Effects of Modulation Index on Induction Motor Application with Hybrid Multilevel Inverter Topology

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Abstract: The research work focuses on the effects of modulation index on induction motor application with hybrid multilevel inverter topology. A low frequency rectified reference sinusoidal waveform is used to compare two triangular carrier signal of a very high frequency. High and low frequency pulse width modulation (PWM) signals are generated for the multilevel power switch controls. H-bridge inverter configuration with a bidirectional switch for voltage divided is adopted for the single-phase induction motor drive due to its optimal performance. The system simulation is performed under variable modulation indices of 0.7, 0.9 and 1.1. The simulated results showed that the total harmonic distortion (THD) in the output voltages of 160.8V, 212.7V and 255.9V at modulation indices of 0.7, 0.9 and 1.1 attain values of 4.08%, 3.15% and 4.23% respectively. Simulation results are obtained using MATLAB/SIMULINK software.

Index Terms: Hybrid multilevel inverter, induction motor, modulation index, pulse width modulation, switching devices.

1 INTRODUCTION

Power electronics involve the study of electronic circuits intended to control the flow of electrical energy. These circuits handle power flow at levels much higher than the individual device ratings. Power electronics have broad areas; it has many converters like AC to DC and DC to AC. In conversion of DC to AC, Multilevel inverter is replacing conventional Inverter because of its high power applications with good potential for further development. The most attractive feature of this inverter is in the medium-to-high-voltage range, motor drives, power distribution, and power conditioning applications. Presently, power sector is growing very fast; industries are demanding power in the megawatt level. This cannot be achieved by using conventional inverter as the semiconductor devices must be connected in series to obtain the required high-voltage operation. This can be only possible when outputs of several conventional inverters are added with transformers or inductors, or direct series connection, or by more complex topologies. For these reasons, a new family of multilevel inverters has emerged as the solution for working with higher voltage levels [1].
The purpose of multilevel inverter is to generate desired multi-staircase single or three phase voltage by combining several DC voltage sources. Solar cells, fuel cells, batteries and ultra-capacitors are the most common independent sources used. One important application of multilevel converters is focused on medium and high-power [2].
In multilevel inverter, the term 'level' is referred to as the number of node to which the inverter can be accessible, 'output voltage' can be defined as voltage across output terminal of the inverter and the ground point. The structural switches will be capable of withstanding very high input voltage for high power application and lower switching frequency for each switching device.

This paper presents effects of modulation index on induction motor application with hybrid multilevel inverter topology. The proposed configuration is simulated using MATLAB/SIMULINK software with multicarrier sinusoidal pulse width modulation strategy under variable modulation index. The structure of this paper is organized as follows. Section I gives the general introduction to the paper title. Section-II deals with the conventional multilevel inverter configuration. Section-III gives the general block diagram of the proposed model. Section-IV the modulation scheme adopted is presented. Section-V inverter interface with asynchronous motor configuration. MATLAB/SIMULINK model are presented in Section VI. Section VII presented the model simulation results and discussions, and finally in Section-VIII conclusion is presented.

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2 MULTILEVEL INVERTER

Multilevel inverters (MLI) for high-power medium-voltage variable-speed motor drives have been widely applied in the industries like compressors, pumps, fans, conveyors, grinding mills, rolling mills, marine propulsion, and rail tractions, to achieve energy savings. In multilevel converters, the semiconductors are wired in a series-type connection, which allows operation at higher voltages. However, the series connection is typically made with clamping diodes, which eliminates overvoltage concerns. Furthermore, since the switches are not truly series connected, their switching can be staggered, which reduces the switching frequency and thus the switching losses. In most of the control and modulation techniques of multilevel inverter, the number of voltage level reduces with the reduction of modulation index that increases the harmonic and total harmonic distortions [3]. Presently, there are mainly four kinds of commercialized multilevel inverter topologies: neutral point clamped (NPC), flying capacitor (FC), cascaded H-bridge (CHB), and the modular multilevel converter (MMC) [4]. Although they can be configured for more than two levels, as the number of levels increase, the power circuit and control complexity due to a large number of devices, increases. An optimum topology for multilevel inverters for more than three levels has not been achieved until now, and research is going on to improve the drive efficiency at reduced circuit complexity and control [5].

