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Immunity of Integrated Drive System, Effects of Radiated and Conducted Emission

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***Abstract*—**In this paper the problems associated with immunity of embedded systems used in Motor-Drive systems are investigated and appropriate solutions are presented. Integration of VSD motor systems (Integral Motor) while partially reducing some of these effects, adds to immunity problem of their embedded systems. Fail safe operation of an Integral Motor in arduous industrial environments is considered. In this paper an integral motor with a unique design is proposed to overcome critical issues such as heat, vibration and electromagnetic interference which are damaging to sensitive electronics without requirement of any additional cooling system. Advantages of the proposed Integral motor are compactness of combo motor and drive system with no external cabling/wiring. This motor provides a perfect shielding for least amount of radiated emission. It has an inbuilt filter for EMC compliance and has been designed to provide lower EMC noise for immunity of the internal electronics as well as the other neighbouring systems.

***Keywords*—**Electromagnetic Interference, Immunity, Integral Motor, Radiated & Conducted Emission, Sensitive Electronics, Variable Speed Drive

I. Introduction

ELECTRIC motors are used to provide motive power for a vast range of end users - with crushing, grinding, mixing, fans, pumps, material conveying, air compressors and refrigeration compressors together accounting for 81 per cent of industrial motive power. International surveys estimate that a whole-of-system approach to optimizing industrial motor driven applications, when coupled with best practice motor management, can deliver savings of between 30 and 60 per cent [1], [2].

Though the Variable Speed Drives (VSD) and their advantages are very well know, but unfortunately, the integration of the knowledge of Electrical Motors and power electronics engineering was not known by industries till last decade. Now VSDs are considered as one of the most important tools for Motor Management and Energy Saving. Though the advancements in semiconductor technology made the low cost, compact and reliable VSDs possible, but still, they are not free from problems. The problems associated with immunity of embedded systems used in such systems are enormous. In the next sections of this paper some of the problems associated with Motor-Drive systems are presented and special solutions to these problems are suggested.

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Finally as a suitable solution, an Integral motor-drive based on these considerations has been designed and proposed which demonstrates a technological advancement in design and proposes a compact unit built to operate in arduous industrial environments. The critical issues such as; management of electromagnetic interference (EMI) within the unit and outside as well as management of other environmental effects on the sensitive drive control unit have been measured and appropriate solutions are proposed.

II. General Problems associated with motor-drive systems

A. Insulation Voltage stress

The high switching frequencies of VSD generates conducted & radiated noise, and additionally they may cause significant damage to the motor and the embedded systems by producing insulation voltage stress [3]. To reduce this effect, selection of lowest carrier frequency of operation for the PWM inverter can be considered [4]. However, the selection of the optimum carrier frequency of operation of the inverter depends upon a balance between different design parameters such as; the optimum harmonic reduction in the motor which is inversely proportional to the carrier frequency, optimum average switching power loss which is proportional to the switching frequency , optimum losses or heat generated in the motor which is related to total harmonics in the motor winding which in turn in related to requirement of cooling system or fan of the motor and finally, the lowest level of Audible Noise generated by the drive system.

The effect of insulation voltage stress particularly increases and has more serious effect if the length of cable between the VSD and motor increases [5], [6].

B. Electromagnetic Interferences (EMI) - Radiated & Conducted Emission

Current harmonics in the VSD input stage can also feed back into the power bus grid, and can disrupt other types of equipment. Harmonics can also cause supplementary losses and temperature-rise of all the elements in the supply system (machines, transformers, cables, capacitor banks). These high frequencies can produce electromagnetic interference (EMI) both as high frequency airborne radiated interference mostly in the inverter to motor cable, as well as the conducted noise in the supply cables, Fig.1.

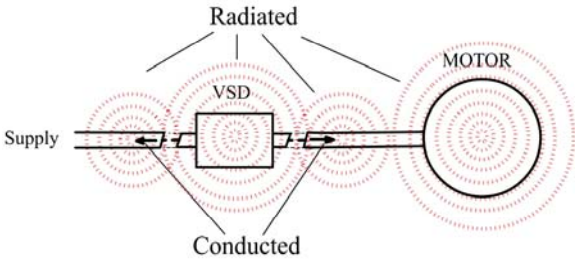

Fig.1 VSD Motor System EMI sources

If proper precautions are not taken, the harmonics can disturb nearly sensitive electronic devices. The fast transitions in current level include high frequencies that, while necessary to the operation of the drive, can have detrimental effects on other pieces of equipment (e.g. leading to measurement or counting errors, and unexpected operation of the processor and embedded system). Possible problems can be avoided in virtually all cases by the following precautions, Fig.2;

