Power Loss Evaluation in T-Type Three-level Inverters

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Abstract

This paper presents an analysis of power losses in three-level T-Type Inverters. The switching loss in different switching frequencies and the conduction loss at different modulation indices and power factors are investigated. Finally, it is shown that the results of analysis coincide with those which resulted from CASPOC software simulation.

1. Introduction

Recently, the efficiency of power converters has gained more attention. The power loss of converters is divided into the switching loss and conduction loss. The switching loss has relation with the switching frequency, and the conduction loss depends on the modulation index (MI) and power factor. Although the less distorted output voltage in two-level converters can be obtained by increasing the switching frequency, it incurs a higher switching loss which results in a lower converter efficiency. One solution to overcome this disadvantage is to use the three-level converter. In this paper, one of multi-level converter topologies, the T-type three-level converter is considered. Its power losses are investigated in different MI, power factors and switching frequencies. The power loss analysis in two- and three-level converters has been found in the literatures extensively [1]-[2]. The switching loss depends on the switching characteristics of device. The turn on and off energy of devices directly affects the switching loss. The conduction loss is based on the V-I characteristics of modules, which was investigated briefly in [2]. In this paper, power loss analysis for T-type three-level converters is performed and its results are compared with the CASPOC (Power Electronic and Green Energy and Electrical Drives Modeling) software simulation.

2. T-type Converter Topology

The configuration of the three-phase three-level T-type VSC is shown in Fig. 1. The basic topology is the extension of the conventional two-level VSC topology with an active bydirectional switch in DC-link mid-point. The bidirectional switch module can be made by different combinations of switching devices, so the RB(reverse blocking)-IGBT is recently used for the middle switch. The voltage rating of the middle switch is just half of the DC-link voltage since it needs to block only the half of the DC-link voltage. Using lower voltage switches at mid-point has advantages of lower cost and lower switching loss [3].

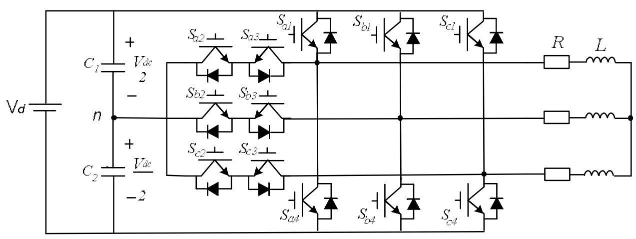

Fig. 1 Three-phase three-level T-Type Inverter.

3. Calculation of Semiconductor Power Loss

The total power losses of switching devices are divided into two parts: conduction losses and switching losses.

3.1 Conduction loss

The conduction loss depends on the power factor *PF* and modulation index *M,* but not affected by the switching frequency. The conduction loss occurs while the switch is in the on state and conducts the current. The total conduction losses for the IGBTs and anti-parallel diodes in one leg of the T-type converter are calculated by (1) - (4) in [4].

- T_1 & T_4

$$P_{Cond} = \frac{MI}{12\pi}\cdot\{3V_{ce0}\cdot[(\pi-\varphi)\cdot\cos(\varphi)+\sin(\varphi)]+2r_{ce}I\cdot(1+\cos(\varphi))^2\} \quad (1)$$

- T_2 & T_3

$$P_{Cond} = \frac{I}{12\pi}\cdot\{V_{ce0}\cdot[12+6M(\varphi\cdot\cos(\varphi)-\sin(\varphi))-3M\pi\cos(\varphi)]+r_{ce}I\cdot(3\pi-4M(1+\cos(\varphi))^2)\} \quad (2)$$

- D_2 & D_3

$$P_{Cond} = \frac{I}{12\pi}\cdot\{V_{f0}\cdot[12+3M(2\varphi\cdot\cos(\varphi)-2\sin(\varphi))-3M\pi\cos(\varphi)]+r_f I\cdot(3\pi-4M(1+\cos(\varphi))^2)\} \quad (3)$$

- D_1 & D_4

$$P_{Cond} = \frac{MI}{12\pi}\cdot\{3V_{f0}\cdot[-\varphi\cdot\cos(\varphi)+\sin(\varphi)]+2r_f I\cdot(1-\cos(\varphi))^2\} \quad (4)$$

where: $r_{ce} = \frac{V_{ce}-V_{ce0}}{I}$ and $r_f = \frac{V_f - V_{f0}}{I}$

I : rated current.

V_{ce} : rated collector-emitter voltage.

V_{ce0} : threshold voltage of IGBT.

V_f : diode voltage drop at rated current

V_{f0} : threshold voltage of diode (0.7V)

M : modulation index $(0 \le M \le 1)$

φ : power factor angle

r_{ce} : IGBT forward resistance

r_f : diode forward resistance

The total conduction loss in T-type three-level converter is three times the amount of summation of (1) to (4).

3.2 Switching loss

For calculating the switching loss of converters, the turn-on and turn-off energy of IGBTs and diodes has to be considered. In fast recovery diodes, the turn-on loss is less than 1% compared with the turn-off loss. So the turn-on loss of the diode is neglected. The more convenient way for calculating the switching loss is to utilize the switching energy-current (E-I) characteristic for turn on and off times. The IGBT switching loss can be calculated in (5) for the turn-on and turn- off energy in IGBTs and diodes,

$$P_{On+Off} = \frac{1}{\pi} \cdot f_s \cdot \left[E_{On}(i) + E_{Off}(i) \right] \quad (5)$$

where E_{on} is the on energy and E_{off} is the off energy, which are a function of the current. Also, these parameters vary depending on the junction temperature [4].

