TURNTIDE™
by Software Motor Company

AC Motor Shaft Currents

Switched Reluctance and Induction Motor Comparison

Revision History

Revision	Description	Date
2.1	Brand Update	July 2020
2.0	Update	July 2020
1.0	Preliminary	May 2020

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1. Introduction

This paper investigates shaft voltages on the SMC Switched Reluctance Motor, compared with Induction Motors. Motor model V03 was used for the investigation and compared with the shaft voltage on an equivalent Induction motor of the same Hp rating. Voltages were measured with an AEGIS Shaft Voltage Tester Digital Oscilloscope (AEGIS-OSC-9100).

2. Background

Because of the high-speed switching frequencies in Pulse Width Modulation (PWM) inverters, variable frequency drives can induce shaft voltages in the electric motors they control [1] [4]. The resulting shaft voltage is a function of the motors winding construction and stray parasitic capacitances.

Once these voltages reach a level enough to overcome the dielectric properties of the bearing grease, they arc through the motor's bearings, discharging along the path of least resistance to the motor's housing. During virtually every VFD switching cycle, induced shaft voltage discharges from the motor's shaft to the frame via the bearings, leaving a small fusion crater (fret) in the bearing race. This process is called Electrical Discharge Machining or EDM.

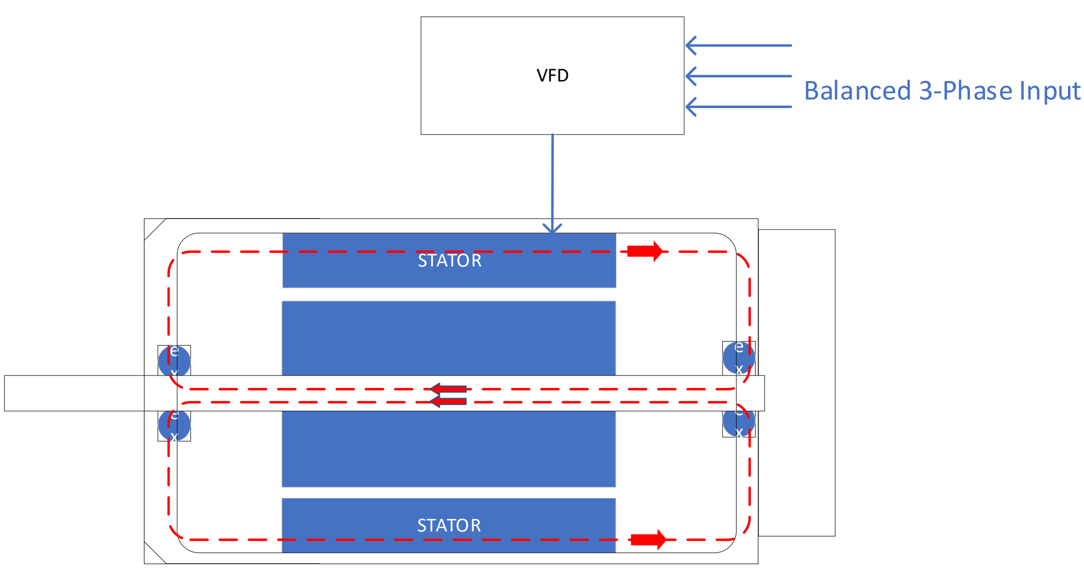
3. Source of Bearing Currents

There are essentially two primary sources of bearing currents in motors: High Frequency Circulating currents and capacitively coupled EDM currents from the Inverter high speed switching. The latter source results in shaft currents an order of magnitude smaller than that of the former.

3.1. High Frequency Circulating Currents from the VFD

This is the primary cause of shaft induced bearing currents in Induction Motors. They are due to zero sequence return currents as a result of the PWM switching waveform generated by the VFD [2] [3]. High frequency circulating currents may flow due to a high-frequency flux produced by the common-mode currents and are in the kHz or MHz range [5]. The current paths are illustrated in Figure 1 below.

