specially when there are many drives tied together with increased complexity.

6.0 REFERENCES

[1] Tom Gilmore & Gary Skibinski, " Pre-charge Circuit Utilizing Non-linear Firing Angle Control", IEEE- IAS Annual Meeting, 1996, pp 1099-1105

TABLE 3.
CURRENTS DURING PARALLEL OPERATION OF DIODE FRONT END AND SCR FRONT END DRIVES.

System Configuration	Im (RMS)	Ic (RMS)	Id/Iscr (RMS)	Ifuse (RMS)
7.5/125 parallel				
7.5 HP precharging	N/A	5.23	23	28
125 HP precharging	N/A	29	16.87	28
7.5 HP motoring	12.26	15.86	36	38
125 Motoring	166.67	98.5	74.20	38
7.5 Motoring	12.40	20	00	15
125 Regenerating	167.00	102	00	15
7.5/125 Parallel +Diodes				
7.5 Motoring	12.21	9.84	15	12.8
125 Motoring	166.7	95.38	91.67	12.8

[2] Ned Mohan, " Power Electronics: Computer Simulations, Analysis, and Education Using Pspice", Minnesota Power Electronics Research & Education, University of Minnesota.