Effect of supply voltage variations on single-phase capacitor clamped multilevel inverter fed induction motor drive

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ABSTRACT

This article presents the effect of supply voltage variations on single-phase capacitor-clamped multilevel inverter-fed induction motor drives. This research is tailored at determining the best torque value and speed to attain a stable state under input voltage variation and minimum time response to realize low percentage harmonic distortions. The effect of constant power quality disturbance harms the performance and behavior of asynchronous motors based on harmonic contents and other energy source integrations. The multilevel inverter has shown good performance in motor drives. This paper deals with the effect of input voltage variations on a single-phase multilevel capacitor-clamped inverter for asynchronous induction motor drives. A five-level capacitor-clamped inverter with an in-phase disposition pulse width modulation technique is adopted. Four high-frequency triangular carrier signals are generated and compared with a reference sinusoidal signal. As a result of this approach, the inverter switches firing signals are generated. The open-loop model is designed and simulated utilizing MATLAB/Simulink and results based on different values of supply voltage are presented. The current and voltage total harmonic distortions (THDs) obtained are 4.97% and 4.46% respectively at the best operating voltage of 400 V and at maximum torque of 47 Nm.

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1. INTRODUCTION

There is a serious need to reduce and checkmate all types of pollution especially air pollution in our environments. Due to scarcity or shortage of fossil fuels and the greenhouse effect, in most recent years, the high need for renewable energy applications has increased significantly. The recent new development in power electronics applications has made it possible to use the entire renewable energy source in different home and industrial applications [1], [2]. Researchers pay more attention to suitable interface converters due to the increasing demand for clean and sustainable energy sources of recent [3]. Fuel cell (FC), wind energy, and photovoltaic (PV) are renewable energies, which have been widely applied to achieve environment-friendly proposes [4]–[6]. Considering other sources causing voltage instabilities like in arc furnaces, welding machines, power boilers and rolling-based mills in which power demands are varying and non-linear loads such as cyclo-converters and power DC-AC converters [7]. Presently, flexible AC transmission systems, high voltage direct current (HVDC) transmission, electrical drives, and dispersed generation (DG) systems among others are major applications of voltage source multilevel inverters. Also, some applications of the converter connect a DC voltage source to the network and some other applications connect separate DC voltage sources to the network [8]. The influence of voltage instabilities on the current, speed, torque and efficiency of an induction machine has been studied in [9]–[11], but this study excludes the addition of an inverter. Due to their numerous advantages in recent years, multilevel inverter topologies have become more attractive for researchers, designers and manufacturers over conventional inverter topologies. Among other merits, they offer enhanced voltage and current output waveforms with fewer ripples, smaller filter size and lower electromagnetic interference (EMI), and most importantly lower harmonic contents [12]. Diode clamped [13], capacitor-clamped, and cascaded multilevel inverters [14] are the conventional classification of multilevel inverters. The first three different members of these topologies have been proposed for conventional multilevel inverters: diode-clamped (neutral-clamped); capacitor-clamped (flying capacitors) [15], [16] and cascaded H-bridge with separate DC sources. A three-level diode clamped inverter topology has been reported in [17], [18]. The configuration of the cascaded H-bridge multilevel inverter [19]–[22] is a series connection of conventional single-phase inverters with separate dc sources. This system enables unequal values of different DC voltage sources. Each topology of the mentioned inverters plays a very vital role in industrial applications. A brief description is depicted in section 2.

The appropriate technique for controlling generated inverter voltage is to adopt the pulse width modulation (PWM) scheme within the multilevel inverter topology [23]. The variable inputs' voltage and frequency can be regulated by applying several PWM schemes to generate regulated output values. The widely applied for voltage source multilevel inverters is the sinusoidal pulse width modulation (SPWM) [24] strategy for multilevel inverter control in recent years, this method will be adopted for this research paper. Many different PWM schemes have been enumerated in [25], [26].

