Estimation of Transient Voltages in Induction Motors Fed by VFDs for Different Cable Lengths

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Abstract: this paper aims to measure the transient voltages at a 3-Phase induction motor fed by VFD for different lengths. Most industries use 3-phase induction motors to drive the mechanical load. But in actual practice, the mechanical load starts with some load according to the situation. The paper focuses on using 3-phase induction motors in various industrial applications. It highlights the importance of VFDs in these applications due to their energy-saving features, compact size, and soft-switching capabilities. This paper aims to contribute valuable insights into the behavior of transient voltages in VFD-driven 3-phase induction motor systems, mainly related to cable length variations, which can be essential for ensuring the reliability and performance of industrial machinery. Bering currents are flowing through the ground.in this, the aim is to find the transient voltages for various lengths of 5-H.P fed by 1.5 mm 3- Phase 4-wire.

Keywords: 3-phase induction motor, VFD, Cable Length, Transient Voltage, Converter circuits, Soft switching loss.

I. INTRODUCTION

3-Phase induction motors have been widely used in Industries for several wards due to the sale in construction and roughen [2], so many industries are using classical methods in running the motors, i.e., it may be running with Y/Δ starter or with rheostat starter. These starting and running methods have significant power loss problems [1]. When speed control is required for the motor or Breaking operation, in the conventional method, the rotor rheostat starter has a great disadvantage of power losses, and a vast arrangement is necessary. The improvement of Power Electronic drives has many advantages in terms of Power loss, Compact size, overload protection, etc., Due to the benefits of this, in modern days, the motors are Operated with Variable frequency drives. These drives are different types. One is scalar PWM drives and vector-controlled PWM drives. The vector-controlled drives use automatic speed and torque controls [4]. Sinusoidal PWM and spatial vector PWM controls are used, in which an automated observation is made with the screen, which is also possible. The output of the inverter is pulsation, which is equal to the sinusoidal. As the switching frequency increases, it become near to the sinusoidal. But with the fast switching, the pulse takes multiple reflections back and forth in the cable. Which leads to transient overvoltage at the motor terminals. These voltages cause severe damage to the insulation of the stator windings [6].There is a capacitance between the stator's rotor and frame at the high switching frequency. Also, between stator wind to ground, stator winding to the rotor winding.

From the motor point of view, the stator winding produces high impedance at high frequency by the inductance of the stator, and the capacitance effect makes the low impedance [7]. There is an impedance mismatching at the terminals of the motor, which produces a voltage doubling impact at the motor terminals when the motor has a low Power rating of less than 25 H.P. The value of the reflective coefficient varies from 0.8 to 0.9.and this value may go 3 to 4 P.U in high rating with long cable length [8]. This paper aims to find the effect of cable length on the voltage at the inverter fed by VFDS, which is controlled by a sinusoidal PWM inverter.

$$\frac{v^-(t+\frac{z}{v})}{v^+(t-\frac{z}{v})}=\frac{Zl-Zc}{Zl+Zc}$$

- V+ is the positive wave moving from the inverter to the motor.
- V^- is the negative wave moving from the motor to the inverter.

2. SYSTEM REPRESENTATION

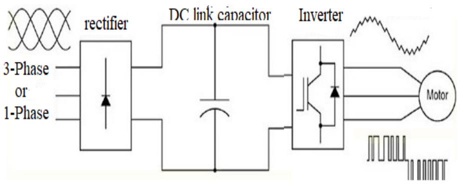

Fig 1: Block diagram of the overall system.

- In the system, there are three control units. It changes fixed A.C to variable A.C system, i.e., rectifier stage
- it changes fixed D.C to variable A.C, i.e., inverting stage
- A constant v/f control application reduces the power loss in the entire system [9].

