On-Line Nonlinearity Compensation Technique for PWM Inverter Drives

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ABSTRACT: Inverter nonlinearity can be considered as the voltage difference between actual voltage and reference value. Performance of inverter fed drives is deteriorating due to nonlinearity. To compensate effects due to nonlinearity trapezoidal voltage is used with voltage drop compensation technique. The method is validated by simulink analysis on an induction machine.

KEYWORDS: Dead Time, Harmonics, Induction Machine, Inverter Nonlinearity, Voltage Drop.

1. INTRODUCTION

Inverter fed ac drives are normally used in industrial application which reduces the cost for motors and its maintenance and providing maximum power savings. Behaviour of the inverter influences the performance of ac machines. The nonlinear characteristics of switching devices such as dead time, switch turn on/off time delay, and voltage drop across the switches and diodes in inverters produce voltage distortion. The most significant nonlinearity is represented by the dead time to avoid short circuit of inverter legs. Voltage drop and turn on/off time inevitably exist in practical devices. However, dead time causes voltage error in the voltage source pulse width modulation (PWM) inverter by producing unwanted harmonics. In case of sensor less drives, this distortion usually causes a non optimal motor exploitation at low speed operation due to an error in the estimated position of the adopted reference frame used by the motor control scheme. In addition, the motor currents will be distorted, resulting in unnecessary torque ripple.

Various solutions have already been suggested to avoid the nonlinear characteristics of the inverter. [1][2]. in most cases, compensation techniques are based on an average value theory and the lost volt seconds are added vectorially to the voltage reference [3]-[5]. Another method is pulse based in which each PWM pulses is corrected [6].

In this paper trapezoidal voltage compensation which is based on average value theory with voltage drop compensation is presented. Effectives of the proposed method are discussed with simulation results.
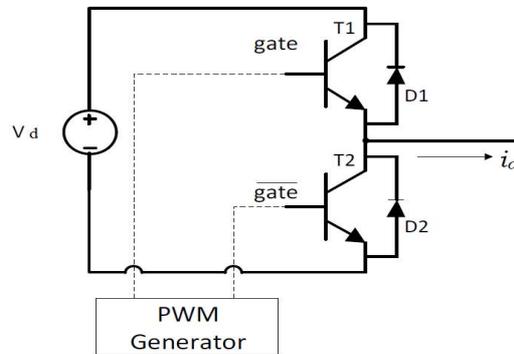
II. ANALYSIS OF INVERTER NONLINEARITY EFFECTS

A. DEAD TIME

Practically turn off time for a switch is more than turn on time. So it is necessary to insert a delay time called dead time to avoid shoot through of switches on the same inverter leg. To analyze the effect of dead time single phase configuration of PWM inverter is considered.

Fig 2 shows the time delay (t_{dead}) between the switches T1 and T2.