- Keeping the link motor-VSD as short as possible;
- Proper grounding;
- Proper shielding;
- Passive or active harmonic filters;

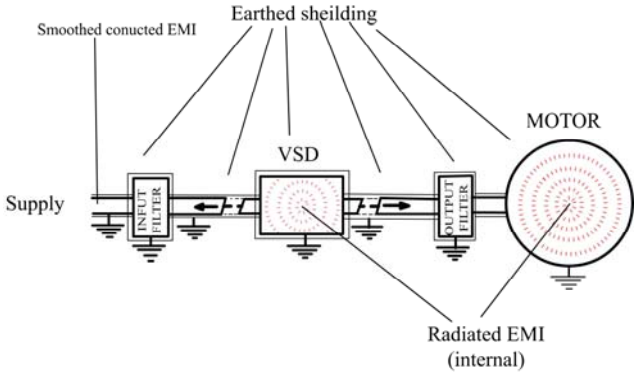

Fig.2 EMI reduction by EMC Filter and Shielding

C. Reduction of system EMI by Integration

To reduce the space requirement to overcome the above EMI problems, many of the manufactures bring together the motor and the drive in a closer form called integral motor, which in turn reduces required installation cost. The reduction of space in these systems is transferring the problems from the system level to the component level. The spatial position of the drive with respect to the motor is practically immaterial, but isolation and shielding of the two systems to minimize their mutual effect on each other is very important Fig.3-(a) & (b).

So far in this paper, the associated problems with Motor-drive systems such as; Bearing Current & insulation Voltage stress, System level Electromagnetic Interferences (EMI) - Radiated & Conducted Emission have been discussed and solutions were proposed. It has also been observed that the integration (integral Motor) can cause reduction of system radiated EMI, but the Component Level EMI problem which is the main source of malfunctioning of the embedded electronics system is not considered.

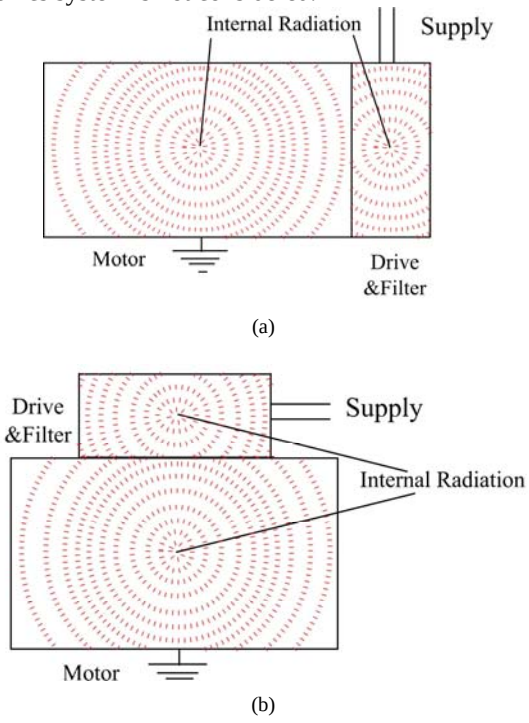

Fig.3 Position of Drive with respect to Motor

III. Proposed Motor

A. Solution to Component Level EMI

In an integral motor with a metallic enclosure drive system, the culprit component has the direct radiation as well as reflected radiation over the susceptible components. The Radiated & Reflected radiation in a small chamber is not controllable and may cause misfiring/failure or malfunctioning of the system. The other fact which increases this effect is the close distance of the drive and the motor. The high frequency EMI produced in the motor winding affects directly to decrease the immunity of the susceptible components Fig.4.

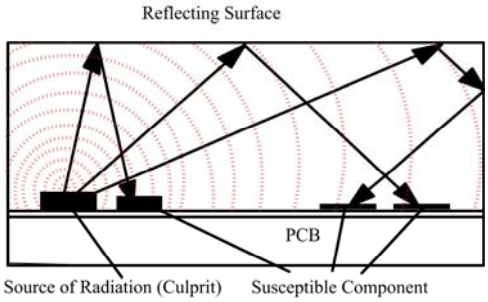

Fig.4 Radiated and Reflected EMI

Due to these problems, achievement of the reliable best performance of a true integration of motor drive system is not easy. To solve a problem, it is important to know what the sources of the problem. For EMI to exist it is necessary to have;

- EMI Source that generates interface (Culprit)
- System or device that is susceptible to interference (Victim)
- Coupling path between the generating and the susceptible system (link or media)

In brief, reduction of the EMI issues call for consideration of;

1) *Reduction of interface levels generated by the culprit system by*
- Harmonic reduction techniques [7]
- Selection of operating frequency
- Frequency dithering
- Modification of Signal Routing
- Addition of local filters
- Reduction of signal level

2) *Increase the immunity threshold of the susceptible system*
- Selection of immune (less susceptible components)
- Selection of operating frequency
- Modification of Signal Routing
- Addition of local filters

3) *Reduce the direct coupling path by;*
- Shielding
- Reduction of the interconnection
- Selection of filter/media
- Increase the separation path

In the next section the proposed integral motor and its design to overcome the above inadequacy is presented.