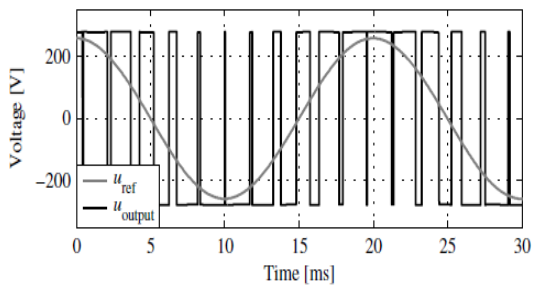

Fig 2: Output from PWM inverter

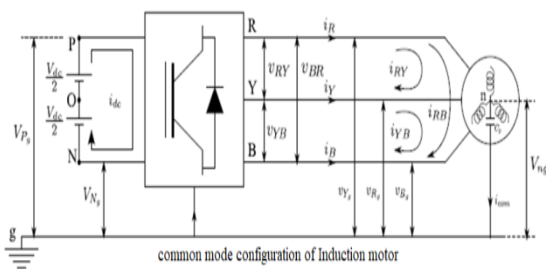

Fig-3 CM configuration

The figure shows the inverter-fed induction motor connected in a standard mode configuration. There is a shaft voltage between neutral and ground in this configuration.

3. High-frequency parameters of cable:

To find the parameters of the wires, two tests have to be conducted,

i. Short circuit test

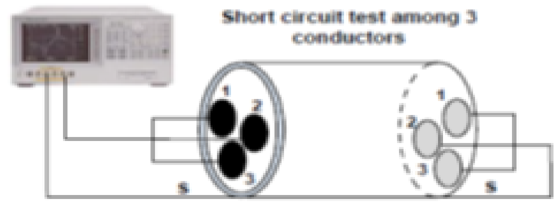

Fig-4: Short circuit test,

Resistance and inductance would be found from the short circuit test series.

ii) Open circuit test.

From the short circuit test series, inductance and resistance can be found. From the Open circuit test, three cable terminals are shorted, and readings are taken from the shorted terminal and sheet of the conductor.

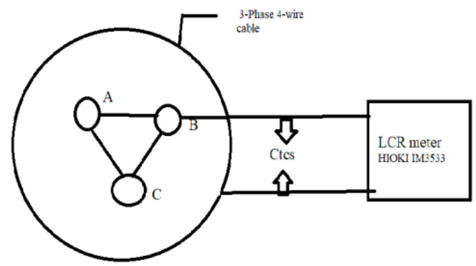

Fig-5 Open circuit (Conductor to ground capacitance)

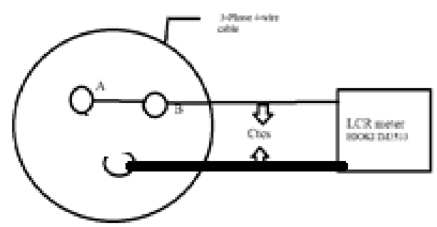

Fig-6 Open circuit (conductor to conductor capacitance)

$C_{eu} = 3C_g$

C_g = Capacitance, conductor to ground

C_{total}=capacitance measure in transfer conduction.

Cc=capacitance

$$C_s=\left(\frac{1}{2}\right)\left[C_{total}-\left(\frac{2}{3}\right) C_g\right]$$

These are measured with an LCR meter.

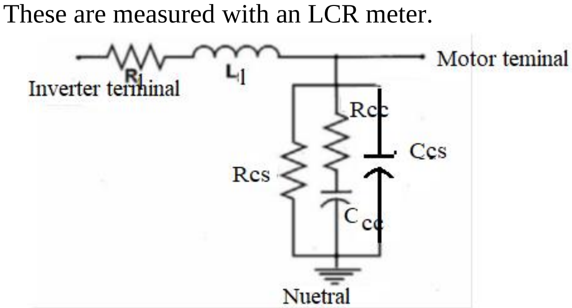

Fig 7: I-Phase modeling of cable

Rl=series resistance

L1=series inductance

Ccs=Conductor to ground capacitance at high frequency

Ccc=conductor to conductor capacitance at high frequency

4. High-frequency representation of Induction motor:

A high-frequency representation of an induction motor is typically used for analyzing the motor's behavior and performance in situations where high-frequency phenomena, such as voltage spikes, switching transients, and harmonics, become significant. High-frequency modeling allows engineers to study how the motor responds to these rapid voltage changes and how they might affect its operation. In high frequency, the induction motor behaves unlike a standard motor. It involves high input impedance compared with low frequency.it is due to the behaviors of the inductance at high frequency [12].