T_{ON} is the time for which the switch T1 is ON. T_{SW} is the switching period. At time t1, T2 transitions from ON to OFF. The turning ON of T1 is delayed by time t_{dead}. This prevents the short circuit across both the switches of the inverter leg and the input dc voltage source. The introduction of the time delay between switching leads to reduced and distorted voltage at the output of the inverter. To examine the effect of dead-time on the output voltage, switching waveforms on one leg of the inverter are examined. The current i_a is positive in the direction of the load. The switchesT1 and T2 conduct when they are ON. During the dead-time period, when both T1 and T2 are OFF, Either the reverse recovery diode D1 or D2 will conduct depending on the direction of i_a.
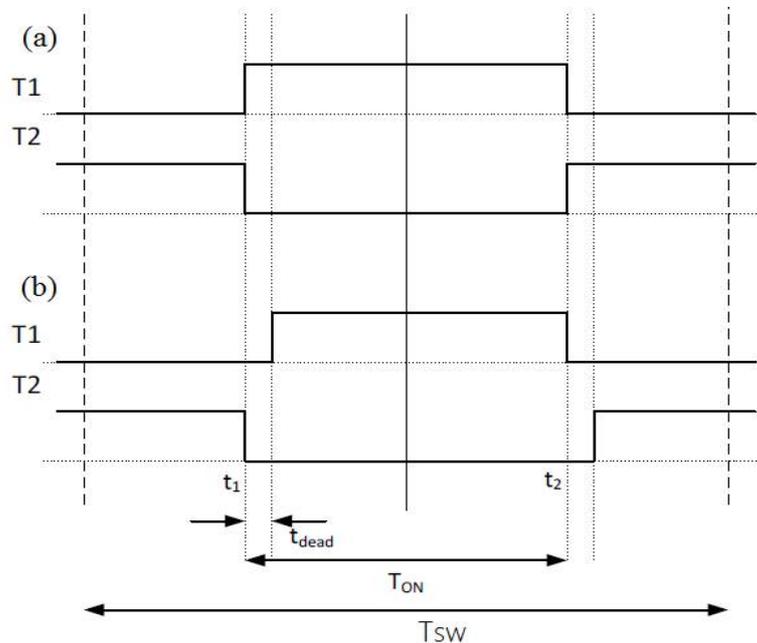
Fig 2 Time delay between turn OFF and turn ON of two switches on the same inverter leg (a) Ideal switching (b) witching with dead time.

Depending up on the direction of the switching transition and the sign of the current in phase 'a' i_a, four conditions are possible.
• The current ia is positive, T1 transitions from ON to OFF, T2 transitions from OFF to ON: During the dead-time period, D2 conducts and D1 blocks the flow of current. Thus, this condition results in the correct voltage being applied to the load

terminals.
• The current ia is negative, T1 transitions from ON to OFF, T2 transitions from OFF to ON: During the dead-time period, D1 continues to conduct and D2 blocks the flow of current. And the condition results a gain in the voltage which being applied to the load terminals.
• The current ia is positive, T1 transitions from OFF to ON, T2 transitions from ON to OFF: During the dead-time period, D2 continues to conduct and D1 blocks the flow of current. And the condition results in a loss of voltage being applied to the load terminals.
• The current ia is negative, T1 transitions from OFF to ON, T2 transitions from ON to OFF: During the dead-time period, D1 continues to conduct and D2 blocks the flow of current. And the condition results in the correct voltage being applied to the load terminals.
In each switching cycle, T1 transitions from OFF to ON (T2 from ON to OFF) once and from ON to OFF (T2 from OFF to ON) once. Due to the distortions, the output voltage of the inverter is not equal to the desired reference voltage.

B. VOLTAGE DROP
The voltage drops of the power devices that distort the output voltage and cause reduction of the fundamental component. This voltage drop can be divided in two parts; one part is constant, which is referred to the threshold value; the other is the resistance voltage drop, varying according to the load current.
So to overcome the effect of inverter nonlinearity proposed method can be adapted.

