Study of Voltage Stresses inside Regenerative Drive

K M Latha[1], Pradip Kumar Dixit[2]

[1]*PG Student, Department of EEE, MSRIT, Bangalore, India*

[2]*Associate Professor, Department of EEE, MSRIT, Bangalore, India*

***Abstract*—This paper investigates the effect of voltage stress on the voltage insulation components inside a regenerative active-front-end adjustable speed drive (ASD). It shows that a high potential voltage insulation issue may exist on various components inside the ASD and cause earlier failures. A simplified system model to describe this phenomenon is described, and the voltage stresses of different components inside the ASD under different grounded conditions and filter capacitor are analyzed. It is concluded that among different grounding systems HRG system gives minimum stress. Appropriately designing the insulation components is critical to protect the drive.**

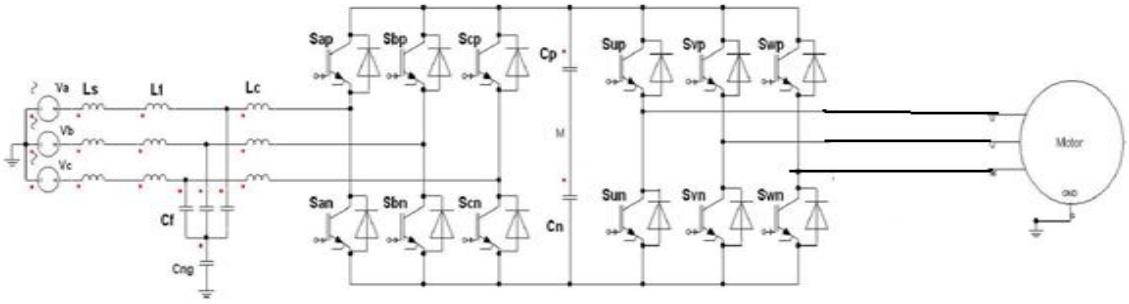
***Keywords*— Active front end (AFE), adjustable-speed drive (ASD), insulation, long cable, system grounding.**

I. INTRODUCTION

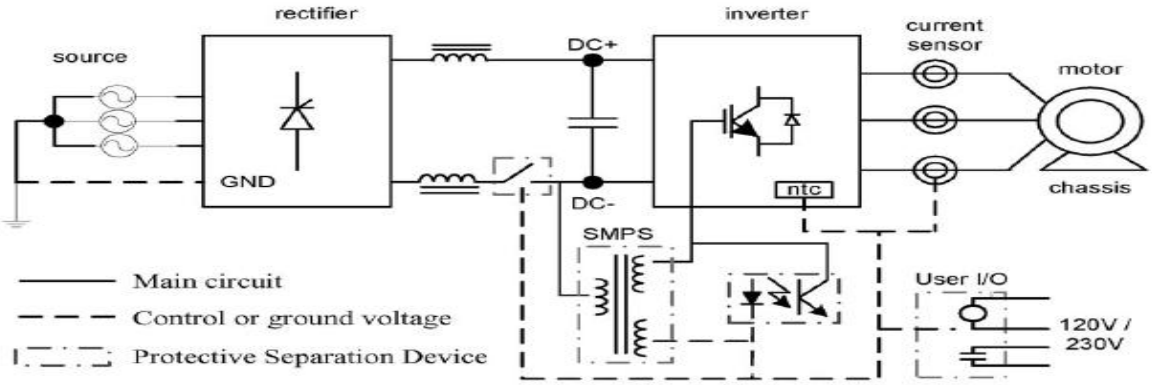
The development of high frequency, Pulse Width Modulation (PWM) based Adjustable Speed Drives (ASDs) has increased the energy efficiency, performance and controllability in the induction motor applications. But high-speed switching used in PWM drive, however, can be accompanied by the serious problems such as ground current escaping to earth through stray capacitors inside motors, conducted and radiated Electromagnetic Interference (EMI), bearing current and shaft voltage and voltage stresses shortening the insulation life of motors and protective components used inside drive. Numerous papers have been published to analyze these issues [1]–[12].References [3]–[6] analyzed the PWM switching and cable length effect on bearing current, electromagnetic interference (EMI) emission, and motor insulation. In [4]–[12], various methods and topologies were proposed to reduce the effect of PWM switching on motor insulation, EMI performance, and bearing current effect. As insulation is also one of the factor which decides the performance and service life of motor and protective components it is necessary to study the voltage stresses caused by fast dv/dt switching in drive. Paper [1] has analyzed PWM effect on voltage stresses considering static load where as this paper aims at the same but considering dynamic load so that results obtained will be realistic. Also studies the effect of filter capacitor and its type of grounding used at source side on voltage stresses. However, analysis of overvoltage failures of components inside the drive has not been fully addressed or discussed. One simple assumption made from these references is that the common-mode capacitance inside the drive is much higher than that of the cable and motor. This is true for majority of applications. However, when an ASD is applied with very long cable or multiple parallel cables, common-.
mode capacitance of the cable and motor may be comparable or even higher than the common-mode capacitance inside the drive. Moreover, ASD manufacturers generally suggested customers to disconnect the common capacitor from the ground under a high-resistance grounded (HRG) or ungrounded system. Under these conditions, the output cable and motor capacitance values are generally much higher than the ASD common-mode capacitance values. High-voltage (HV) stresses may be generated inside the drive instead of the motor side [2]. Thus, understanding the voltage stresses inside the drive under different grounding configurations is critical for design engineers.
As discussed in [2], there are two types of HV components in an ASD. The first type of components is the main circuit components that transfer power from the source to the load, including inverter insulated-gate bipolar transistor, rectifier diode/SCR, dc link choke, dc bus capacitor, etc. They are all located in the differential-mode circuit, and their voltage stresses are generally no higher than the dc bus voltage. Selection of voltage ratings for these components is straightforward. The second type of components provides protective separation between the control and main circuits, including opto-coupler, print circuit board, sensors, voltage/current transducer, switch mode power supply transformer, etc. These components must be able to support voltage stresses between HV and the ground. Reference [2] analyzed the voltage stresses inside an ASD with a diode/SCR. In this paper, the voltage stresses inside a regenerative ASD under different configurations are studied.