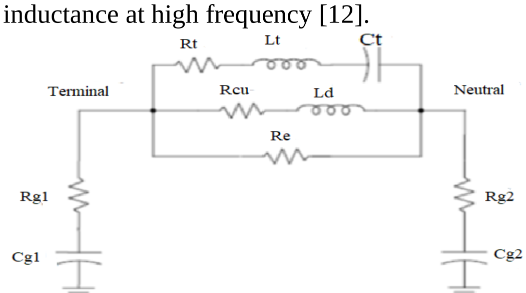

Fig-8: Equivalent circuit of I.M

Two tests must be done to get the parameters of the induction motor at high frequency.at different frequencies in the frequency spectrum, other parameters are obtained.

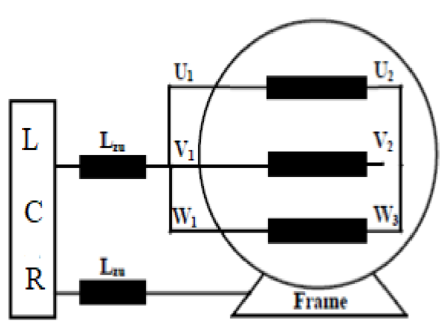

Fig 9: Common mode [10]

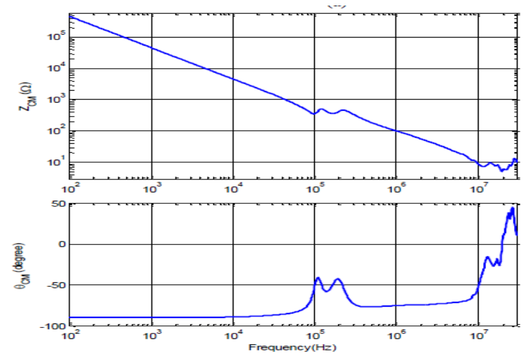

Fig 10: Frequency analysis of Induction motor (CM)

From this above circuit, a capacitance to ground, resistance of the stator, and inductance of the stator would obtained. A high-frequency representation of an induction motor is a valuable tool for understanding and optimizing motor performance in applications with significant high-frequency effects. It enables engineers to design more robust and efficient systems and address potential issues related to rapid voltage changes and harmonics.

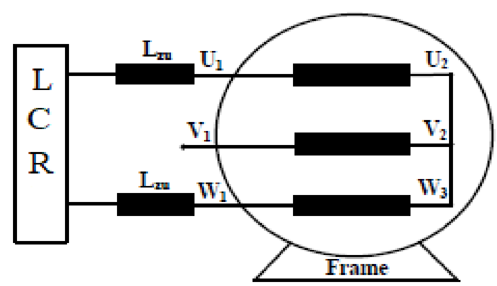

Fig 11: Frequency analysis of Induction motor.

The above configuration would obtain capacitance from conductor to conductor and second resonance parameters.