3. Results of Analysis

In inverter system, the DC-link voltage is 600-V and the RL load is connected. The 4MBI300VG IGBT module (Fuji Electric Co.) is used, which has 1200-V IGBT at each leg and 600-V RB-IGBT at mi-point. The needed parameters for calculating power loss are listed in Table I [5]. The rated current of the module is chosen as 20-A. The conduction loss and switching loss are calculated with the parameters in datasheets. Due to the dependence of conduction loss on both power factor and MI, 3-D plot for total conduction loss versus power factor angle and MI is illustrated in Fig. 2. Fig.3 shows the switching loss. The Fig. 4 shows 3-D plot of the total power loss in T-type converter as a function of power factor angle and switching frequency at unity MI. It is evident that the total power loss in 5-kHz switching frequency and 0.9 power factor is about 285-W.

Table I. Parameters of Devices in T-Type converters

T_1 & T_4		T_2 & T_3	
Parameter	Characteristic	Parameter	Characteristic
$V_{CE0}(V)$	0.9	$V_{CE0}(V)$	0.8
$V_{CE(Sat)}(V)$	1.1	$V_{CE(Sat)}(V)$	1.2
$I_C(A)$	20	$I_C(A)$	20
$V_F(V)$	0.9	$V_F(V)$	--
$V_{F0}(V)$	0.7	$V_{F0}(V)$	0.7
$E_{On}(mJ)$	4.1	$E_{On}(mJ)$	2
$E_{Off}(mJ)$	4	$E_{Off}(mJ)$	2.5
$E_{rr}(mJ)$	1	$E_{rr}(mJ)$	--

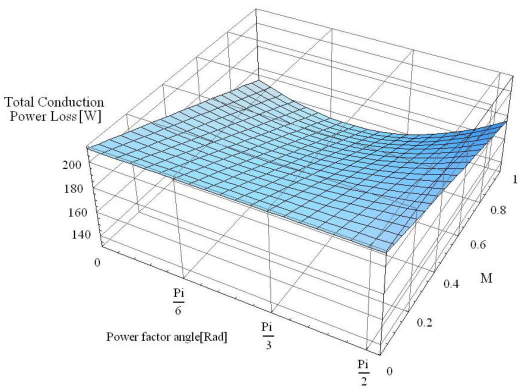

Fig. 2 Total conduction loss in T-type converter.

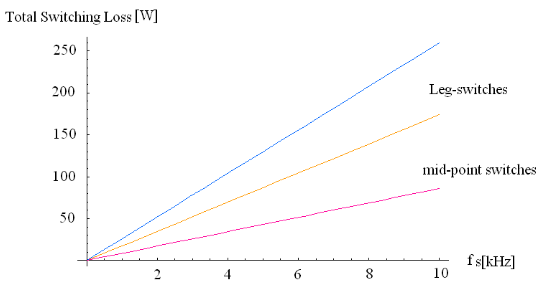

Fig. 3 Switching loss in T-type converter.

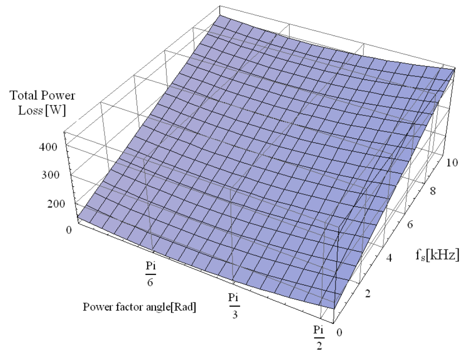

Fig. 4 Total power loss in T-type converter (*MI=1*).

4. Evaluation of CASPOC Simulation

In this section, the CASPOC software is used to model the power loss in T-type converter. The parameters are set, as follows: $V_{dc} = 600 - V$, $f_s = 5 - kHz$, $R_L = 15 - \Omega$, $l_L = 0.1 - mH$, $PF = 0.9$, $MI = 1$ and the rated current for switches is 20-A.

Fig. 5 shows the total power loss in T-type converter. The power loss model in CASPOC software has been used to get the power loss. The mean value of power loss in the graph is about 285-W, which is almost the same as the value resulting from analytic method [6].

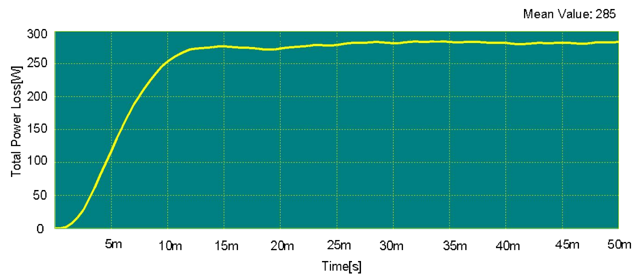

Fig. 5 Total power loss in T-type converter from CASPOC simulation.

5. Conclusion

In this paper, the power loss has been investigated for three-level T-type converter. The conduction loss at different MI and power factors as well as switching loss at different switching frequencies has been analyzed. Is has been shown that CASPOC simulation results are similar to those from analytic method.

Acknowledgment

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Reference

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