In recent years, induction motors are playing vital roles in industrial, residential, and commercial drive applications [27]. This induction motor is classified based on phase as single, three and multi phases. Among other applications of single-phase induction motors include: fluid pumps, cooling compressors, small fans mixer, toys, high-speed vacuums, electric shavers, and drilling machines equipment. Also, applications of three-phase include lifts, cranes, hoists, large capacity exhaust fans, driving lathe machines, crushers, oil extracting mills, and textiles. For stability in operation, and phase failure, which is associated with three-phase, therefore, multiphase configurations are emerging in recent years [28]. The inverter topology and PWM scheme adopted have shown good performance index of the induction motor under supply voltage variation by closing some research gaps. The stator voltage and current harmonic contents obtained are less than 5% and 11% respectively. Therefore, the heating of the windings and torque vibration are significantly reduced. Also, the increase in supply voltage improves the motor speed stability time.

The key aim of this work is to determine the best machine output performance characteristics for varying DC supply voltages on single-phase capacitor clamped-multilevel inverter-fed induction motor drive under split-phase, capacitor-start, capacitor-start-capacitor-run, and main and auxiliary windings operation modes. This proposed work has not been carried out on single-phase capacitor clamped-multilevel inverter-fed induction motor drives before now. This research work is geared towards solving the problems of unbearable harmonics distortions and long-time dynamics stability responses in conventional methods. This paper is structured as follows: i) In section 1, presents a general introduction; ii) Section 2 details circuit configuration and operation of the proposed topology; iii) Thus section 3 presents computer-simulated results; and iv) Finally, in section 4 conclusion is presented.

2. METHOD

The power circuit configuration displayed in Figure 1 consists of varying DC voltage source from solar panels, two voltage divider capacitors, a three-level single-phase inverter topology, and a single-phase split-phase asynchronous motor in an open-loop speed control system. The DC input voltage is converted into a three-level AC output voltage. The generated single-phase inverter output voltage is fed to the main and auxiliary windings of the motor. Table 1 depicts the gating signal switching logic pattern of the 3-level capacitor-clamped power DC-AC power converter topology as shown in Figure 1. The output voltage is generated as the difference between voltage drop at Leg-A and Leg-B.

Figure 2 (in Appendix) presented the graphical technique of generating firing signals for triggering Figure 1 of the proposed circuit diagram. Figure 2(a) showed the carrier signals (Vtri1, Vtri2, Vtri3 and Vtri4) and reference signal (Vref). The carrier signals are operating at a very high frequency while the reference is operating at a fundamental frequency. The four carrier signals are all in phase with two carriers placed above the zero axis and the remaining two below the zero axis. Figure 2(b) displayed the firing signals of power switches of the proposed system.

The power switch firing signals are displayed in Figure 2(b), the firing signal ga1 is generated by comparing Vref and Vtri2. Likewise, the firing signal ga2 is generated by comparing Vref and Vtri1. By comparing Vref and Vtri4, signal gb1 is generated and in this same way, by comparing Vref and Vtri3, signal gb2 is generated. Other signals can be generated by negating the already generated signals.

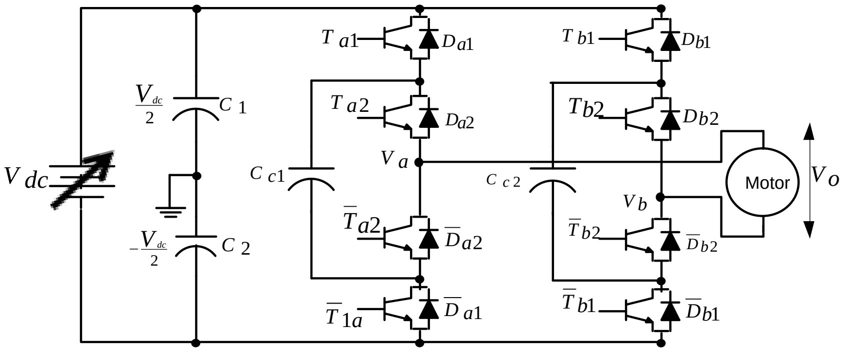

Figure 1. Power circuit configuration for split-phase asynchronous motor drive

Table 1. Output voltage based on the power switches state (1 = ON and 0 = OFF)

