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Performance Evaluation of Switching Capacitor Cascaded Multilevel Converter for Ac Distribution System FED Induction Motor Drive

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ABSTRACT:

In this project we are using the techniques that are used in a cascaded multilevel inverter based on switched-capacitor for high-frequency ac power distribution system and here in this topology we are getting the input from the fuel cell and battery and that energy is fed to a cascaded multi level inverter, here we are using a new topology to control the output of the multi level inverter, and that controlled output is fed to an industrial application like three phase induction motor. The overall system is designed and simulated in MATLAB software, the total system designing is done in graphical user interfacing (GUI) environment .to develop overall system here we are using the elements in SIMULINK library.

*Keywords-****Multilevel inverter, Cascaded inverter, Digital control, Total Harmonic distortion, switching losses.***

I.INTRODUCTION

Power electronic converters, especially dc/ac PWM inverters have been extending their range of use in industry because they provide reduced energy consumption, better system efficiency, and improved quality of product, good maintenance and so on. It should be noted that lower switching frequency usually means lower switching loss and higher efficiency. Large electric drives and utility applications require advanced power electronics converter to meet the high power demands. As a result, multilevel power converter structure has been introduced as an alternative in high power and medium voltage situations[1]. A multilevel converter not only achieves high power ratings, but also improves the performance of the whole system in terms of harmonics, dv/dt stresses, and stresses in the bearings of a motor. Several multilevel converter topologies have been also developed i) diode clamped, ii) flying capacitors, and iii) cascaded or H-bridge. Referring to the literature reviews, the cascaded multilevel inverter (CMI) with separated DC sources is clearly the most feasible topology for use as a power converter for medium & high power applications due to their modularization and extensibility[2]. The Hbridge inverter eliminates the excessively large number of (i) bulky transformers required by conventional multilevel inverters, (ii) clamping diodes required by multilevel diode-clamped inverters and (iii) flying capacitors required by multilevel flying-capacitor inverter. As a preliminary study the thesis examined and compared the most common multilevel topologies found in the published literature[3]. Starting from the essential requirements, the different approaches to the construction of multilevel inverter are explained and compared. In particular, aspects of total harmonic distortion (THD) and modulation which are required or desirable for multilevel converters are discussed[4]. Sine-triangle carrier modulation is identified as the most promising technique to pursue for both technical and pedagogical reasons. Since cascaded multilevel inverter is considered to be suitable for medium & high power applications, the harmonic analysis of 3- level, 5-level, & 7 level cascaded multilevel inverter induction motor drives through analysis, simulation & experiment [5].

As alternatives to effectively solve the above-mentioned problems, several circuit topologies of multilevel inverter and converter have been researched and utilized. The output voltage of the multilevel inverter has many levels synthesized from several DC voltage sources. The quality of the output voltage is improved as the number of voltage levels increases, so the quantity of output filters can be decreased [6]. The elementary concept of a multilevel converter to achieve higher power is to use a series of power semiconductor switches with several lower voltage dc sources to perform the power conversion by synthesizing a staircase voltage waveform[7]. Capacitors, batteries, and renewable energy voltage sources can be used as the multiple dc voltage sources. The commutation of the power switches aggregate these multiple dc sources in order to achieve high voltage at the output however, the rated voltage of the power semiconductor switches depends only upon the rating of the dc voltage sources to which they are connected. A multilevel converter has several advantages over a conventional two-level converter that uses high switching frequency Pulse Width Modulation (PWM).Staircase waveform quality: Multilevel converters not only can generate the output voltages with very low distortion, but also can reduce the dv/dt stresses; therefore electromagnetic compatibility (EMC) problems can be reduced[8]. Multilevel inverters have drawn tremendous interest in the power industry. They present a new set of feature that are well suited for use in reactive power compensation. Multilevel inverters will significantly reduce the magnitude of harmonics and increases the output voltage and power without the use of step-up transformer. A multilevel inverter consists of a series of H-bridge inverter units connected to three phase induction motor. The general function of this multilevel inverter is to synthesize a desired voltage from several DC sources. The AC terminal voltages of each bridge are connected in series[9].

