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High Frequency Coaxial Transformer for DC/DC Converter Used in Solar PV Systems.

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Abstract—This paper discusses the design and analysis of a high frequency coaxial transformer (HFCT) for a DC/DC converter used in solar PV power systems. The experimental results demonstrate that the transformer voltage ratio is in good agreement with the turns ratio. The low leakage impedances measured for this transformer at various frequencies up to 500 KHz indicate the advantages of the coaxial transformer structure. This unique winding structure also provides a small capacitive coupling between the primary and secondary windings. The simulation results confirm the uniform distribution of magnetic flux in the magnetic core, and the uniform distribution of eddy current density in the windings.

Index Terms— High Frequency Coaxial Transformer, Eddy Current, Magnetic Flux,

I. INTRODUCTION

Photovoltaic arrays are coupled to the grid using a dc-ac converter and an isolation transformer. The isolation transformer is typically large given that the operating frequency is the utility frequency. A way of avoiding the use of a large transformer is to employ a dc-ac-dc converter with a high frequency (HF) link isolation transformer. In this event, the transformer is designed for HF operation and hence its size can be reduced significantly. Higher output power from multiple solar PV modules is achieved by connecting each PV array to its own resonant dc-ac converter and single phase transformer. The dc-ac resonant converter output signals are phase shifted with respect to each other by 120 degrees. The secondaries of the HF link transformers are connected in a three phase wye configuration and the output is connected to a three phase rectifier, as shown in Fig. 1. The transformers with small size and high power efficiency at high operating frequency are often required in DC/DC converter systems. Conventional transformer designs cannot perform well at HF because the insertion loss and eddy current loss are too high. The HFCT presented in this paper can address the aforementioned problems and provide a better performance in HF applications.

II. TEST RESULTS FOR THE COAXIAL TRANSFORMER

Figure 1 (a) shows the HFCT construction (right side at bottom) and the packaging of a three phase system (top image of right side). The solar PV system requires an isolation transformer therefore the number of turns on the primary and secondary windings is the same and equal to 6 at a frequency of 500 kHz and a voltage of 450 V. Each winding is comprised of 7 thin insulated wires that are used to form a litz wire. The turns ratio (n=6/6=1) is in good agreement with the voltage ratio (V1/V2) from 100 kHz to 1 MHz. The measured results from 100kHz to 1MHz indicate that the leakage inductance, Leq (0.689μH) is relatively small compared with a conventional transformer (3.53μH) at 500kHz, while Req increases slightly with frequency due to the skin depth effect. The leakage inductance decreases in a linear fashion over the frequency range of interest. The magnitude of the magnetizing inductance tracks the frequency response of the permeability, μ, which rises in the high frequency range. The coupling capacitance (20.9 pF) between primary and secondary windings is much smaller than the values (210pF) observed in conventional transformers with a similar rating. The coaxial transformer performed well over an extended frequency range (100 kHz to 1MkHz), while the leakage inductance and winding loss of a conventional transformer increase rapidly above a frequency of 200 kHz.

III. MAGNETIC FIELD ANALYSIS OF COAXIAL TRANSFORMER

A FEM-based numerical method was used to determine the magnetic flux and eddy current distributions. The excitation source is applied to the outer winding and the inner winding was open circuited. Figure 1 (b) shows the current distributions in both the primary and secondary windings, where the eddy current density in the outer (primary) winding is somewhat higher than the one in the inner (secondary) winding. The peak current density including eddy current was determined at the surface of the outer winding; 743A/cm2 for the open circuit case, and 810A/cm2 for the short circuit case. The maximum current densities in the inner (secondary) winding for both open circuit and short circuit cases were found to be less than 61.63A/cm2 and 60.7A/cm2 respectively.

IV. CONCLUSION

A HFCT using uniformly distributed litz wire winding structure has been investigated. The turns ratio and voltage ratio in the HF range of interest are in good agreement with each other. The minimum leakage inductance (0.689μH) and coupling capacitance (20.9pF) have been achieved by using such winding structure. The flux and eddy current distributions were uniform and the high current density appeared at the surface of the outer winding, and was 743A/cm2 for the open circuit case, and 810A/cm2 for the short circuit case. The current densities in the inner winding were over 10 times smaller than the outer winding.

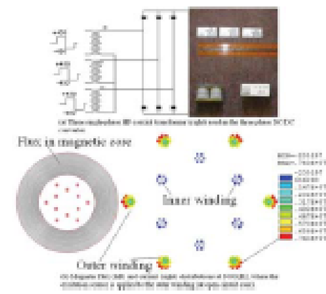

Fig. 1 HF coaxial transformer and its magnetic filed distribution.