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# Discussion and Closure

## Discussion on “Effect of Multilevel Inverter Supply on Core Losses in Magnetic Materials and Electrical Machines”

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Rasilo *et al.* [1] investigates into the impact of multilevel inverters on core losses in electrical machines. The goal of this discussion is to suggest possible add-ins to the literature review of [1] that may give a better understanding of the prior art.

Here is the citation from the Introduction Section of [1]: “Indeed, compared to the huge amount of experimental and theoretical power-loss studies in electrical machines supplied from traditional two-level inverters [12], it is surprising that only [13]–[15] were found to really investigate the effects of multilevel inverters on losses in magnetic cores. . . . In each study [13]–[15], the core losses were found to be significantly reduced when more voltage levels were used.”

In fact, normalized PWM core losses in electrical machines fed by multilevel inverters were considered in [2] and [3] that link integral PWM eddy current core loss to inverter PWM voltage quality, namely, PWM voltage ripple normalized mean square (NMS) that has simple closed-form expression in asymptotic (relatively high PWM frequency) approximation [3].

For a 2-level inverter,

$$NMS_2^{AC}(m) = (2/\pi)m - 0.5 m^2 \quad (1)$$

where  $m$  – modulation index,  $0 \leq m \leq 1$ .

For a 3-level inverter,

$$NMS_3^{AC}(m) = (1/\pi)m - 0.5 m^2, \quad 0 \leq m < 0.5 \quad (2)$$

$$NMS_3^{AC}(m) = (1/\pi)m - 0.5 m^2 - 0.5 + (1/\pi) \cdot \arcsin(1/(2m) + (2/\pi)\sqrt{m^2 - 0.25}), \quad 0.5 \leq m < 1. \quad (3)$$

For an arbitrary level count  $n$ , the general NMS expression is given by formula (10) in [3].

This way, [2], [3] suggested first order approximation of normalized integral PWM eddy current induced iron core loss dependence on modulation index and predicted essential loss reduction with inverter level count increase (see Fig. 1). In addition, [2], [3] anticipated that PWM eddy current iron core loss practically does not depend much on PWM frequency and becomes a dominating PWM loss mechanism in iron cores of electrical machines for relatively high (apparent) switching frequency (above 2–3 kHz).

For 2-level inverter fed induction motors, the propositions of [2] and [3] are confirmed by FEM analysis and experiments in [4], for permanent magnet and induction machines fed by 2- and 3-level inverters—in [5] and [6].

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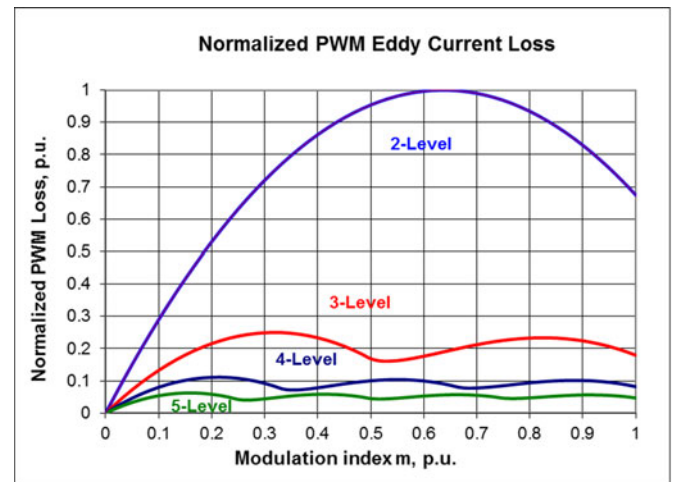


Fig. 1. Normalized integral PWM iron loss for 2, 3, 4, and 5 voltage levels.

Finally, it is necessary to acknowledge that in their recent work on the PWM common-mode elimination impact on iron core loss of electrical machines fed by multilevel inverters [7] the authors refer to the relevant asymptotic NMS analysis [8].

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