II VOLTAGE STRESS ANALYSIS

In paper [1], response of common-mode midpoint-to-ground voltage is analyzed, by considering Simplified common-mode circuit of considered drive. System is analyzed for under damped and over damped conditions there by circuit was



(a)



(b)

Fig. 1. Schematics of AFE drive with common-mode and cable models. (a) Diagram of ASD with AFE rectifier. (b) Components that are exposed to HV stresses

predicted for solid grounding and high resistance grounding. According to [2], the HV sides of the protective separation components in the dc bus are either no higher than those in the positive bus or no lower than those in the negative bus. The low-voltage sides are the control voltages that are very close to GND voltage. Therefore, the insulation voltage of the bus components can be approximated as the voltage between the GND and the dc bus terminals. The voltage stresses between the ground and the dc bus terminals can be calculated by adding the common and differential-mode voltages.

A) Differential Mode Voltage Between DC Bus Terminals to the GND

For the differential-mode circuit, the middle or neutral point of the dc bus voltage is equal to the GND voltage. This voltage stress between dc bus terminals to the GND can be approximated as half the dc bus voltage for a Y grounded system

Vpg_DM=Vng_DM=Vdc/2

where *Vpg*_DM is the maximum voltage between the positive dc bus and the GND in the differential-mode circuit, and *Vn* is the minimum voltage between the negative bus voltage and the GND in the differential-mode circuit.

B) Common Mode Voltage between DC Bus Terminals to the GND

Fig. 2 shows a simplified circuit of Fig.1a that can explain the voltage stresses of different parameters to the voltage stresses of *V*mg (terminal to ground voltage) during switching of either side converter. In this figure, both the input and output are simplified as a simple *RLC* circuit. *Vi* and *Vr* are two voltage sources that represent the common mode voltage generated by either the rectifier or the inverter of the drive.

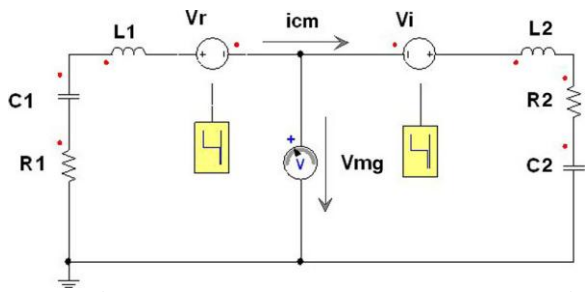


Fig. 2. Simplified common-mode circuit modeling voltage stresses of the drive.