Figure 1. High frequency bearing currents [5]



Conventional two-level, three-phase voltage source inverter (or VFD) consists of three phase-legs, each of which is a series connection of two semiconductor switches. A representative two-level three-phase inverter motor drive is illustrated in Figure 2, where the three inductors represent the motor windings, and the capacitor Cs represents the stray capacitance between motor windings and the grounded motor case. During normal operation, the output potential of each phase leg with respect to ground (i.e. Va, Vb, and Vc) is continuously switched between the positive and the negative DC bus potential due to the pulse width modulation of the switches. The sum of the phase voltages is always different from zero at the neutral point. The resultant voltage appearing between the neutral point of the motor and ground is referred to as the Common Mode Voltage (CMV, *Vcm*). This voltage continually changes depending on the switching states of the inverter and is expressed as;

$$Vcm = (Va + Vb + Vc)/3$$

The eight switching states of PWM operation and the corresponding CMV waveform are illustrated in Figure 3 and Figure 4 respectively. From Figure 3 and Figure 2, *SV*135 generate +Vdc/6 CMV, *SV*246 generate -Vdc/6 CMV, and SV0 and SV7 lead to +Vdc/2 and -Vdc/2 CMV, respectively. From Figure 4, it is seen that CMV has a six-step waveform in every switching period, where the length of each step varies with modulation strategy and modulation index. The six-step CMV induces shaft voltages through capacitive and magnetic coupling in the motor. Once the shaft voltages exceed the breakdown voltage of the lubricant, they discharge through the bearings, causing the electric discharge machining (EDM) currents.