B. Other Design Considerations

Keeping in mind the guide lines from the last section, the EMI/EMC problems may be approached at the component, PC board or enclosure levels. However, it is much more efficient to deal with these problems as close to the source or susceptible victim as possible. Switching from the system level EMI to the component level EMI is possible if, we consider that the Culprit system's radiation affects the susceptible systems in the same way as that of the radiating Culprit components (Power switching devices/Power modules) affecting the other more susceptible components such as analogue and less immune digital components. To overcome the conducted EMI, the PCB design will require proper track design for power & control signal, increasing the separation of the power and signal tracks and by filtering of each component at its input/output. Additional EMC line filter will filter out the effect of conducted EMI To/From the supply line.

Shielding the system can be used as first line of defense for radiated emission. Shielding is very useful tool for reduction of interference of the culprit system with other external susceptible systems. However, it does not protect the internal susceptible components within the system. An Integral motor with the drive in built within the motor, if properly shielded may provide good external EMC compliance, but care should be taken in design of the PCB and its tracks to provide sufficient immunity to electronics within the system.

IV. Experimental Results

The proposed integral motor-drive system has been designed with an inbuilt filter (Fig5), to minimize the conducted EMI in an integrated drive system.

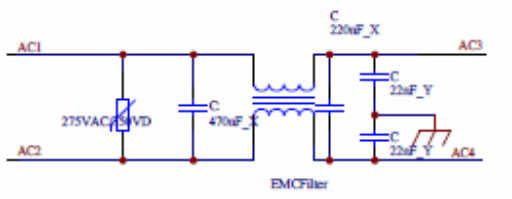

Fig. 5 Inbuilt EMC filter (1 phase 240V, 2.2KW VSD)

The experimental tests presented in this section prove the validity of the above considerations for a superior design. The internal EMC filters have minimized the Conducted EMI (Fig 6 & 7).

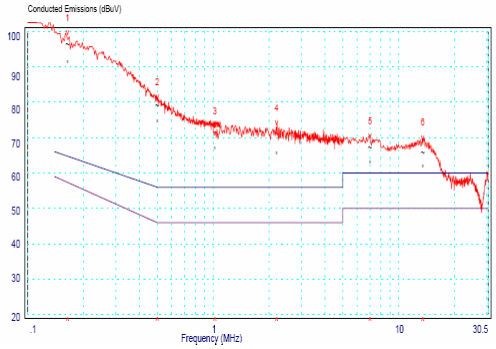

Fig.6 Conducted Emissions without Common Mode Filter

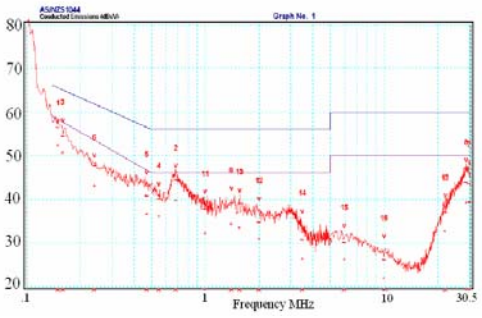

Fig.7 Conducted Emissions with Common Mode Filter

The integral motor in this case, will have a short link between the motor and the drive which minimizes the amount of disturbance powers if a proper filter is used (Fig 8 & 9).

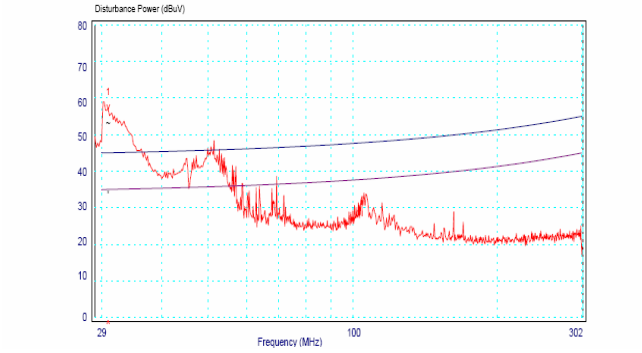

Fig.8 Disturbance Power (System without Filter)

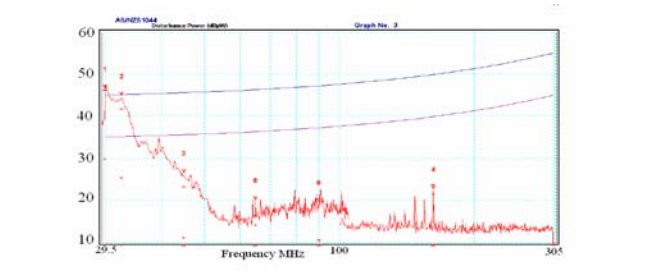

Fig.9 Disturbance Power (System with Filter)

The metallic casing of the integral motor and proper grounding of the system provides an easy shielding of the system with least effect of external radiation to the surrounding environment (Fig 10& 11).