II. CASCADED MULTILEVEL INVERTER

The cascaded H-bridges inverter consists of H-bridges in series configuration. Such technology is very attractive for application such as [6-7] motor drive systems, power distribution, power quality and power conditioning application. Each H-bridge inverter module can generate three different output voltage levels namely 0, +Vdc and -Vdc. The multilevel inverter of Fig.1 utilizes two independent DC sources and consequently will create an output phase voltage with seven levels. N is the number of independent DC sources per phase, m is the number of levels, l represents the number of switches with freewheeling diodes per phase, then the following equations are applied for CMLI A simplified single phase topology is shown in Fig. 2.1.The output voltage will be +10V (top inverter H1) when switches T11 and T14 conducts. Similarly, 10V will be obtained when T12 and T13 conducts. The output voltage is +20V only when T21 and T24 are conducting and the output voltage is -20V only when T22 and T23 are conducting. The output voltage +30V is available when switches T11, T14 ,T21 and T24 conducts and -30V is available when switches T12,T13 T22 and T23 conducts.

III. PURPOSE OF HARMONIC REDUCTION

The output voltage of multilevel inverter is a symmetric stepped voltage waveform. The output voltage will have fundamental and the associated harmonics. The dc link supply for each full bridge converter is provided separately, and this is typically achieved using These harmonics produce additional heating, when the output voltage of the inverter is fed to the load. Therefore in order to reduce that, harmonic reductions is necessary. Diode rectifiers fed from isolated secondary windings of a three-phase transformer. Phase-shifted transformers can supply the cells in medium-voltage systems in order to provide high power quality at the utility connection. A cascaded multilevel inverter made up of from series connected single full bridge inverter, each with their own isolated dc bus. This multilevel inverter can generate almost sinusoidal waveform voltage from several separate dc sources .This type of converter does not need clamping diodes or flying capacitors. Each level can generate eleven different voltage outputs by connecting the dc sources to the ac output side by different combinations of the eleven switches. The number of output phase voltage levels m in a cascade inverter is defined by m = 2s+1, where s is the number of separate dc sources. The 11-levels of voltages are 0, V/5, 2V/5, 3V/5, and 4V/5, V, -V/5, -2V/5, -3V/5, -4V/5,-V. The output voltage of an M-level inverter is the sum of all the individual inverter outputs. Each of the H-Bridge's active devices switches only at the fundamental frequency, and each H-bridge unit generates a quasi- square waveform by phase-shifting it's positive and negative phase legs switching frequency. Further, each switching device always conducts for 180˚ (or half cycle) regardless of the pulse width of the quasi-square wave so that this switching method results in equalizing the current stress in each active device. A multilevel inverter has four main advantages over the conventional bipolar inverter. First, the voltage stress on each switch is decreased due to series connection of the switches.