Figure 2. Conventional Two-level three-phase VFD

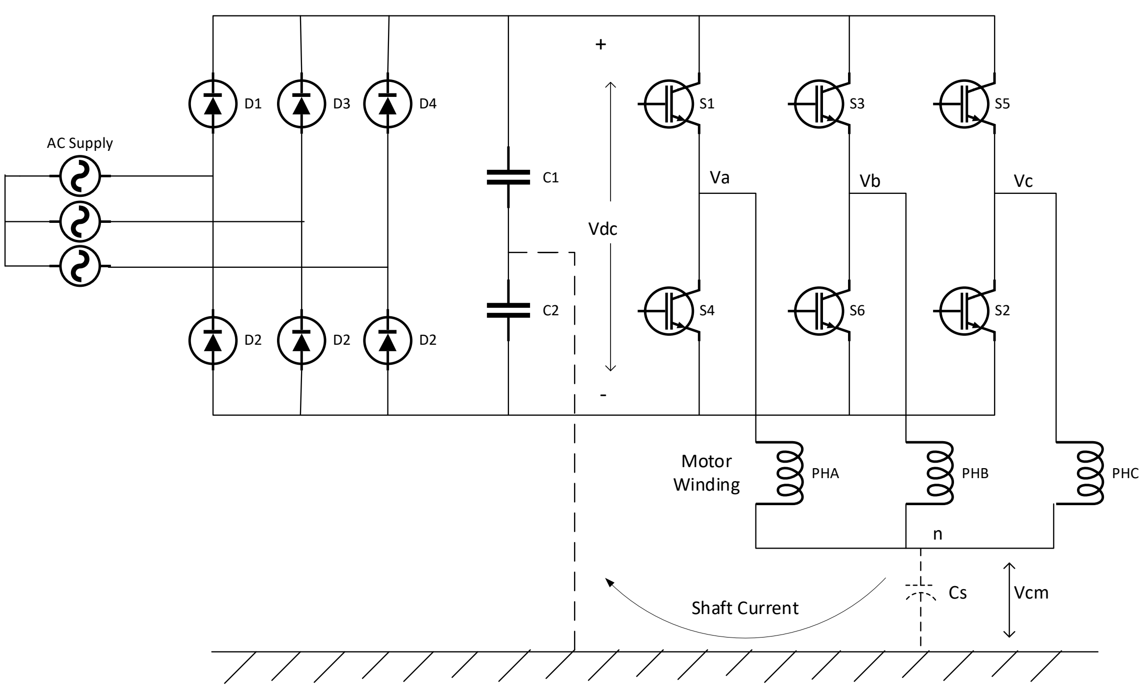


Figure 3. Switching States of PWM Operation

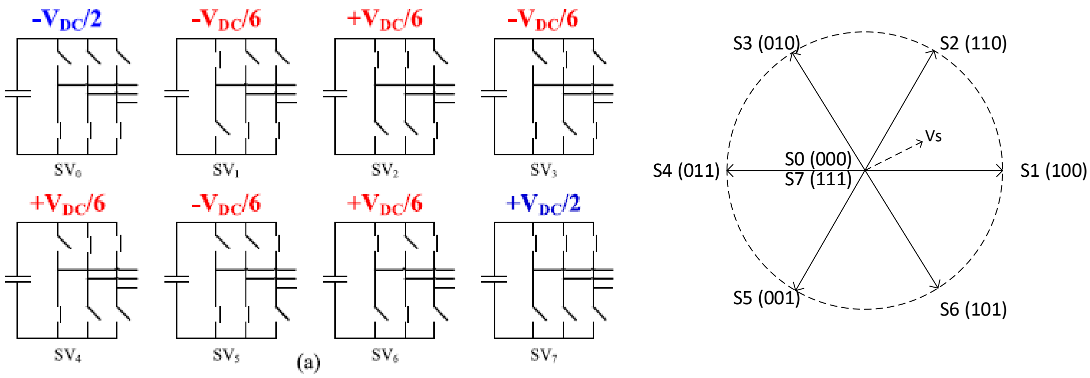
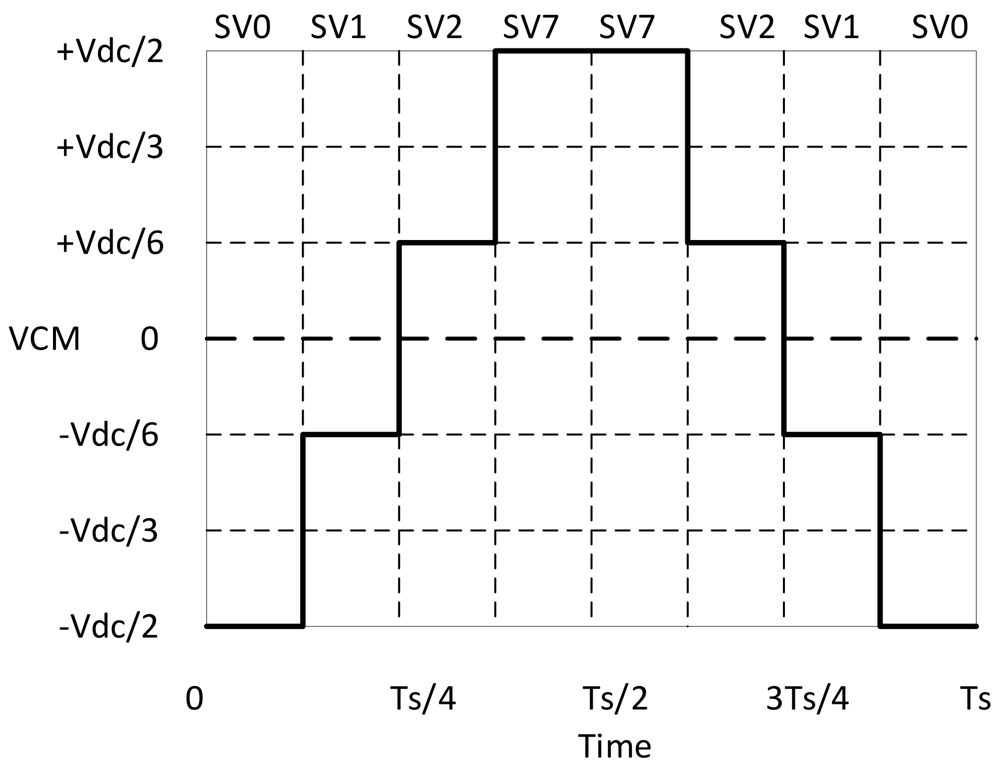