3 MULTILEVEL INVERTER STRUCTURE

A voltage level of three is considered to be the smallest number in multilevel converter topologies. Due to the bi-directional switches, the multilevel VSC can work in both rectifier and inverter modes. This is why most of the time it is referred to as a converter instead of an inverter in this paper. A multilevel converter can switch either its input or output nodes (or both) between multiple (more than two) levels of voltage or current. As the number of levels reaches infinity, the output THD approaches zero. The number of the achievable voltage levels, however, is limited by voltage-imbalance problems, voltage clamping requirements, circuit layout and packaging constraints complexity of the controller, and, of course, capital and maintenance costs.

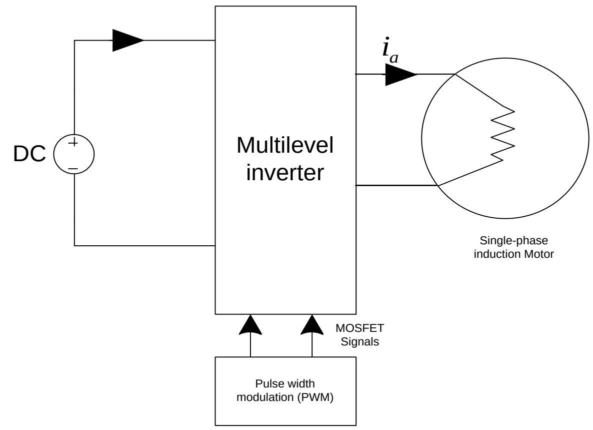

Fig. 1.General block model of the proposed system

Fig. 1 shows the general structure of the multilevel converter system. In this case, a single-phase motor load is shown on the AC side of the converter. Generally, variable-speed induction motor employs the inverter as power-varying component. However, the converter may interface to an electric utility or drive another type of load. The goal of the multilevel Pulse-Width Modulation (PWM) block is to switch the converter GTOs in such a way that the phase voltages mimics the reference signals [6].

4 MODULATION SCHEME

A Modulation scheme can be used to create the variable frequency, variable voltage ac waveforms. The sinusoidal PWM compares a high frequency triangular carrier with a sinusoidal reference signals knows as modulating signals to generate the gating signals for inverter switches as depicted in Fig. 2 below. The requirements of multilevel modulation technique are as follows.

1 .Voltage quality should be good
2. Modular design Simultaneous switching of multiple voltage levels is not allowed.
3. Switching frequency of power devices should be minimized.
4. Power modules should share the load equally.
5. Control algorithm should be simple.
6. Implementation cost should be low.

When it comes to a multilevel inverter modulation, there are basically categorized into two groups:
1. Modulation with fundamental switching frequency
2. High switching frequency PWM [1].

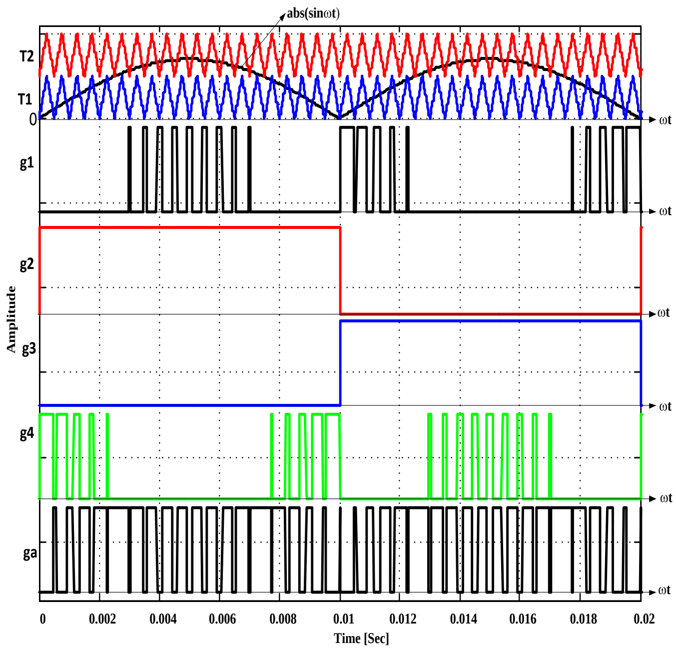

Fig. 2. Switching pattern of the proposed single-phase multilevel inverter topology.