Same circuit is referred for Psim modeling of different grounding systems wherein table1 is also considered to know line inductances and filter capacitors considered for different

grounding systems. Paper [1] gives single line diagram for different grounding systems.

Table I
Equivalent Inductance and Capacitance Values of Different Grounded Systems

Grounding	Filter	C1	L1
Solid	Y	Inf	Lc
HRG	Y	Inf	Ls+Lf+Lc
Ungrounded	N	0	Lf+Lc

III. SIMULATION RESULTS

In the present work Active front end (AFE) drive is modeled using Psim. The model developed has been used to obtain the stresses for different grounding methods.

During the study, the drive and motor data used are shown as shown in Table2.

Table2: Ratings considered

ASD Rating	480/150hp
Rectifier switching frequency	4kHz
Inverter switching frequency	2kHz
Motor	460V/200hp
Line side inductor Lf	420µH
Rectifier side inductor Lc	140µH
Common mode filter capacitor Cng	2µF
Filter capacitor Cf	30µF

A) DC Bus-to-GND Voltage in differential mode

In differential mode operation dc bus voltage is found as 1kv and terminals to ground voltages are measured and are found to be half of dc bus voltage i.e.500v and is shown in Fig.3 and Fig.4. This condition is true for all grounding conditions.

B) DC Bus-to-GND Voltage in common mode for Different Ground Systems

Fig. 5(a)–(c) shows the voltage stresses between dc bus terminals to the GND under solid Y, HRG, and ungrounded systems, respectively. From this figure, it can be found that the peak voltage under the ungrounded system is much higher than that of the HRG or solid system. Minimum stresses are found in high resistance grounded system. For all grounding conditions, the voltage stresses between the dc bus terminals to the GND are much higher than half the dc bus voltage and need special attention.

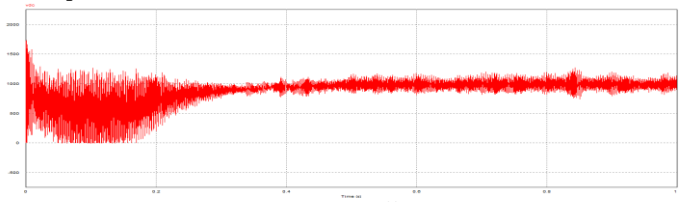


Fig.3:DC bus voltage in differential mode

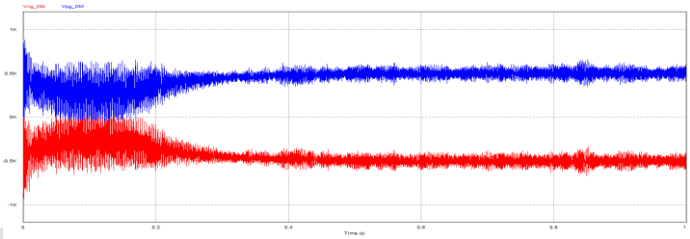


Fig.4: DC Bus-to-GND Voltage in differential mode

C) Input-to-GND Voltage under Different Ground Systems

Fig. 5(a)–(c) shows the voltage stresses between input terminals to the GND under solid Y grounded, HRG, and ungrounded systems, respectively. It can be found that the peak voltage under the HRG system is much lower than that of the Solid or ungrounded system. This is because impedance of source is less compared to LCL filter.
Results shown in Fig.5 and Fig.6 are for 1.98µF filter capacitor value. When measurements are done for other filter values towards infinity it is found that voltage stresses increase beyond these results which is shown in table 3.

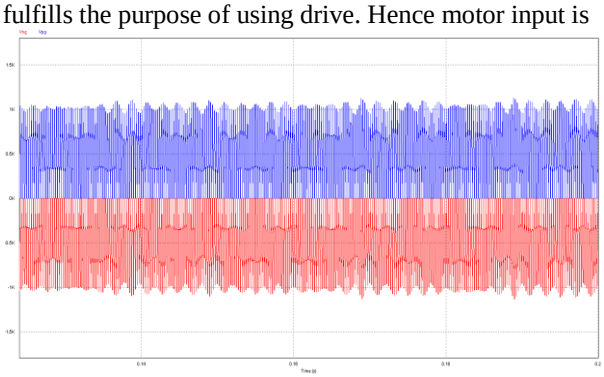
Table.3: Voltage stress comparison

Type of GND	Solid	HRG						UnGnd
Value of filter capacitor	1.98 µf to ∞	1.98µF	30µF	100 µF	500 µF	1mF	5mF	No filter cap
Max voltage stress	1.28 KV	1.7KV	1.7 KV	1.7 KV	1.7 KV	2KV	1.6 KV	1.75KV
Min Voltage stress	1.1KV	0.851 KV	1.3 KV	1.3 KV	1.3 KV	1.5 KV	1.38 KV	1.4KV
Input to motor	497.3V	390.5 V	556.5V	563.9V	546.9V	557.6V	539 V	558.73V