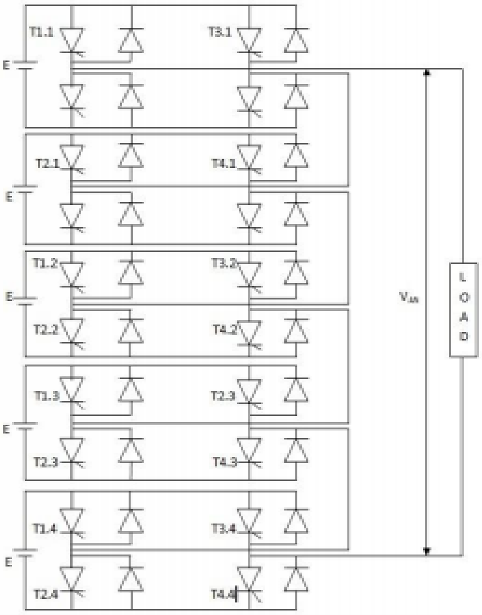

Fig. 1 Eleven Level Cascaded H-Bridge Topology

Therefore, the rated voltage and consequently the total power of the inverter could be safely increased. Second, the rate of change of voltage (dv/dt) is decreased due to the lower voltage swing of each switching cycle. Third, harmonic distortion is reduced due to more output levels. Fourth, lower acoustic noise and electromagnetic interference (EMI) is obtained. It consists of a full-bridge inverter circuit and inverter produces output voltage in eleven levels: The advantages of the inverter topology are Improved output voltage quality, Smaller filter size, Lower Electromagnetic interferences, Lower total harmonics distortion compared with conventional eleven level pulse width modulation ,Reduced number of switches compared to the conventional 11-level inverter.

IV. FEATURES OF CASCADED MULTI LEVEL INVERTER

For real power conversions, (ac to dc and dc to ac), the cascaded-inverter needs separate dc sources. Connecting separated dc sources between two inverters in a back -to-back fashion is not possible because a short circuit will be introduced when two back -to-back inverters are not switching synchronously.

- Multi level inverter employees the principle of phase control to vary the output voltage.
- They can generate the output voltage with low distortion. They reduce the device voltage stress and draw input current with low distortion.
- They can operate at low switching frequency.
- Increasing the output voltage and power does not increase the rating of the device.
- They have no electromagnetic interference.

An n level cascaded H-bridge inverter requires Switching devices=2(n-1) and Voltage source=(n-1)/2.The output voltage is the sum of the voltage that is generated by each cell. The number of output voltage levels are 2n+1, where n is the number of cells. These topologies are intensively used for high-power applications and standard drives for medium-voltage industrial applications[4]. Solutions with a higher number of output voltage levels have the ability to synthesize waveforms with a better harmonic spectrum and to limit the motor-winding insulation stress. However, increasing the number of devices tends to reduce the overall reliability and efficiency of the power converter.