Switching States	T_{a1}	T_{a2}	$\bar{T}_{a1}$	$\bar{T}_{a2}$	T_{b1}	T_{b2}	$\bar{T}_{b1}$	$\bar{T}_{b2}$	V_a (V)	V_b (V)	V_{out} (V)
	Leg-A				Leg-B						
1	0	0	1	1	0	0	1	1	0	0	0
2	0	1	1	0	0	0	1	1	$\frac{V_{dc}}{2}$	0	$\frac{V_{dc}}{2}$
3	1	0	0	1	0	0	1	1	$\frac{V_{dc}}{2}$	0	$\frac{V_{dc}}{2}$
4	1	1	0	0	0	0	1	1	V_{dc}	0	V_{dc}
5	0	0	1	1	0	1	1	0	0	$\frac{V_{dc}}{2}$	$-\frac{V_{dc}}{2}$
6	0	1	1	0	0	1	1	0	$\frac{V_{dc}}{2}$	$\frac{V_{dc}}{2}$	0
8	1	1	0	0	0	1	1	0	V_{dc}	$\frac{V_{dc}}{2}$	$\frac{V_{dc}}{2}$
9	0	0	1	1	1	0	0	1	0	$\frac{V_{dc}}{2}$	$-\frac{V_{dc}}{2}$
10	0	1	1	0	1	0	0	1	$\frac{V_{dc}}{2}$	$\frac{V_{dc}}{2}$	0
11	1	0	0	1	1	0	0	1	$\frac{V_{dc}}{2}$	$\frac{V_{dc}}{2}$	0
12	1	1	0	0	1	0	0	1	V_{dc}	$\frac{V_{dc}}{2}$	$\frac{V_{dc}}{2}$
13	0	0	1	1	1	1	0	0	0	V_{dc}	$-V_{dc}$
14	0	1	1	0	1	1	0	0	$\frac{V_{dc}}{2}$	V_{dc}	$-\frac{V_{dc}}{2}$
15	1	0	0	1	1	1	0	0	$\frac{V_{dc}}{2}$	V_{dc}	$-\frac{V_{dc}}{2}$
16	1	1	0	0	1	1	0	0	V_{dc}	V_{dc}	0

3. RESULTS AND DISCUSSION

The model simulation of the proposed research system has been developed. The computer simulation results are presented based on variable input voltage supply to the motor through the capacitor multilevel inverter topology. The obtained results are discussed in detail in the next section of the work. The voltage effects on the motor speed, torque, stator current and voltage are explained. The results of the simulation of the single-phase capacitor clamped five-level inverter-fed asynchronous induction motor in MATLAB/Simulink are depicted in Figures 3 to 5. The effects of supply voltage applied to the inverter and induction motor were observed and adequately explained.

Figure 3 depicts the output voltages and currents, Figure 3(a) displays the result at the supply voltage of 200 V, Figure 3(b) presented the result at a supply voltage of 240 V, Figure 3(c) indicated the result at a supply voltage of 280 V, Figure 3(d) displayed result at a supply voltage of 320 V, and finally at 400 V supply voltage the result is depicted in Figure 3(e). Due to the nature of the load, it is observed that by a certain phase angle, the load current lags the load voltage.