5 INDUCTION MOTOR DRIVES USING MULTI-LEVEL INVERTER.

Many current and future designs will incorporate the use of induction motors as the primary source for traction in electric vehicles. Designs for heavy duty trucks and many military combat vehicles that have large electric drives will require advanced power electronic inverters to meet the high power demands (>250 Kw). Development of electric drive trains for these large vehicles will result in increased fuel efficiency, lower emissions, and likely better vehicle performance (acceleration and braking). Multilevel inverters are uniquely suited for these applications because of the high VA ratings possible with these inverters [7].

The first railway-traction-drive application of a three-level PWM converter and inverter system is the class 1822 dual-voltage locomotive of Austrian Railways (OBB) [8]. The three-level configuration was used initially because of the high-voltage DC-operation requirement. The available 4.5kV gate-turnoff thyristor (GTO) devices are not suitable for a two-level scheme operating directly off 3kV DC catenaries. Here the three-level configuration was used to achieve higher power and lower harmonics at both the input and output of the traction drive.

The multilevel voltage source inverters unique structure allows them to reach high voltages and power levels without the use of transformers [9]. They are especially suited to high voltage vehicle drives where low output voltage total harmonic distortion (THD) and electromagnetic interference (EMI) are needed. The general function of the multilevel inverter is to synthesize a desired voltage from several levels of dc voltages. For this reason, multilevel inverters can easily provide the high power required of a large EV or HEV drive.

As the number of levels increases, the synthesized output waveform has more steps, which produces a staircase wave that approaches the desired waveform. Also, as more steps are added to the waveform, the harmonic distortion of the output wave decreases, approaching zero as the number of levels increases. As the number of levels increases, the voltage that can be spanned by connecting devices in series also increases. The structure of the multilevel inverter is such that no voltage sharing problems are encountered by the active devices [10]. In this work, the single-phase three-level inverter feds a single-phase asynchronous motor (split-phase) modeled in the dq stator reference frame. Main and auxiliary windings are in quadrature. The Matlab-Simulink block is shown in Fig. 6.

6 MATLAB – SIMULINK MODELLING

From a 240 Volts DC source supplies a single-phase, three-level hybrid inverter with a 0.25Hp, 1500rpm, 220V, 50Hz single-phase induction motor load as shown in Fig. 3. Pulse width modulation technique is adopted with variable modulation index. The MATLAB/Simulink subsystem modules is used to implement the system simulation. The inverter topology is based on the model described in [11]. Fig. 4 depicts the firing signals generator for the power switches (IGBT) which are distributed to the inverter model as shown in Fig. 5. The inverter output is connected to the stator windings of the single-phase induction motor as depicted in Fig. 6 below.