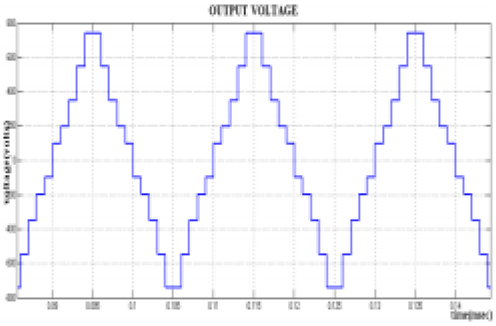

Fig .2 Eleven Level Output Voltage

V. RECENT ADVANCES IN CONTROL AND OPERATIONAL ISSUES

In contrast to modulation methods, which required—and still do—substantial research and development, to adapt to the special needs and switching states of multilevel topologies, their control has been a more straightforward extension. In fact, multilevel-converter-powered variable-speed motor drives are controlled using the same methods used for 2L-VSCs, i.e., v/f control (or scalar control), field-oriented control (FOC, also known as vector control), and direct torque control (DTC) [4]. The main reason is that both v/f control and FOC have a modulation stage embedded in the control loop. Hence, the control scheme does not change; only the modulation stage must be replaced. In other words, the two-level PWM or SVM needs to be replaced by an appropriate modulation scheme that best fits the particular multilevel converter. As can be appreciated in Table I, both methods are used by several manufacturers in the field. In contrast, DTC relates each switching state or voltage vector generated by the converter to a specific change in the motor flux and torque, which cannot directly be extended from the two-level to the multilevel case. The main reason is that the number of vectors over proportionally increases with the increase in voltage levels, making it difficult to define voltage vector selection criteria according to the flux and torque errors. Nevertheless, this has been addressed for 3L-NPC converters by using multiple hysteresis band controllers and a finer sector division of the space vector complex plane [157] and has successfully been used in industry, as can be observed in Table I. The extension of direct torque control for other topologies and converters with more levels has also been reported in [158] and [159]. More recently, some characteristics of FOC and DTC have been combined into another motor drive control method called SVM-DTC [160], which combines linear controllers and the SVM modulation stage of the FOC scheme with the load angle control concept of DTC (control of the angle between stator and rotor fluxes). This control method achieves fast dynamic control of the torque such as DTC but introduces a modulation stage that fixes the switching frequency, which is one of the major drawbacks of traditional DTC. This method can easily be extended to multilevel converters, again by just replacing the two-level modulation stage by a multilevel modulation method [161]. In case of multilevel converters with a high number of levels, the modulation stage is not even necessary, and the nearest level generation can be used [162]. Following the analogy between motor side and grid side control schemes, multilevel converters connected to the grid are controlled with voltage-oriented control (VOC) and direct power control (DPC) [163], which are the grid side counterpart of FOC and DTC, respectively. Further enhancements that use a grid virtual flux concept to better synchronize the control method to the grid have been introduced in [164] and applied to multilevel converters in [49]. As with motor control, a combination of both methods has been proposed, originating SVM-DPC, which has been applied to a 3L-NPC [165]. Both VOC and SVM-DPC need only a multilevel modulation stage update, whereas DPC has been extended for multilevel converters in [166]. Apart from the development of modulation methods and the extension of control methods for multilevel converters, some operation-specific issues such as capacitor voltage control, common-mode voltage reduction/elimination and fault detection, and diagnostic and tolerant operation of multilevel converters are equally important. Several multilevel converter topologies suffer from voltage unbalance among the dc-link capacitors at certain modulation indexes and operating conditions [40], [41], [123], [167]–[176]. Probably the most well-known problem in this topic is the capacitor unbalance of NPC or DCC topologies. Particularly, the unbalance in 3L-NPC has extensively been studied, and several solutions have been reported [9]. Considering the successful industrial presence of the 3L-NPC and the fact that it is commercialized by at least nine manufacturers, it can be concluded that, from a practical point of view, this is a solved problem. This is not the case for DCC topologies of four and more levels. The reason is that, for diode front-end DCCs of more than four levels, the capacitors cannot properly be balanced with conventional modulation techniques producing a typical multilevel converter stepped waveform. Instead, some switching states are avoided to perform balance control, leading to higher dv/dts. This is why it is still the subject of attention and research. As an alternative, additional hardware, which is usually a dc–dc stage, is added to aid in the control of capacitor voltages [124]. The unbalance problem is not an issue in backto-back configurations since the active front end is responsible for the dc-link voltage control. The challenge of dc-link voltage balance is not exclusive to the NPC family. In fact, although FCs have an autobalance property when used with PS-PWM, the dynamic response of the capacitor voltages is very slow. Therefore, some works propose additional control mechanisms also based on switching-state redundancies to improve the dynamic performance of the voltage balance. In [172] and [177], a model and an analytical study on the balancing problem and dynamics of FC are presented. Recently, a voltage-balancing passive circuit has been proposed to assist the voltage balancing in an FC [178], [179]. In [180], the voltage-balancing control of the capacitors of an MMC is studied. The CHB is the only one that has no unbalance problems since each dc link is fed by an isolated dc source. However, for STATCOM, AFs, and other applications in which the capacitors are floating (not connected to a dc source), a voltage control algorithm is necessary to keep the voltages controlled at the desired level. This issue is not exclusive for the CHB; in fact, the same challenge is applied to any other topology used in applications where the capacitors are floating. The common-mode voltage generated due to inverter switching is detrimental to the motor shaft and bearings. Several new strategies to eliminate the common-mode voltage have recently been proposed [74], [94]–[97], [122], [251]. The use of predictive control in the field of multilevel converters has very recently been introduced as a very attractive and promising alternative [252]. In effect, the use of predictive control avoids the need for modulators and linear controllers to generate, for example, controlled currents to the load. This method uses a simple cost or quality function that has to be minimized. This function can also include additional terms to balance the capacitor voltages in an NPC inverter and to reduce the number of commutations [253]. Since some of the multilevel converter topologies have modular structure, there is a more straightforward fault-tolerant capability of these topologies under abnormal conditions. The faulty circuit can be bypassed, and the converter can be reprogrammed to generate reduced voltage [254], [255]. In [256]– [259], fault analysis and fault operation for an NPC and ANPC are presented.