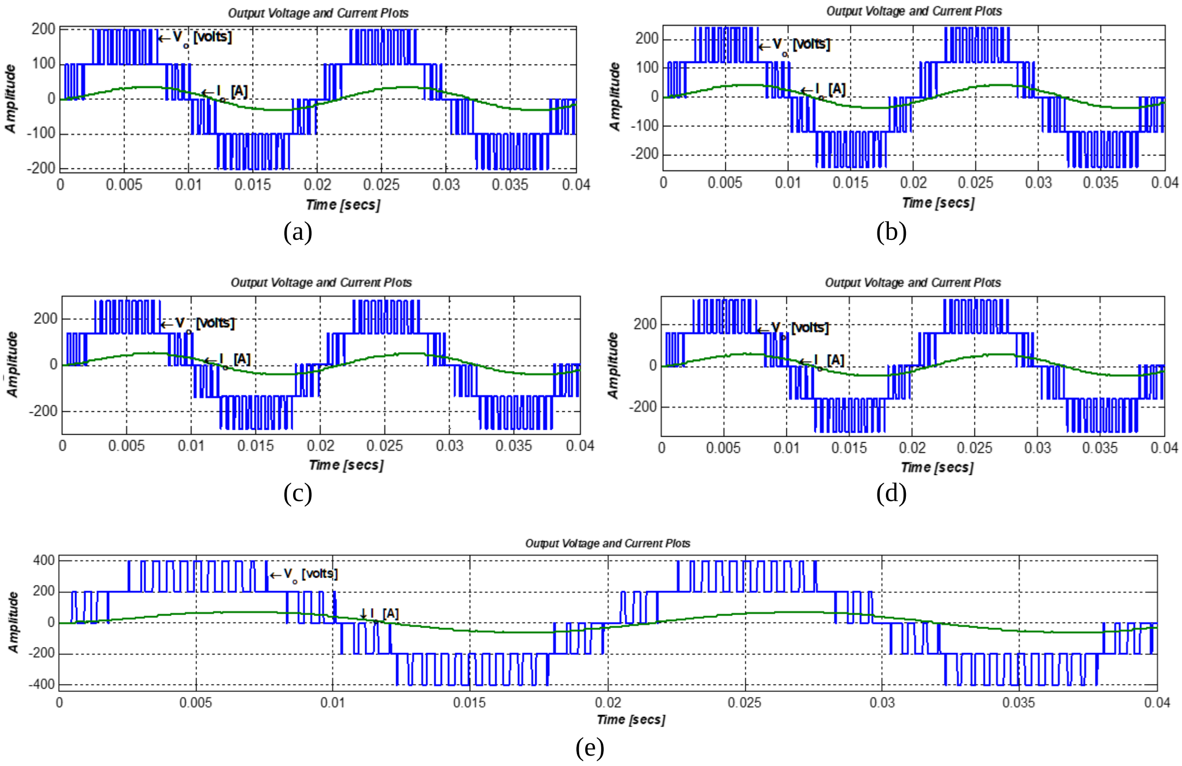

Figure 3. Inverter outputs currents and voltage (a) 200 VDC applied voltage, (b) 240 VDC applied voltage, (c) 280 VDC applied voltage, (d) 320 VDC applied voltage, and (e) 400 VDC applied voltage