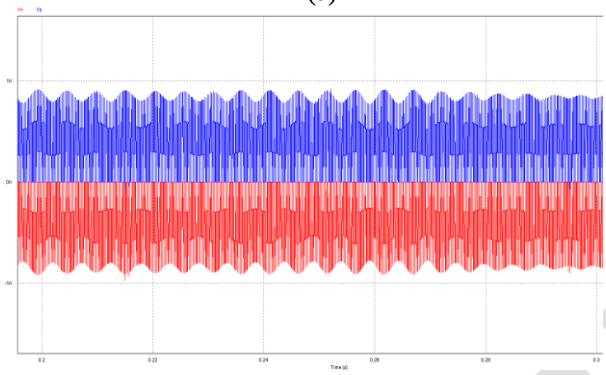
D)Input voltage to Motor for different grounding systems

input to motor is also of great concern. Proper input to motor

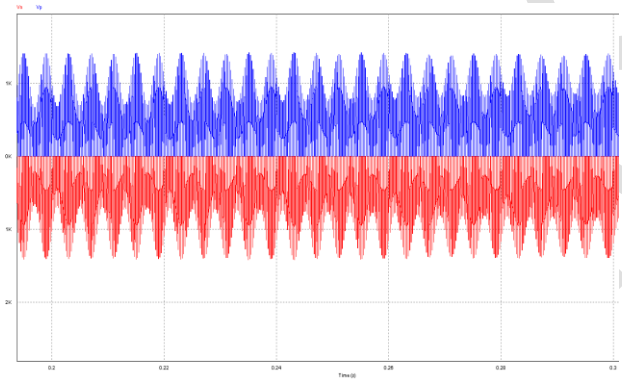
fulfills the purpose of using drive. Hence motor input is



(a)



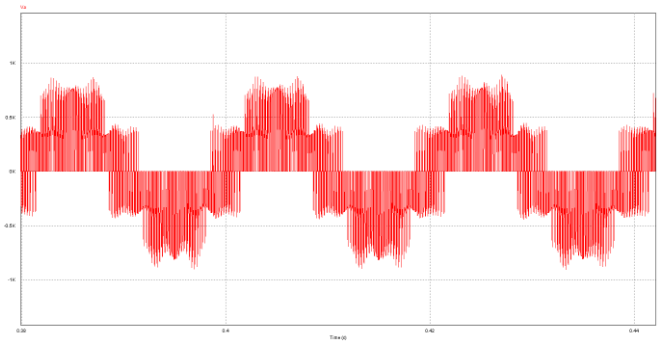
(b)



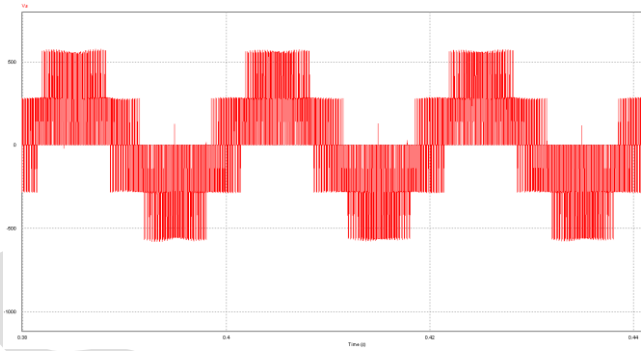
(c)

Fig.5.DC bus-to-GND voltage stresses under different grounding *Vpg*: DC+ to GND; *Vng*: DC− to GND. (a) Solid Y grounded system (peak voltage: 1.1kV). (b) HRG system (peak voltage: 0.890 kV). (c) Ungrounded system (peak voltage: 1.3 kV).