VI.RECENT ADVANCES IN MULTILEVEL CONVERTER APPLICATIONS

Before the introduction of multilevel converters, current source topologies such as the PWM current source inverter (PWM-CSI) and the LCI, and direct conversion topologies such as the cycloid converter dominated the medium-voltage high power application field. Currently, the load LCI and cycloid converter still dominate for very high power applications, such as ship propulsion, hydro pumped storage, and large fans, and low-speed high-torque applications, such as grinding mills [260]. The PWM-CSI also has a very important presence in megawatt-motor-drive applications (pumps, fans, compressors, etc.) due to transformer less operation, low switching dv/dts, simple converter structure, low switch count, and reliable over current/short-circuit protection [260]. The main drawback of the current source topologies lies in the limited dynamic performance due to the use of large dc chokes as dc link. This is where multilevel voltage source converters step in as an interesting alternative since they can achieve higher dynamic performance but without the dv/dt problems and voltage limit of the classic 2L-VSI. However, this comes at the expense of more complex circuit structures and lower reliability. Nevertheless, multilevel voltage source converters have successfully been applied and are an important alternative that competes with PWM-CSI in classic applications: compressors, pumps, fans, rolling mills, and conveyors, to name a few [2], [3], [5]–[9]. It is worth noticing that these processes are the most common medium-voltage applications in the industry today. In this section, newer and more dynamic performance demanding applications now commercially available and other promising applications under research and development are briefly discussed and referenced for further reading. Table II groups the most recent references per application for a particular topology family, and due to the high amount, not all of them can be discussed in detail. Table II also serves to show how active a particular topology is for a particular application by a simple reference count per topic. A. Applications in Power Systems An actual problem of the electrical grid is power distribution control and management. In this area, Flexible AC Transmission Systems (FACTS) have been introduced as the solution in order to enhance the controllability and the power transfer capability of the network. Among the many different technologies that are considered as FACTS are AFs, static compensators (STATCOM), dynamic voltage restorers (DVRs), unified power flow controllers (UPFCs), and unified power quality conditioners. All these systems can, in one way or another, provide instantaneous and variable reactive power compensation in response to grid voltage transients (voltage sag, swell, harmonics, etc.), enhancing the grid voltage stability [225], These devices (AF, STATCOMs, DVRs, and UPFCs) are currently gaining importance due to more demanding grid codes [261], which even require lowvoltage-ride-through capability during voltage sags. Several multilevel converter applications for these systems have been proposed, which are listed in Table II. Fig. 12(a)–(c) shows a CHB-based STATCOM, an NPC-based AF, and a sevenlevel FC H-bridge AF proposed for a marine propulsion power system, respectively. The CHB and NPC topologies seem to be the most suited for STATCOM applications. In this case, the CHB and NPC both have floating capacitors, and therefore, the first does not suffer from the complex transformer needed for motor applications. A comparison of both topologies for a STATCOM with energy storage is presented in [228]. The study shows that the CHB presents better efficiency and dynamic performance, as well as a much simpler control method. Nevertheless, for the topologies analyzed in [228], the NPC features a higher operating range. Currently, at least one major manufacturer offers 3L-NPC-based commercial STATCOM systems [11],