Figure 4. VFD Common Mode voltage in one switching period

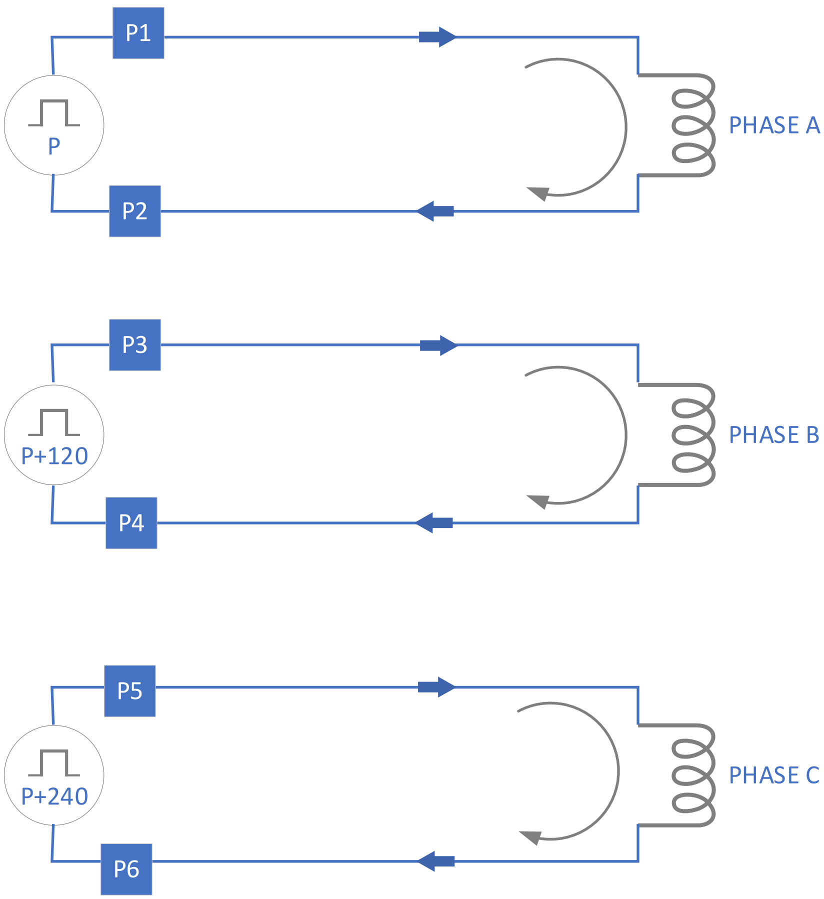


Note: This Phenomenon of High Frequency Circulation Currents is only applicable to Induction Motors.

3.2. SRM Winding Configuration

With SRMs the phenomenon of Common Mode Voltages generating shaft currents does not exist. SRMs have three balanced differential windings and there are no common mode voltages between the stator winding and ground. The SRM winding configuration is illustrated in Figure 5 below.