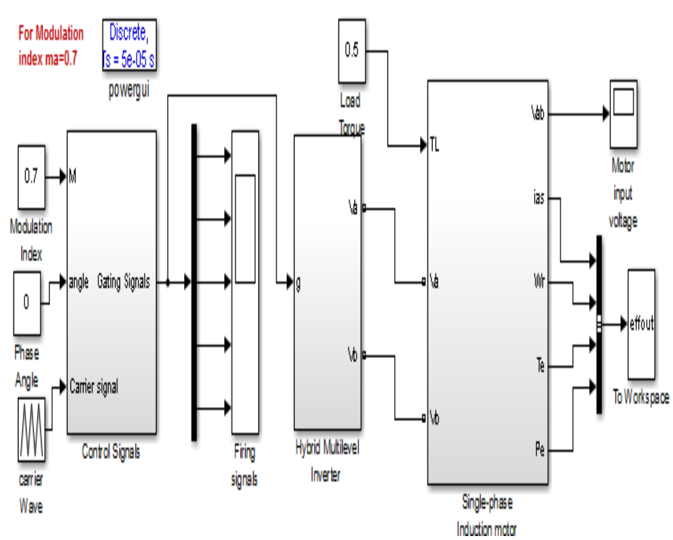

Fig. 3 General MATLAB/Simulink model

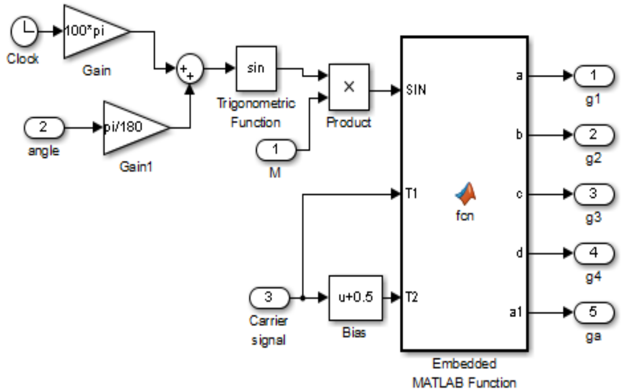

Fig. 4 Simulink subsystem for control signals

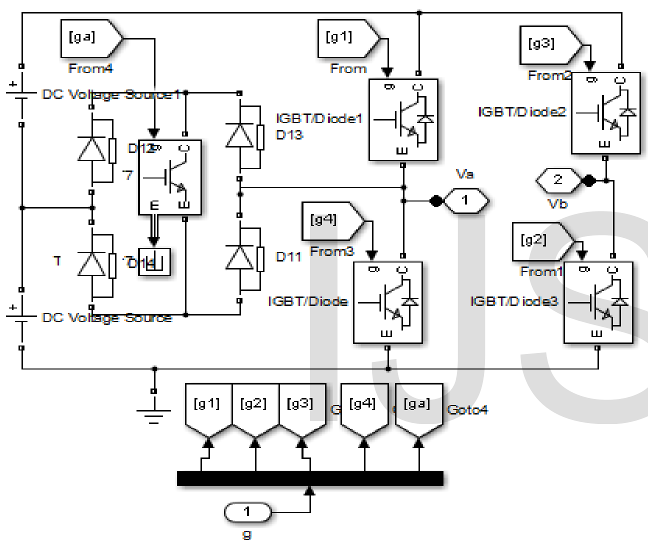

Fig. 5 Simulink subsystem for multilevel inverter power circuit.

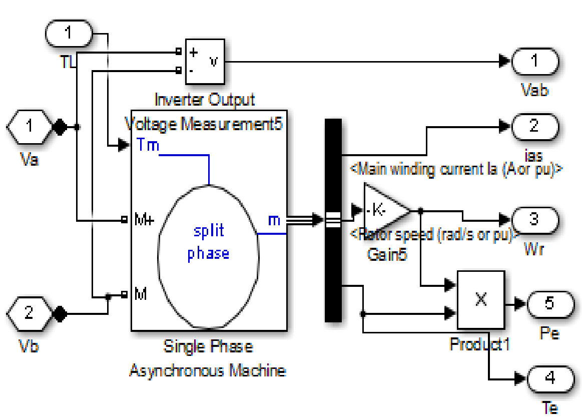

Fig. 6 Single phase induction motor

7 SIMULATION RESULTS AND DISCUSSIONS

Fig. 7 (a, b, c) displays the inverter output voltages at different modulation index, which serves as the induction motor input voltage. The inverters output voltages are determined at various amplitude modulation indices ranging from 0.7 to 1.1 at an interval of 0.2. The induction motor stator currents are displayed in Fig. 8 with Fig. 8c attaining stability at 0.5secs for 1.1 modulation index. Fig. 9c is the torque plot stabilizes faster than Fig. 9a but has a high torque magnitude after attaining stability state as shown in Fig. 10. The rotor speed waveforms are displayed in Fig. 11, here, at M=1.1 the stable state speed occurred at 0.6s with speed value of 1500RPM. Figs. 12 – 14 depict the harmonic spectrum contents, the lowest Total Harmonic Distortion (THD) occurred in Fig. 13 at M=0.9 with output voltage content as 212.7V. Table 1 summaries the results analysis at variable modulation indices.