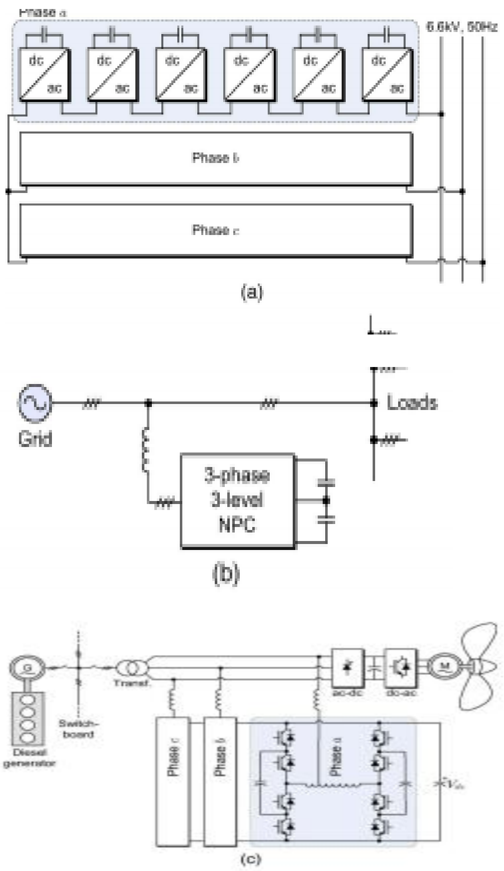

Fig. 3. (a) Thirteen-level CHB-based 6.6-kV 1-MVA transformer less STATCOM [232]. (b) 3L-NPC-based

AF [239]. (c) Seven-level FC H-bridge AF with tapped reactor connection for Marine power system [244].

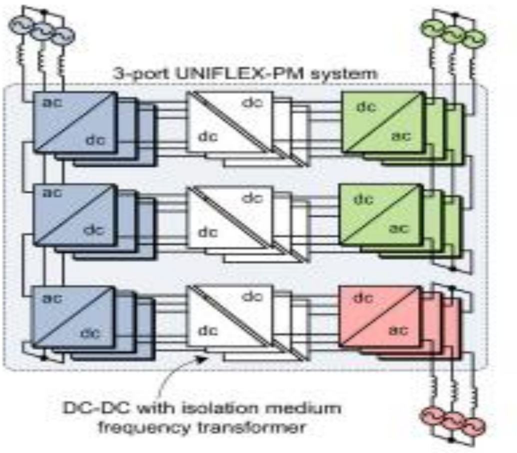

Fig. 4. Three-port UNIFLEX-PM system based on CHB multilevel converters for power management of integrated power systems in distributed generation [117].

from 6 to 32 MVAR, that are capable of connecting from a 10-kV up to a 132-kV grid with the aid of a transformer, featuring IGCT devices and a water-cooled (plus water/air heat exchanger) system. An MMC-based system called SVCplus is also commercialized for STATCOM applications in [12]. Distributed generation has also experienced an important development in the last decade. The integration of several grids to interconnect and distribute power generated at a more local level by diverse renewable energy sources and even interconnect storage or grid compensation systems will demand a smarter grid with new converter topologies that operate at higher voltages and power, with increased efficiency and power quality to ensure proper power management. This complex mixture of grid requirements and system flexibility imposes challenges that are difficult to achieve with classic topologies; therefore, multilevel converters are also being proposed in this application field. Particularly, in [117], [226], [262], and [263], a Universal Flexible Power Management system (UNIFLEXPM) is presented and capable of interconnecting different grids, with each one with their loads, possible renewable energy sources, different power flows, and particular characteristics (power rating, number of phases, etc). In Fig. 13, a threeport UNIFLEX-PM system is shown and is capable of interconnecting three different points of common coupling, which are symbolized as three-phase grids. The power converter is based on three-phase CHB multilevel converters in back-toback configuration with an intermediate dc–dc converter stage with a medium-frequency isolation transformer to decouple the grids and provide galvanic isolation between them.

VII. SIMULATION RESULTS

A. *Cascaded output*

i. Firing pulses

The firing pulses for the switches provided for single leg are as shown in figure.5