Figure 5. SRM balanced differential windings

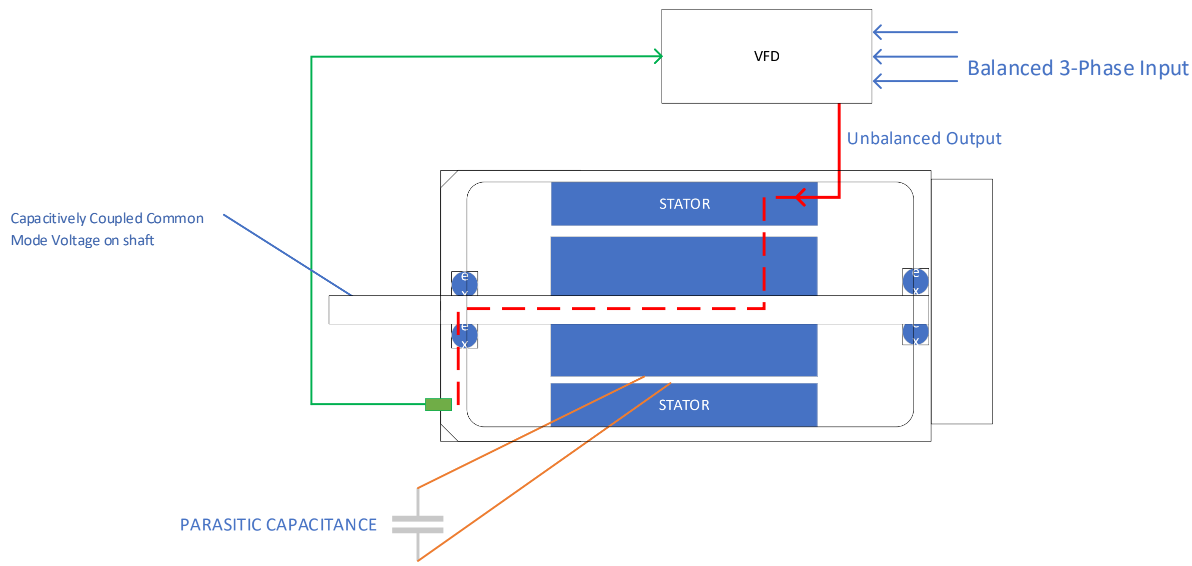


Note: SRMs have no High Frequency Circulating Shaft Currents

3.3. Capacitive EDM Currents from the VFD

Shaft voltages from this method is much reduced from the zero sequence or CMV return currents discussed above. The high frequency switching speed or edge rates of insulated-gate bipolar transistors (IGBT) used in these drives produce common mode voltages on the motor's shaft during normal operation through parasitic capacitance between the stator and the grounded motor frame [5]. The capacitive EDM current flow is illustrated in Figure 6 below. These are very low amplitude voltages below what is deemed critical to produce dangerous levels of shaft currents. The widths of these pulses are also in the vicinity of 100ns or so, not 10-20us as in a PWM cycle.

Figure 6. Capacitive EDM shaft current [5]



Note: This Phenomenon of Capacitive EDM currents is present in all motors driven by Inverters

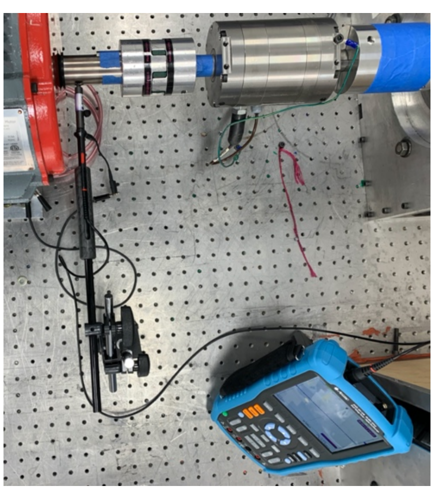
4. Reference Limit

The NEMA MG1 Part 31.4.4.3 identifies capacitive shaft voltages of approximately 10 to 40 volts peak (or 20 to 80 volts peak-to-peak), at PWM cycles in tens of microseconds, as a level which could cause electrical discharges in a motor's bearings.

5. Shaft Voltage Measurements

Aegis shaft voltage measurement system AEGIS-OSC-9100, Shaft Voltage Tester, was used to compare the voltages of the SMC V03 motor and a typical induction motor of the same HP rating. The test setup is depicted in Figure 7 below [5].

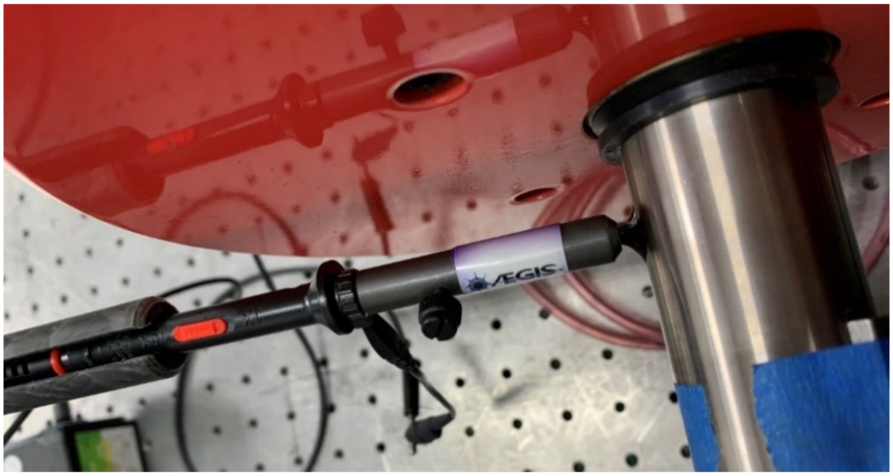
Figure 7. Test probe and digital scope set up