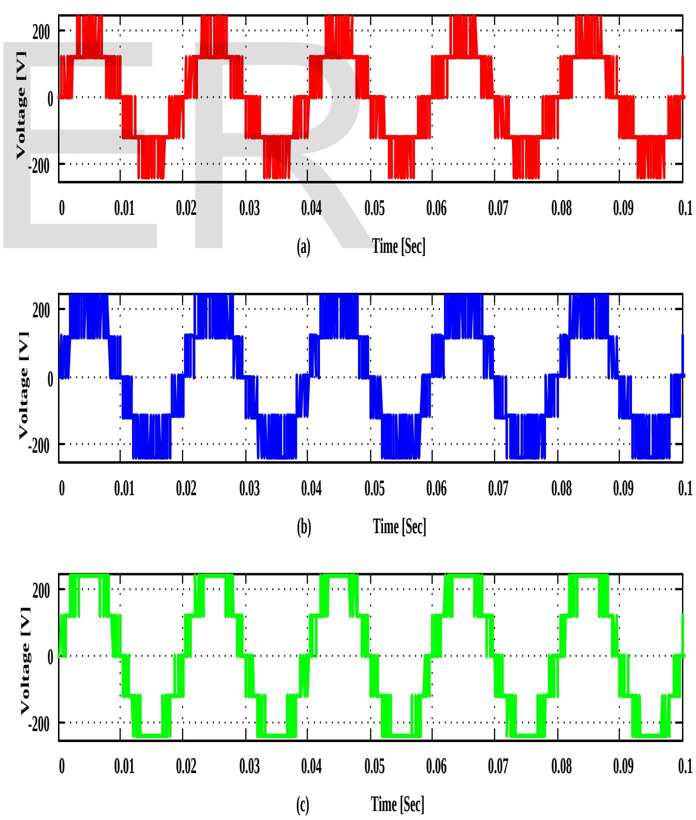

Fig. 7 Inverter output voltage (a) M=0.7, (b) M=0.9 (c) M=1.1

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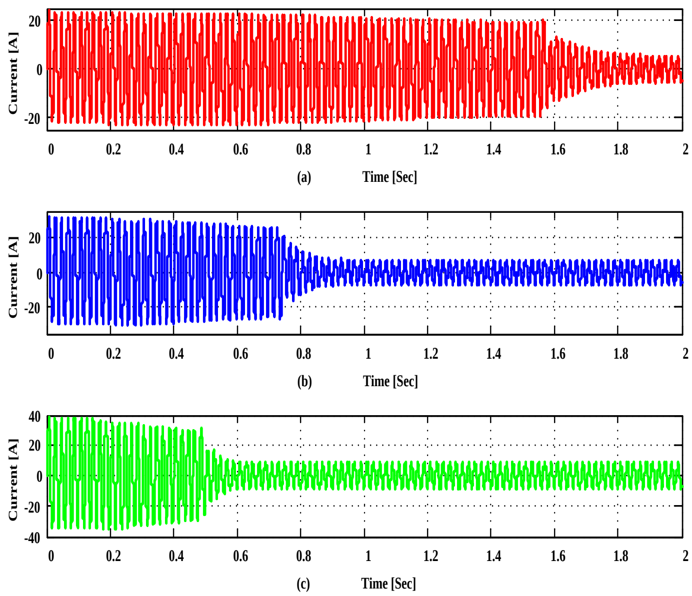