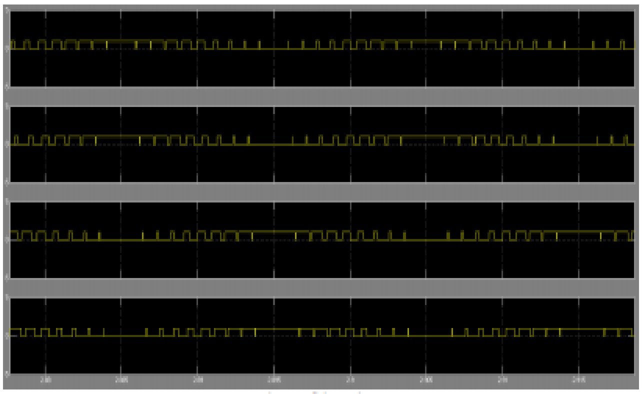

Figure 5.firing pulses

ii. Output Voltages

The output phase voltage waveforms of three phase 5 level of cascaded are as shown

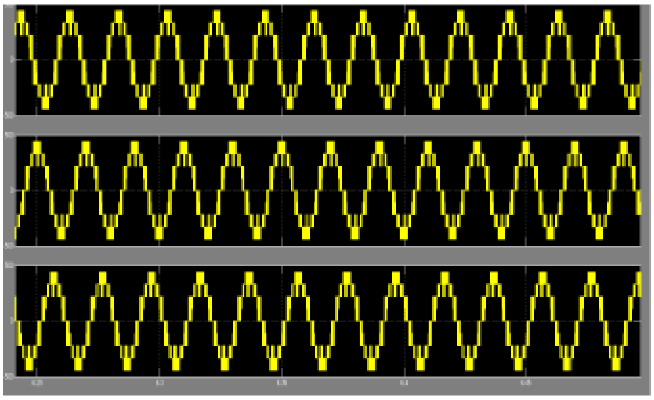

Figure 6. Three phase voltage waveforms

B. Induction motor output

i. Stator currents

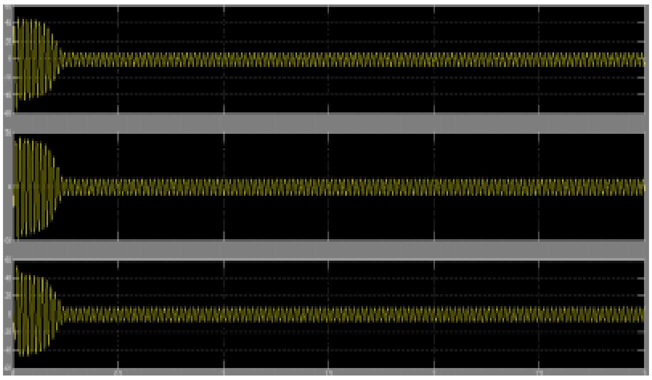

Figure 7

Speed, Rotor Position, Electromagnetic Torque

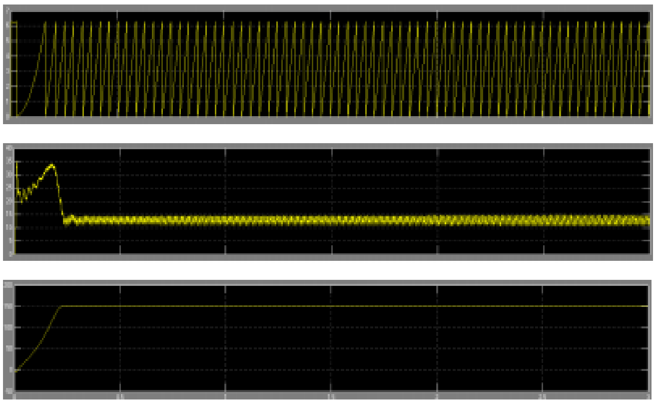

Figure 8

VIII. CONCLUSIONS

This paper has reviewed the present state of the art in multilevel converter technology by discussing the most recent contributions on topologies, modulation, and applications. At this point, it can be concluded that multilevel converters have reached a certain level of maturity, given their industrial presence and successful practical application. Nevertheless, the high amount of recent publications on the subject and the fact that the number of commercially available topologies has doubled in the past few years reveal that there is still plenty of room for further development. It is clear that the development of power electronic devices, the changes and evolution of the industrial processes, and new more demanding standards and regulations will drive and shape the future of multilevel converter technology.

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