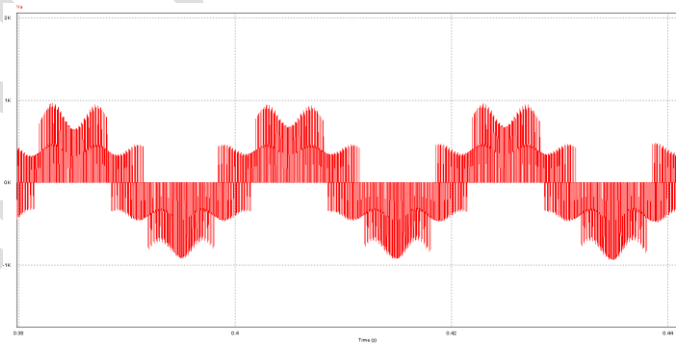
measured for different grounding systems and for different filter capacitor values. Fig.7 shows motor input voltage waveforms taken for 1.98µF filter capacitor value. Fig. shows that motor input is better for HRG system compared to solid and ungrounded systems. Also HRG system gives voltage within motor rating in acceptable range. For other values of filter capacitor values waveforms will get more and more distorted resulting in increased harmonics. THD for different grounding systems is shown in Table 4, it shows THD is very for ungrounded system and requires care. Detailed table of



(a)



(b)



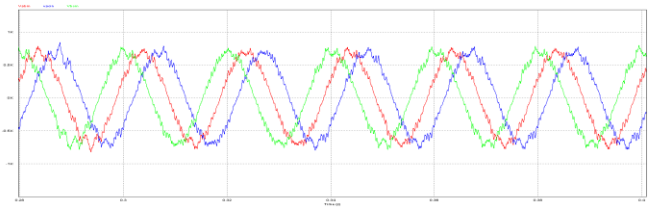
(c)

Fig. 6. AC input-to-GND voltage under different grounding. *Vag/Vbg/Vcg*: input phases A, B, and C to GND, respectively. (a) Solid Y ground system (peak voltage: 0.794kV). (b) HRG system (peak voltage:0. 565kV). (c) Ungrounded system (peak voltage: 0.924 kV).

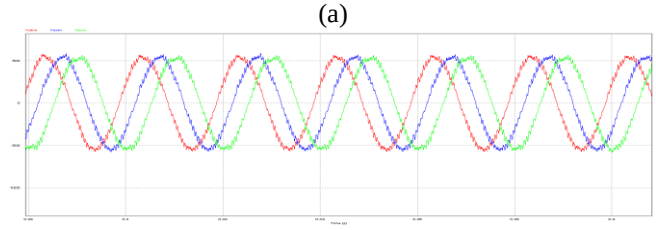
THD for different grounding systems is discussed in Table 4.

IV. TOTAL VOLTAGE STRESSES ON PROTECTIVE COMPONENTS

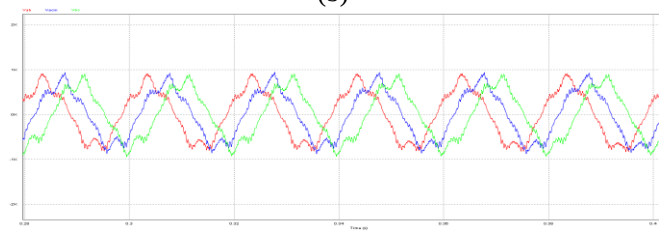
Total stresses acting on protective components are sum of stresses measured in differential mode and in common mode operation. Depending on total stresses obtained protective components can be designed or can be chosen to withstand that much stresses thereby avoiding insulation failures and hence can minimize failure of process.



(a)



(b)



(c)

Fig.7: Motor input voltage waveforms for (a) solid grounded system(RMS 492V)(b) HRG system (RMS 390.5V) (c) ungrounded system (RMS 558V)

Table 4:THD comparison

Type of grounding	Filter capacitor value	THD
Solid Grounding	1.98µF towards infinity	7.0993
High resistance grounding	1.98µF	5.62
	30µF	8.905
	100µF	9.735
	500µF	5.983
	1mf	6.0154
	5mF	5.3141
Ungrounded	No filter capacitor	22.9924

CONCLUSIONS

This paper has investigated the voltage stresses inside a regenerative ASD under different grounding conditions and filter capacitor values. The work also involves, to find the appropriate grounding system and the value of filter capacitor which gives stresses within the specified limit and less Total Harmonic Distortion (THD) in the input to the Induction Motor.