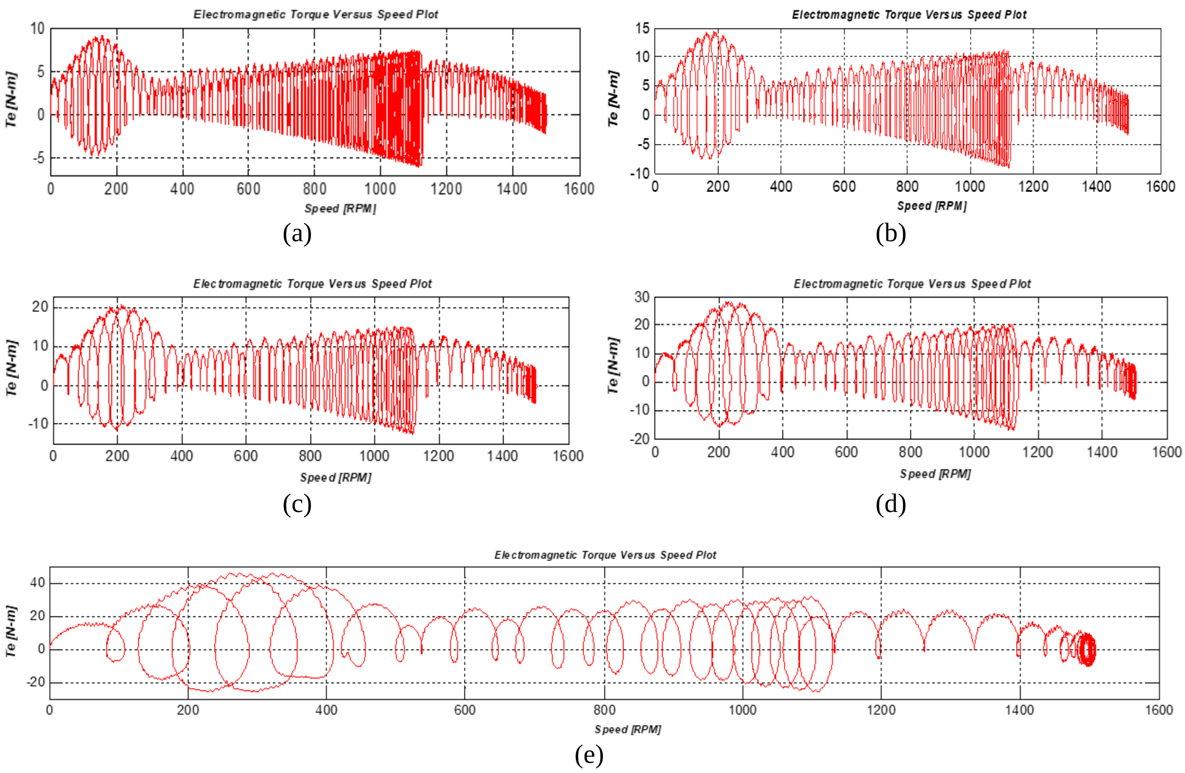

Figure 4. Machine generated electromagnetic torque versus speed for (a) 200 VDC applied voltage, (b) 240 VDC applied voltage, (c) 280 VDC applied voltage, (d) 320 VDC applied voltage, and (e) 400 VDC applied voltage

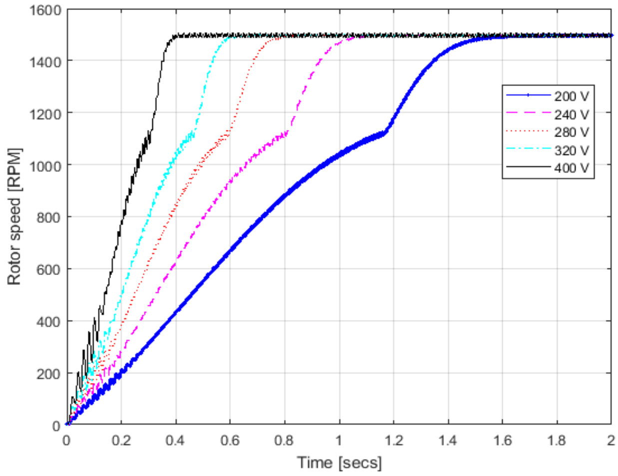

Figure 5. A waveform plot of variable output speed versus voltage for asynchronous motor drive

The induction motor mechanical torque plot is shown in Figure 4. The maximum torque of 9.40 Nm occurred at 0.08 sec and the system stability occurred after 1.4 sec as obtained in Figure 4(a). Figure 4(b) depicts a plot with maximum torque of 14.5 Nm which occurred at 0.07 sec and attains stability after 1 sec. The maximum torque of 20.00 Nm occurred at 0.06 sec and the system stability occurred after 0.8 sec as obtained in Figure 4(c). Also, Figure 4(d) a plot with maximum torque of 29.20 Nm which occurred at 0.05 sec and attains stability after 0.60 sec. The maximum torque of 47.00 Nm occurred at 0.04 sec and the system stability occurred at 0.4 sec as obtained in Figure 4(e). Figure 4(e) indicated the best performance characteristics with respect to electromagnetic torque and speed wave profiles based on input voltage variations.

Figure 5 presents the combined motor speed performance at various input voltages. It is observed that as the input voltage increases the time for motor speed stability reduces. It also noticed that the motor speed stabilized fastest at 400 V and least at an input voltage of 200 V. Table 2 shows the performance indices of the various input voltages at a glance. The supply voltage does not affect the voltage THD and affects the current THD. It is also realized that at 200 VDC, the input current THD was highest (10.85%) and least (4.97%) at 400 V. Table 3 showed comparative analysis of different multilevel inverter system with the proposed system and it is noticed that the proposed system offered least the voltage total harmonics distortions of 4.46%.