III. PROPOSED METHOD

3.1.Trapezoidal voltage compensation
Trapezoidal voltage compensation is a novel method used to compensate for the low-order harmonics from the inverter nonlinearity. The proposed method is similar to the observer-based method, where the nonlinearity is regarded as voltage distortions. However, the trapezoidal voltage compensation method can adapt to varying operating conditions without the aid of any observers & the physical parameters are not necessary.
To analyse the effect of inverter nonlinearity in ac machine induction machine is taken as an example. The inverter nonlinearity is entirely separated as the nonlinear loads $d(i_{as})$, $d(i_{bs})$, $d(i_{cs})$ .An averaged model of the inverter was taken and averaged for one sampling period, to consider the temporal distortions. These distortions can also be separated from the inverter and are reflected on the nonlinear loads, $D(i_{as})$,$D(i_{bs})$, and $D(i_{cs})$ as shown in Figure 3.a. Since the inverter nonlinearity is entirely separated as the nonlinear loads, pole voltages can be synthesized equal to their references in the circuit in Figure 3.b This is summarized in equation (1).
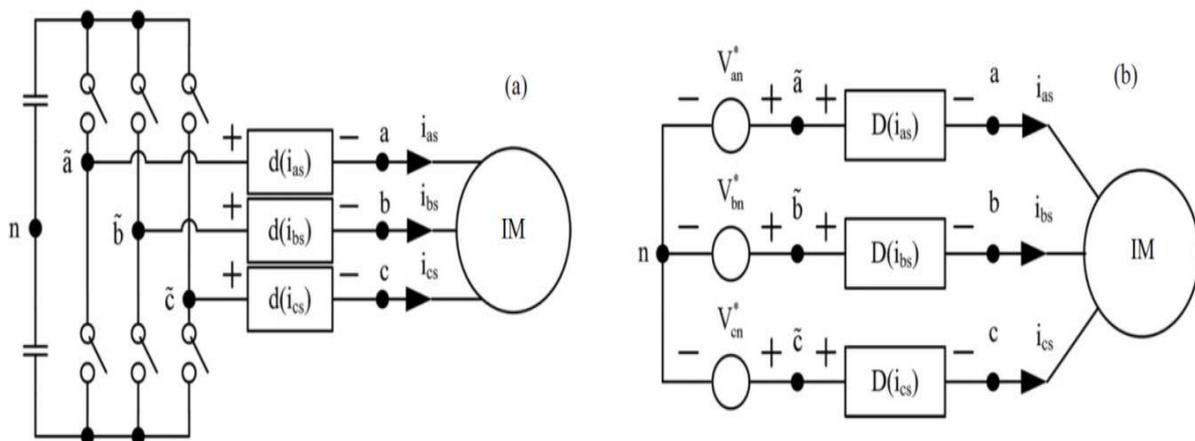

Fig 3: Modelling of an inverter: (a) inverter with ideal switches (b) averaged inverter model for one sampling period

$$* , V$$

$$= V^* , V$$
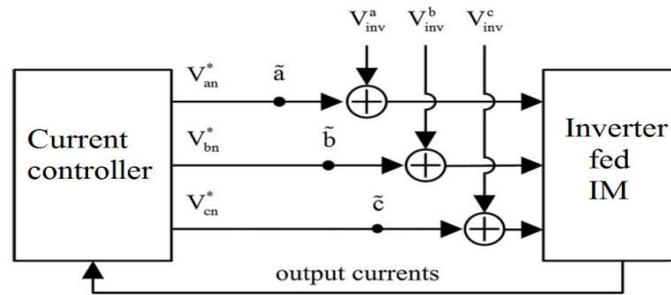$$= V^* \qquad 1$$

$$V \quad = V$$

Fig 4: Addition of compensation voltages switches

The superscript "*" denotes the reference value. The compensation principle is clarified with Figure 4.

$$V \quad = -D \ i \quad + V \qquad 2$$

$$V \quad = -D \ i \quad + V \qquad 3$$

$$V \quad = -D \ i \quad + V \qquad 4$$

Where $D(i_{as})$, $D(i_{bs})$ and $D(i_{cs})$ is the distorted voltages.

3.1.1. Distorted Voltage under the Stationary Condition
The back electromotive force (EMF) of a induction machine is zero under the stationary condition. Furthermore, voltage drops on the inductances of the IM can also be ignored in the average sense when the currents are regulated as dc values by a pulse width modulation (PWM) of VSI. Under these conditions, the IM can be modelled as a three-phase resistive load, and the voltage reference would be in phase with the output current.
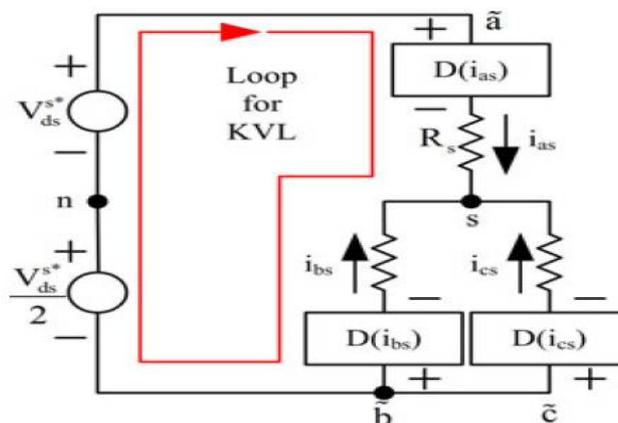