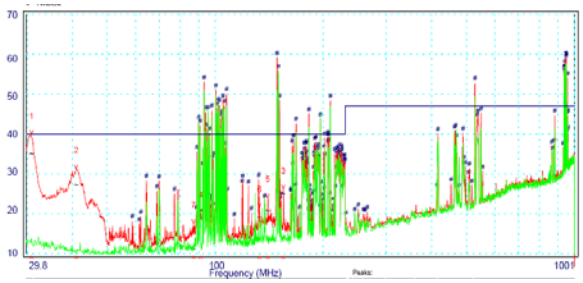

Fig.10 Radiated Emission without a proper filter

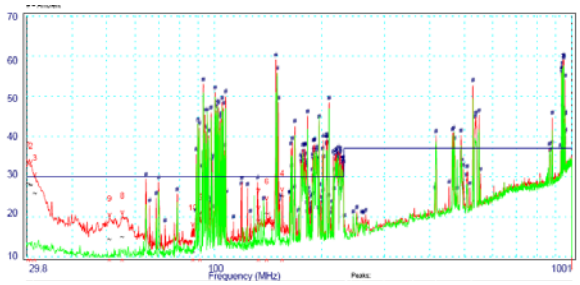

Fig.11 Radiated Emission with Filter

An Integral motor with the drive in built within the motor, and if properly shielded will provide good external EMC compliance, but care should also be taken in design of the PCB and its tracks to provide sufficient immunity to electronics within the system.

Electronic components within the integral motor will experience high radiated and conducted EMI from the motor winding and the switching components. It requires well design of power electronics and control system to be reliable under these conditions. The solution to this type of problem is simple. The designer has to use the most immune available components and then an insulation shielding technique can be used to reduce the direct destructive EMI to an accepted level for susceptible components. In this paper, MSP430 has been used as the processor which has high immunity of EMI and an insulation layer of Epoxy has been used to cover the electronics components, which added up the following advantages to the system (Fig. 12):

- Good electric insulator and Lower Level of EMI
- Good thermal conductive property resulting to increase in thermal surface & better cooling of the components
- Increase the level of IP protection of the electronic components
- Increasing the mechanical strength of the control system to withstand vibration

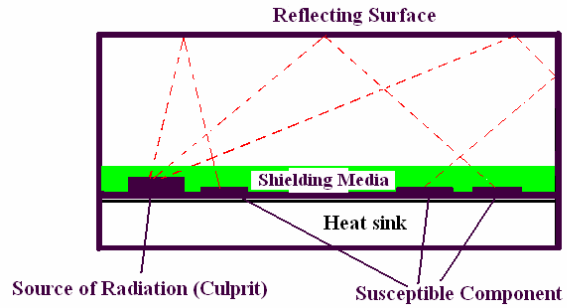

Fig.12 Reduction of Radiated and Reflected EMI using Shielding/Insulation

The reduction of the radiated EMI using shielding insulator provides the immunity of susceptible electronic systems to higher level of emission. The insulated media provides a shielding between the electronic components and the heat radiated from motor winding. It provides a heat sink to the embedded system and cooler normal operation. This media also provides mechanical strength to the parts to withstand higher vibration.

V. Conclusion

A motor drive system may fail a reliable operation or may affect the other susceptible systems in enormous number of ways. In the proposed system it is tried to minimize these effects. The integral motor in this case, has a short link between the motor and the drive which minimizes the amount of disturbance powers with an inbuilt proper filter. The metallic casing of the integral motor and proper grounding of the system provides an easy shielding of the system with least

effect of external radiation to the surrounding environment and care has been taken in design of the PCB and its tracks to provide sufficient immunity to electronics within the system. The effect of high radiated and conducted EMI from the motor winding as well as the switching components has been reduced to an accepted level by a well designed power electronics, control system and choice of reliable components. The reduction of the radiated EMI which provides the immunity of electronic systems has been obtained by addition of an insulated shielding media. This media provides shielding to heat transferred from the motor and of course it adds mechanical strength to the parts to withstand higher vibration in arduous industrial environments.

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