Table 2. Performance indices of various input voltage amplitudes

DC applied voltage (V)	RMS voltage (V)	Stator current (A)	Speed stability time (Sec)	Voltage THD (%)	Max. torque (N/m)	Current THD (%)
200	158.10	33.28	1.60	4.46	9.40	10.85
240	189.70	39.89	1.15	4.46	14.50	10.04
280	221.30	46.52	0.80	4.46	20.00	8.83
320	252.90	53.15	0.60	4.46	29.20	6.81
400	316.20	66.38	0.40	4.46	47.00	4.97

Table 3. Comparative analysis of different multilevel inverter system with the proposed system

Multilevel inverter systems	Input voltages	THD of output voltage
Voltage of DCTO-AC converter using simplified capacitor voltage-controlled scheme [29]	500 VDC	18.59%
Capacitor voltage balanced hybrid multi-level inverter for3-phase [30]	200 VDC	35.77% for 3φ, 1φ=11.92%
Comparative analysis of capacitor clamped and step-up switched capacitor multilevel inverters with self-voltage balancing [31]	36 VDC	22.56%
Single phase multilevel inverter for induction motor drives [32]	400 VDC	9.83%
Proposed system	400 VDC	4.46%

4. CONCLUSION

The effect of input voltage variations on single-phase capacitor clamped multilevel inverter-fed asynchronous induction motor drive has been studied, modelled and simulated in MATLAB 2018a environment. The modelled and simulated results showed that the system has the following results: best maximum torque of 47.00 Nm at 0.04 sec and least percentage input current total harmonic distortions of 4.97% at voltage input of 400 V. This shows a rapid time response to attain the proposed system stability. It is observed from the speed-time plots that the speed of the motor stability increases directly proportional to the increase in the supply voltage. Machine stator current and maximum torque increase with the increase in the input voltage. Such a system may find application in high-power applications as obtained in underground water pumps and drilling machines. Further studies are needed to investigate the performance of the other members of the multilevel inverters based on THD values and the number of power switches.

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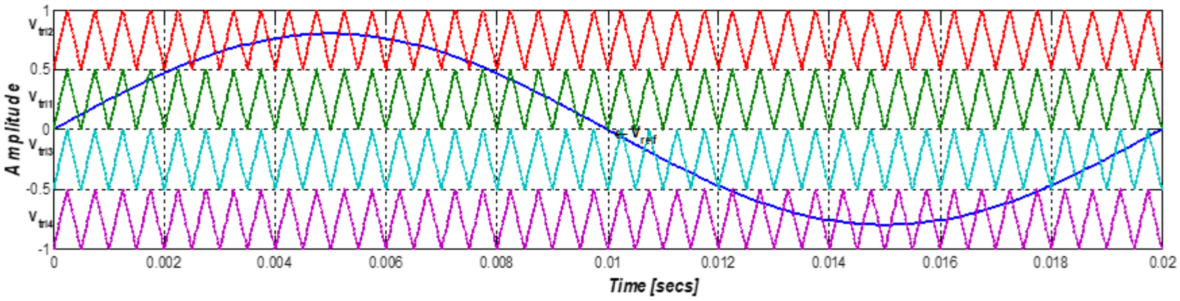
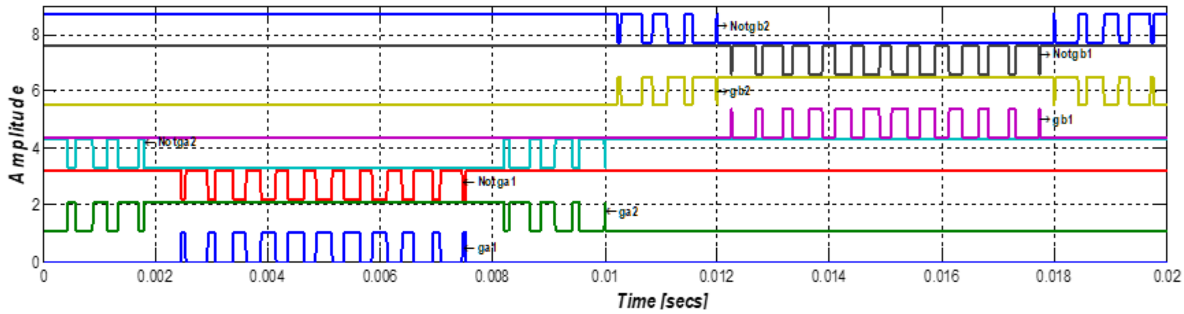
APPENDIX



(a)



(b)

Figure 2. Modulation signals and switching pulses (a) level-shifted carrier-based and reference signals and (b) gating signal for the power switches

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