Parameters:

Table: Cable parameters for different Ratings [12]

Cable Gage	R_s [mΩ]	L_s [µH]	Rp_1 [MΩ]	Rp_2 [KΩ]	Cp_1 [pf]	Cp_2 [pf]
6	1.5	0.24	173.9	13.9	137.1	22.5
8	6.0	0.20	262.1	21.2	119.7	15.3
10	7.0	0.28	221.7	18.9	125.4	17.7

Table 2: Induction motor Parameters

Ratings	C_g [pf]	R_g [Ω]	L_d	R_e	C_t	L_t	R_t [kΩ]

[HP]			[mH]	[KΩ]	[pf]	[mH]	
5	314	35.5	4.0	5.6	31.4	2.7	1.15
10	704	23.2	1.3	1.4	70.4	0.09	0.086
40	260	12	0.86	2.5	26.1	0.48	0.1

5. Results & Analysis:

For simulation, MATLAB is used. The inverter is a sinusoidal PWM inverter. Cable is modeled as distributed by taking per meter length parameters. Induction motor parameters are taken as lumped parameters.

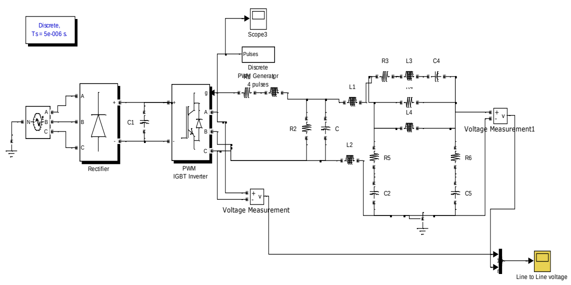

Fig 12: Simulation in MATLAB-2019

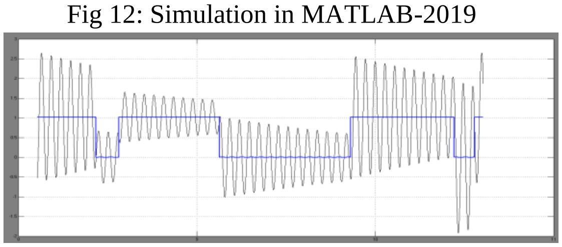

Fig 13: For 5-H.P 100m length

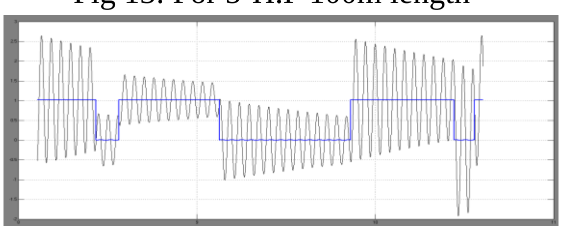

Fig 14: For 5-H.P 15m Length

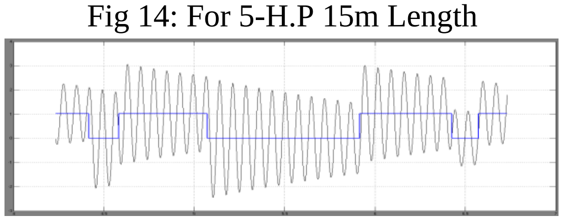

Fig 15: 5 H.P 150m length

Table 3: Comparison of the cable lengths and voltages

S.No	Gage of the cable	Voltage at inverter terminal	Voltage at the motor terminal
1	6	400	586
2	8	400	585.5
3	10	400	585.4

7. CONCLUSIONS

These conclusions have practical implications for designing and operating systems using VFDs to drive 3-phase induction motors.

- When designing or upgrading systems with VFDs and long cable runs, knowing the potential for increased transient voltages with longer cables is essential. Mitigation measures may be necessary to ensure the reliability and safety of the system.
- Choosing cables with a larger gauge (lower AWG number) can help reduce transient voltage levels. Thicker cables have lower impedance and better handle high-frequency switching without significant voltage spikes.
- Engineers should consider the specific cable length and gauge requirements when designing and specifying components for VFD-driven systems. This will help achieve the desired performance and minimize the risk of transient voltage-related issues.
- Further research and experimentation may be warranted to explore additional factors impacting transient voltage behavior, such as cable insulation materials and grounding practices.
- Overall, your findings contribute valuable information to understanding transient voltage behavior in VFD-fed induction motor systems and offer practical guidance for engineers and industries to optimize system performance and reliability.

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