Fig. 8 Motor stator currents (a) M=0.7, (b) M=0.9 (c) M=1.1

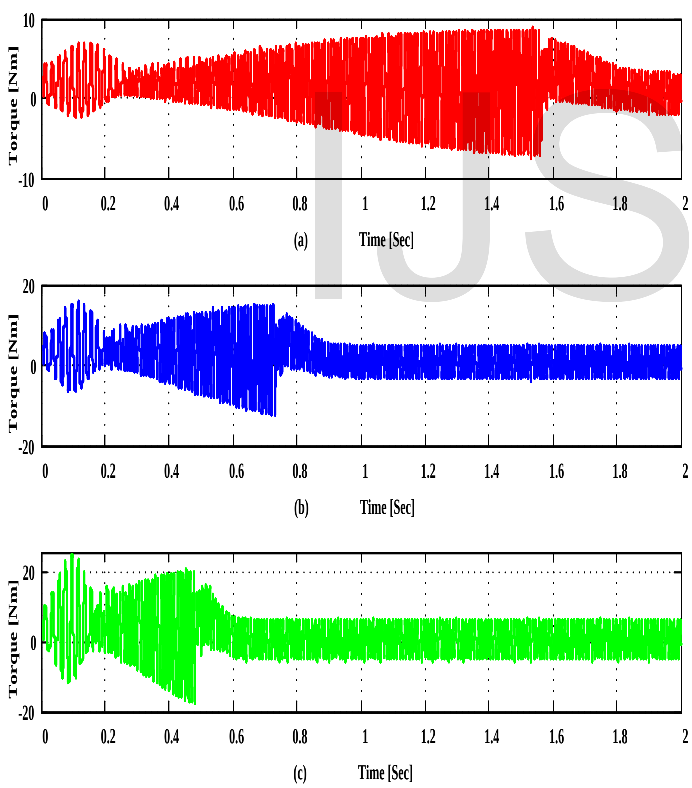

Fig. 9 Electromagnetic Torques for (a) M=0.7, (b) M=0.9 (c) M=1.1

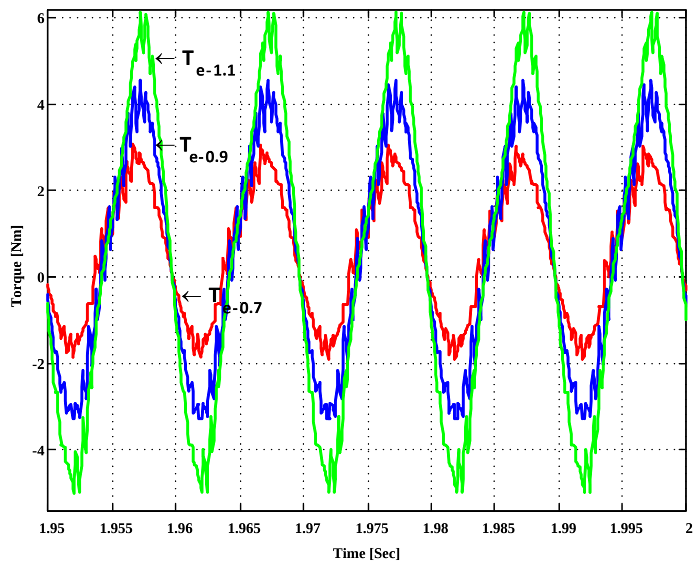

Fig. 10 Electromagnetic Torques at steady state for (a) M=0.7, (b) M=0.9 (c) M=1.1

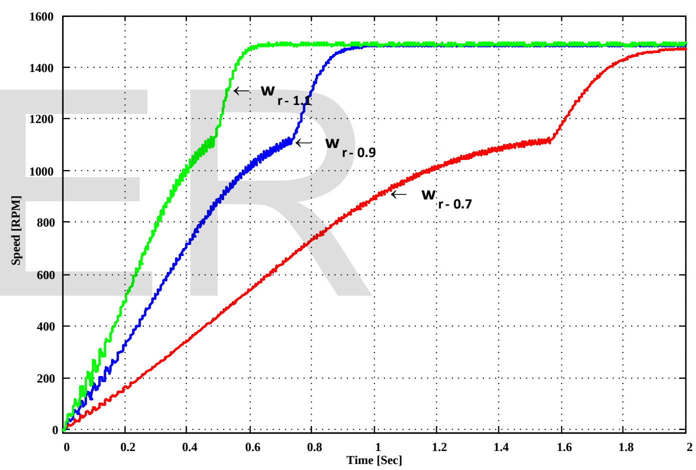

Fig. 11 Rotor speeds for (a) M=0.7, (b) M=0.9 (c) M=1.1

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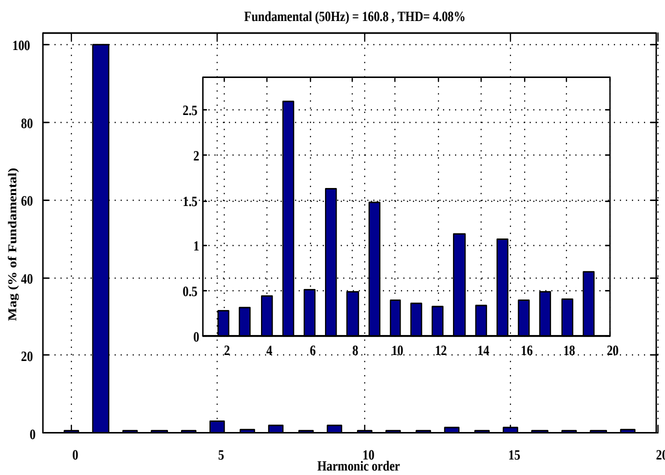