Fig 5: Driving circuit of a IM under the stationary condition

Applying Kirchoffs voltage law (KVL) to the loop in Figure 5, the voltage equation can be derived as Where Rs is the

equivalent resistance, which includes the resistances of the IM and switch modules. If the distortion from the dead time is only considered, the distorted voltage can be assumed as a constant V_{dead}.
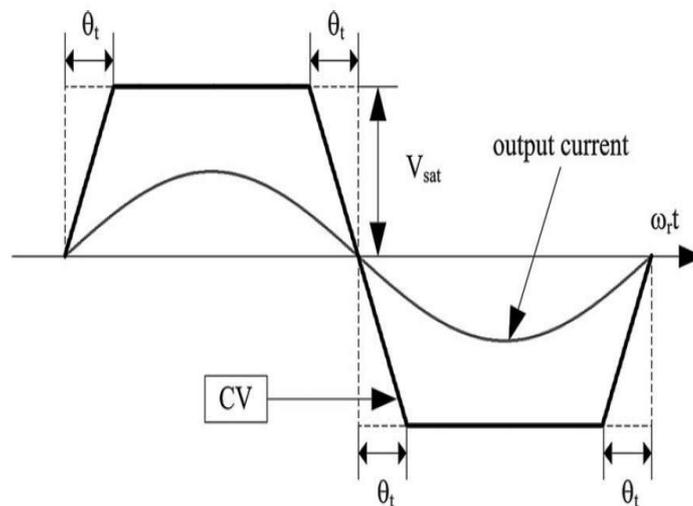
3.1.2. Shape of the compensation voltage (CV)

Fig 6: Shape of the compensation voltage (trapezoidal voltage)

The trapezoidal voltage, CV in Figure 6, was utilized for the compensation .This voltage should be in phase with the output current and trapezoidal angle Өt can be adjusted for the suitable compensation. The low-order harmonics of the trapezoidal voltage, except for the fundamental, can be modulated by adjusting Өt. In the conventional methods, ratios of the low-order harmonics to the fundamental can be considered as being fixed once the compensation voltage is determined. This distinction can facilitate the adaptation of the proposed method to varying operating conditions. Namely, the magnitude of the harmonic voltages for the compensation can be appropriately modulated through adjusting Өt even if magnitude of the harmonic distortions from the inverter nonlinearity is changed due to altered operating conditions.

3.1.3. Modulation of the compensation voltage
The phase angle of the output current should be identified for to synchronize the trapezoidal voltage with the output current, and to modulate the trapezoidal angle. Trapezoidal angle of the compensator can be adjusted by using a odulator.