For a solid Y grounded system, the dc-to-GND voltage is high for a regenerative AFE drive and requires special attention. The ac-side-to-GND voltage is low compared to ungrounded system and common mode filter can be designed to get proper input.

For an HRG grounded system, both dc-to-GND voltage and ac-side-to-GND voltage are less compared to other two grounding systems for regenerative drives with dynamic load.. The filter capacitor of value 1.98µF helps in obtaining less stresses and better input to motor.

For an ungrounded system, the ac input-to-GND voltage is high for regenerative AFE drive and requires much special attention. The dc-side-to-GND voltage is also high under single-drive condition; however, it may become high when a multiple-drive system is applied.

So a system with high resistance grounding is suggestible to get minimum stresses and better input to motor. In the future, more investigation can be made with multilevel inverter and by considering cable length.

I would like to express my sincere thanks to **Dr. PremilaManohar, Professor and Head of Department EEE** engineering and my guide **Dr. Pradipkumar Dixit, Associate Professor, Department of EEE,** for their guidance and cooperation in writing this paper.

REFERENCES

[1] Lixiang Wei, *Member, IEEE*, Zhijun Liu, *Member, IEEE*, and Gary L. Skibinski "Investigation of Voltage Stresses Inside Adjustable-Speed Drives", IEEE transactions on industry applications, vol. 49, no. 1, january/february 2013.

[2] L. Wei, Z. Liu, and G. Skibinski, "DC bus voltage clampmethod to prevent over-voltage failures in adjustable speed drives," in *Proc. IEEE ECCE*, 2010, pp. 750–756.

[3] S. Chen, T. A. Lipo, and D. Fitzgerald, "Source of induction motor bearing currents caused by PWM inverters," IEEE Trans. Energy Convers., vol. 11, no. 1, pp. 25–32, Mar. 1996.

[4] D. Busse, J. Erdman, R. J. Kerkman, D. Schlegel, and G. Skibinski, "Bearing currents and their relationship to PWM drives," *IEEE Trans. Power Electron.*, vol. 2, no. 2, pp. 243–252, Mar. 1997.

[5 R. J. Kerkman, D. Leggate, and G. Skibinski, "Interaction of drive modulation and cable parameters on AC motor transients," *IEEE Trans. Ind. Appl.*, vol. 33, no. 3, pp. 722–731, May/Jun. 1997.

[6] G. Skibinski, D. Leggate, and R. J. Kerkman, "Cable characteristics and their influence on motor over voltage," in *Proc. IEEE Appl. Power Electron. Conf.*, Atlanta, GA, Feb. 23–27, 1997, pp. 114–121.

[7] G. Skibinski, R. J. Kerkman, D. Leggate, and D. Schelgel, "EMI emissions of modern PWM AC drives," *IEEE Ind. Appl. Mag.*, vol. 5, no. 6, pp. 47–81, Nov./Dec. 1999.

[8] S. Ogasawara, H. Ayano, and H. Akagi, "An active circuit for cancellation of common-mode voltage generated by a PWM inverter," *IEEE Trans. Power Electron.*, vol. 13, no. 5, pp. 835–841, Sep. 1998.

[9] A. Julian, G. Oriti, and T. Lipo, "Elimination of common-mode voltage in three phase sinusoidal power converters," *IEEE Trans. Power Electron.*, vol. 14, no. 5, pp. 982–989, Sep. 1999.

[10] M. M. Swamy, K. Yamada, and T. Kume, "Common mode current attenuation techniques for use with PWM drives," *IEEE Trans. Power Electron.*, vol. 16, no. 2, pp. 248–255, Mar. 2001.

[11] Y. C. Son and S. K. Sul, "A new active common-mode filter for PWM inverter," *IEEE Trans. Power Electron.*, vol. 18, no. 6, pp. 1309–1314, Nov. 2003.

[12] D. Hyypio, "Mitigation of bearing electro-erosion of inverter-fed motors through passive common-mode voltage suppression," *IEEE Trans. Ind. Appl.*, vol. 41, no. 2, pp. 576–583, Mar./Apr. 2005.

[13] H. Akagi and T. Doumoto, "An approach to eliminating high-frequency shaft voltage and leakage current from an inverter-driven motor," *IEEE Trans. Ind. Appl.*, vol. 40, no. 4, pp. 1162–1169, Jul./Aug. 2004.