Fig. 12 FFT display for M=0.7

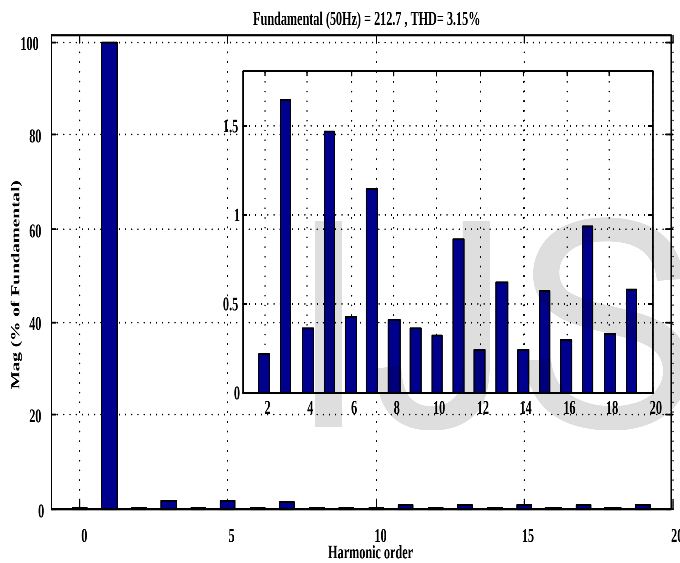

Fig. 13 FFT display for M=0.9

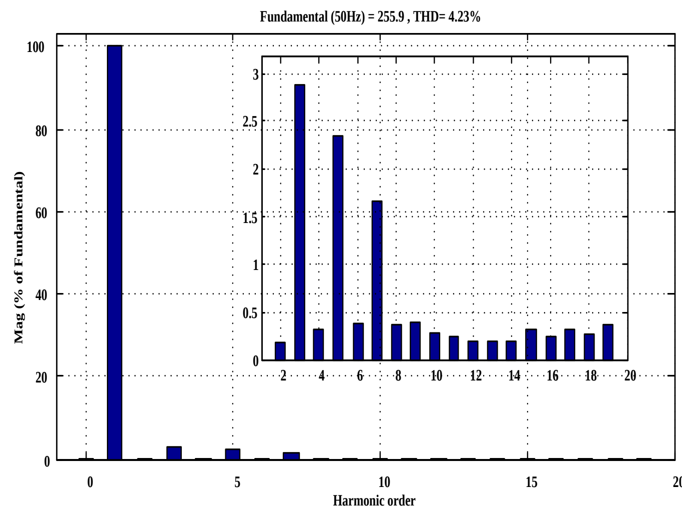

Fig. 14 FFT display for M=1.1

Table 1 Comparison between different modulation indices:

Parameters	RMS output voltage (V)	Transient current (A)	Steady current (A)	Steady speed (RPM)	Total harmonic distortion (%)	Maximum Torque (Nm)	Minimum Torque (Nm)
M=0.7	160.8	25.0	6.0	1500	4.08	9.0	-7.0
M=0.9	212.7	35.0	7.0	1500	3.15	15.0	-12.0
M=1.1	255.9	40.0	8.5	1500	4.23	26.0	-20.0

8 CONCLUSION

It can be seen from the simulated results that the THD in the output voltages of 160.8V, 212.7V and 255.9V at modulation indices of 0.7, 0.9 and 1.1 attain values of 4.08%, 3.15% and 4.23% respectively. This paper shows that the inverter output voltage varies directly proportional to modulation index. Also, as the modulation index increases the maximum torque occur increases. It can be concluded that for low voltage induction motor application low modulation index (M=0.7) can be used but it has great effect on the stator windings. Thus, for minimum harmonic content induction motor application, modulation index of 0.9 can be selected. For high voltage induction motor application, 1.1 modulation index can be used but it has high effects on the stator windings and motor torque.

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