IV. MATLAB/SIMULINK ANALYSIS OF PROPOSED METHOD

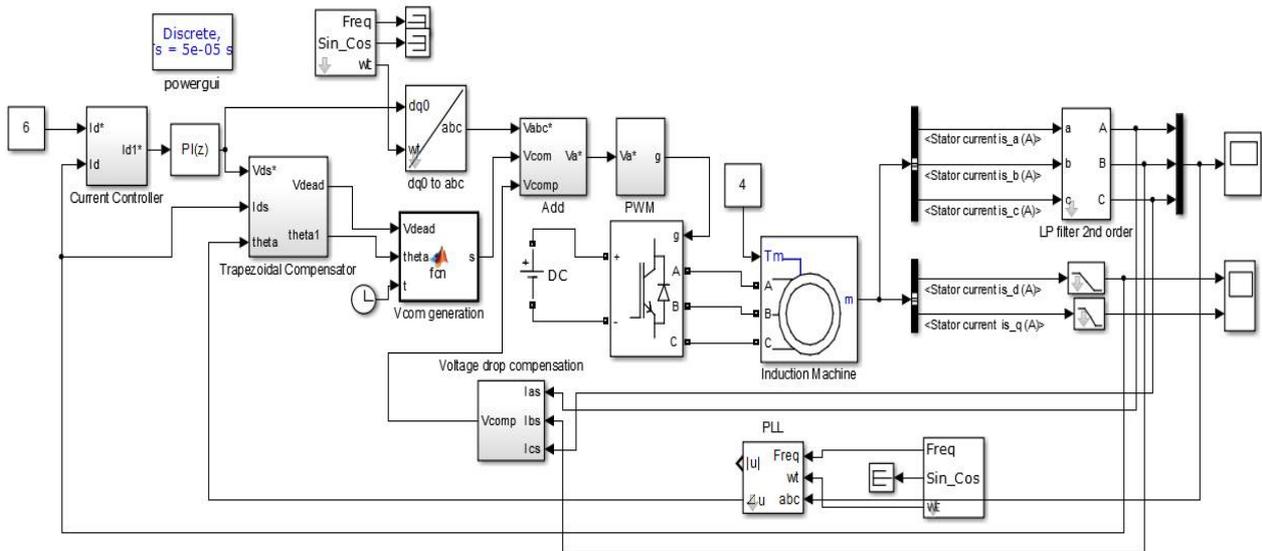#### A. SIMULINK MODEL OF TRAPEZOIDAL VOLTAGE COMPENSATION

Fig 7.Simulink model for inverter nonlinearity compensation

Fig 7 shows a three-phase motor rated 10HP, 460 V; 1500 rpm is fed by a PWM inverter. The PWM inverter is built entirely with standard Simulink blocks. Its output goes through Controlled Voltage Source blocks before being

applied to the IM block's stator windings. The load torque applied to the machine's shaft is originally set to its nominal value (4 Nm). The current control loop regulates the motor's stator currents. A compensation voltage generated from trapezoidal compensator block is added with the output from controller. Switching pulses for the inverter is generated by using PWM block. Hysteresis controller is used for current control. In addition, the preset dead time was 5 µs.
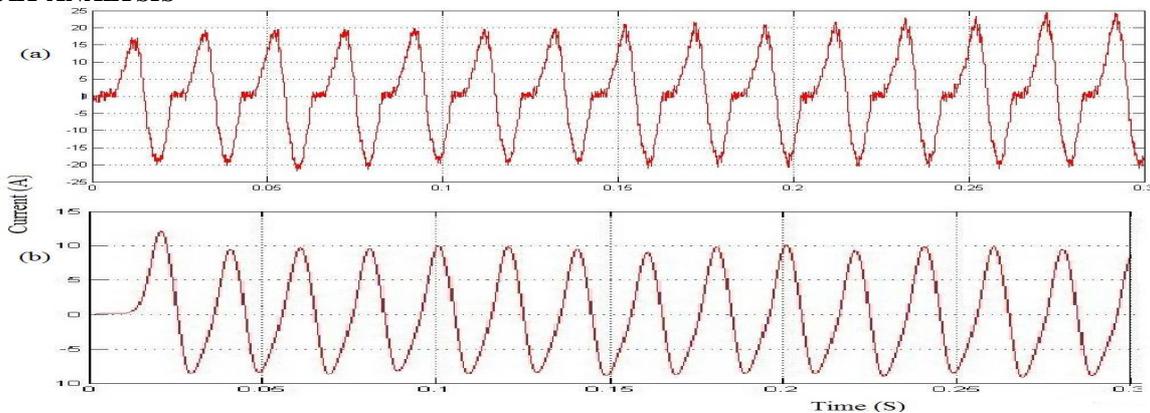
B. RESULT ANALYSIS

Fig 8 .Stator current output of IM (a) without compensation (b) with proposed method

Figure 8 showing the output current of IM without compensation and with compensation. In figure 8 (a) without compensation the inverter nonlinearity induce wave form distortion and harmonics. With proposed method of compensation waveform distortions are reduced. The lower order harmonics can be controlled through the trapezoidal angle. By varying

the Ɵt FFT results obtained at the output current for phase "a" (I_a) shown in figure 9. Minimum value for harmonics is getting at an angle of angle 16.9^0.