5.1. SMC V03 Motor Measurements

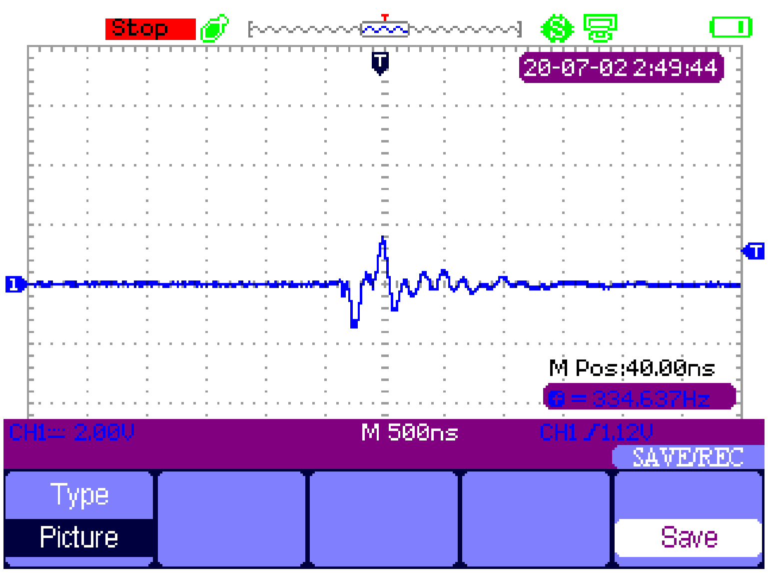
The voltage probe contact detail on the V03 shaft is shown in Figure 8.

Figure 8. V03 test probe contact detail



As expected, only a very small induced voltage was observed as shown in Figure 9 below. The narrow 1.6V spike is as a result of the capacitively coupled high-speed voltage transitions, not circulating currents due to phase common mode voltage.

Figure 9: V03 shaft voltage detail



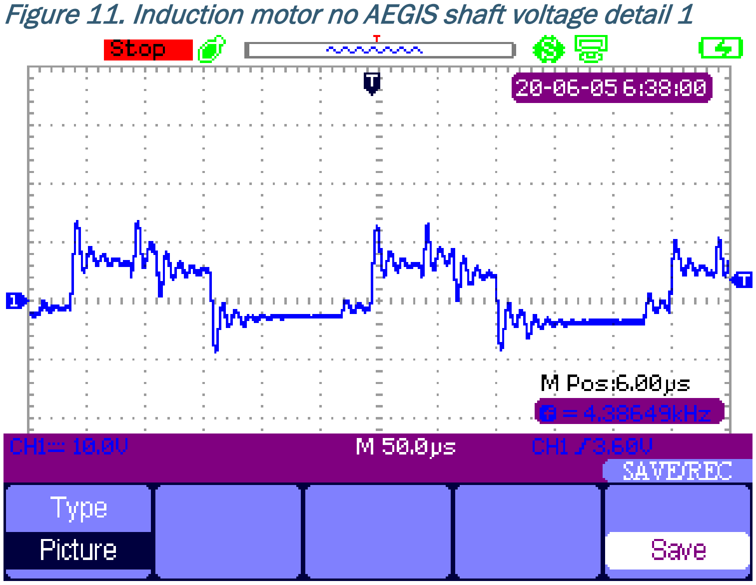
5.2. Induction Motor Measurements

The Induction motor used for comparison with the V03 was a 10 HP induction motor. The test probe contact detail is shown in Figure 10.

Figure 10. Induction motor test probe contact detail

As expected, the VFD-driven induction motor exhibits severe shaft voltage as a result of the common mode voltage at the phase neutral point. As previously discussed, the common mode voltage, coupled through the winding capacitance to the motor grounded frame, sets up a circulating current through the shaft and bearings. The shaft voltage is shown in Figure 11 below attaining a peak amplitude of 12-13V. The width of these pulses corresponds to the VFD PWM switching period.

Figure 11. Induction motor no AEGIS shaft voltage detail 1



6. Summary and Conclusions

As expected, the SRM motor architecture does not exhibit the severe common mode-induced shaft voltages and subsequent bearing currents as a VFD driven induction motor does. Only a very low amplitude and narrow width stray capacitance induced voltage was observed which is not deemed sufficient to cause EDM effects in the bearings. The measured shaft voltages are summarized below in Table 1 for comparison.

Table 1. Shaft Voltage Summary

Motor	Description	Shaft Voltage	Duration
V03-1000-4	SMC 600 RPM	1.6V	100 ns
10 HP IM	IM without Aegis Ring	13V	20-30 usec

7. References

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