Harmonic value is varying between 20.19-16.97o while varying Ɵt changing from 7 to 220. Result showing that at an angle of 16.9^0, harmonic value is minimum.
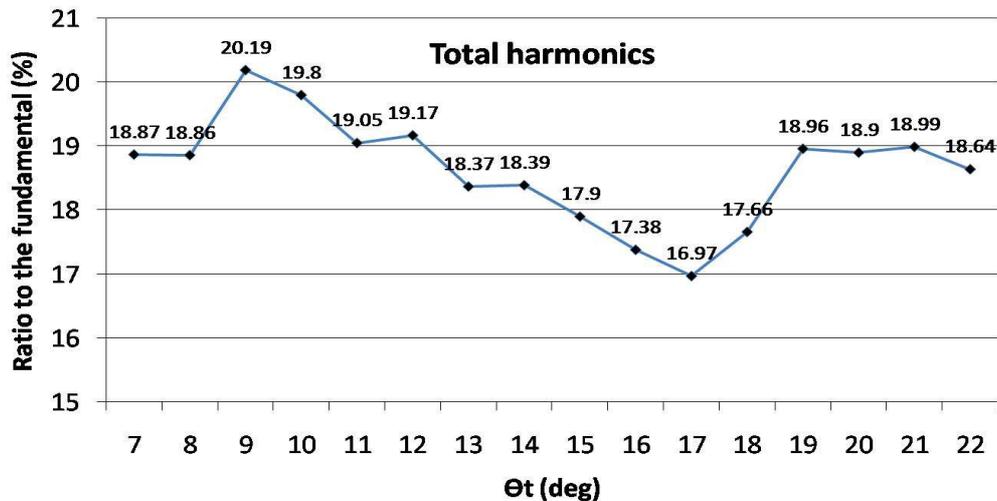

Fig 9. FFT results for the output current (Ia)

V. CONCLUSION

Dead time which is introduced to avoid the shoot through of inverter leg and the voltage drop due to switching devices causes harmonics and reduction of the fundamental components. To overcome inverter nonlinearity effect proposed method can be used which reduce harmonics by large amount. And it can adapt to varying operating conditions.
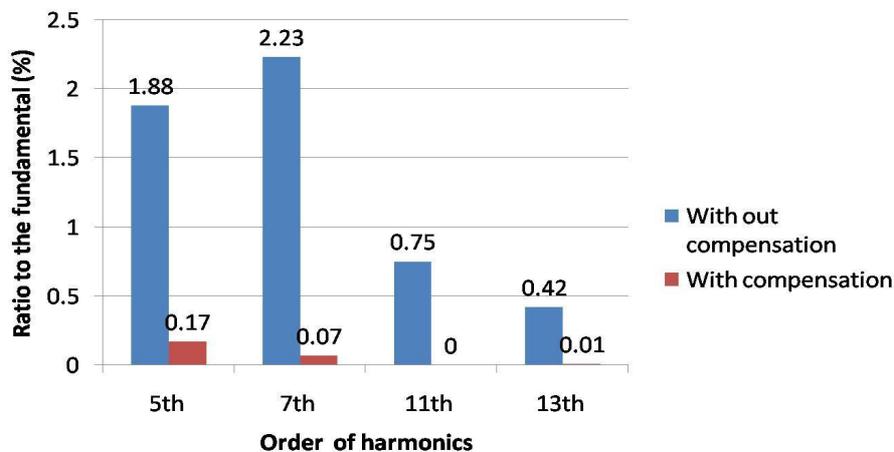

Fig 10. Comparison of FFT results for the output current without and with compensation.

From the figure 10, total and the lower order harmonics reduced with the trapezoidal voltage compensation.

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