UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF STAIRCASE-OUTPUT MULTILEVEL INVERTER

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FK 2011 111

Development of Staircase-Output MultiLevel Inverter

By

EHSAN ESFANDIARI

Thesis submitted to school of graduate studies, University Putra Malaysia, in fulfillment of the requirement for degree of Doctor of Philosophy

September 2011

Dedicated to:

All two billion people that are deprived from electricity, in hope to day for them to be able to use it, and to advanced that are using it now and to all science and nature advocates.

Dedicated to my wife, Somaieh, my daughter, Alae and my parents

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

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Chair: Norman Bin Mariun, PhD, PEng

Faculty: Engineering

Due to several scenarios attached to the fossil fuel resources, the world has experienced a trend popularly towards alternative energy sources especially, renewable and clean in extraction as well as generation. This has raised the demand bar for the often popular solar and wind as the energy sources. As a result, renewable power conversion marketing has also dramatically increased during the past decade. Due to the application of inverters in power generation, the coinciding interest is shared equally and thus has created the basis of research interest on multi-level inverters. To acquire desired form of power, especially when precision, reliability and the economy of the project is considered upon, a multi-level inverter is a beneficial choice. They present ability to control higher amount of voltage and current, low THD, low cost, simple control methods, and

compactness. Having exhibited its share of advantages in electronic power conversion, certain previous structures have indicated some limitations which risk hampering its fair deal of positive attributes. Such as the implementation of series connected switches (cascaded), a factor behind the inefficiency, operational heat generation and unreliability. A cascaded structure imposes two important limitations to the system: it limits the efficiency and reliability by increasing the on-state power dissipation in the converter; it directly limits the reliability by increasing the likelihood of failure.

The selection of multi-level inverter configurations, on the basis of on-state voltage drop of switches is possible through developing a new mathematical method to calculate the comparative efficiency in staircase diode-clamped, H-bridge and the proposed inverter with p-n junction and MOSFET switches. These calculations rely on the on-state voltage drop of p-n junction switches, conducting resistance of MOSFET switches, break down voltage, number of levels, peak output voltage, voltage steps magnitude and the load. The calculations show the important effect of on-state voltage drop of switches on the efficiency in staircase multi-level inverters.

Using an affordable multi-winding transformer, a low frequency multi-level DC-AC-AC inverter is proposed and proves to be an advantageous choice. The most important advantage of this multi-level inverter is that only four switches conduct during each step,

which means that it operates with lower number of serial conducting switches, resultantly increasing the efficiency and reliability. Higher reliability when switches fail in open-circuit and short-circuit behavior is another advantage of this inverter structure however, it is recommended to use switches that fail in open-circuit owning to higher reliability of the inverter in open-circuit failures. Furthermore, some important factors that affect the reliability of inverters have been improved in the proposed inverter, including: duty cycle of conducting switches, voltage stresses, switching frequency, switches` temperature and dependency to capacitors. The system is controlled with a cheap microcontroller. A 5-kW 47-level prototype showed 97.4% ± 0.2% peak efficiency decreases to 91% under a full load and THD starts at 0.66% under a 50-W load increases to more than 7.5% under a full load. The novel proposed inverter, Switch-Ladder multi-level inverter, is a reliable and efficient choice for PV and renewable applications, where the output voltage peak is low and the volume and weight are not important parameters.

ABSTRAK tesis yang dikemukakan kepada Senat University Putra Malaysia sebagi memenuhi keperluan untuk ijazah Doktor Falsafah

Reka bentuk dan Pembangunan Inverter Tangga-Output Multi-Level

Oleh

EHSAN ESFANDIARI

September 2011

Pengerusi: Norman Bin Mariun, PhD, Peng

Fakulty: Kejurateraan

Disebabkan oleh krisis bahan api, dunia telah mengalami satu trend popular, khususnya sumber tenaga alternatif yang boleh diperbaharui dan diekstrak serta dijana dengan bersih. Hal ini menimbulkan permintaan tinggi terhadap sumber tenaga popular iaitu tenaga angin dan solar. Akibatnya, pemasaran penukaran tenaga yang boleh diperbaharui juga telah meningkat secara dramatik sejak sedekad akhir-akhir ini. Oleh kerana pelaksanaan penyongsang dalam penjanaan kuasa elektrik, minat yang tercetus ini dikongsi sama rata dan dengan demikian telah mencipta dasar kepentingan kajian dalam penyongsang berbilang-aras (multi-level inverters).

Penyongsang berbilang-aras mensintesis voltan yang dikehendaki yang hampir kepada sinusoidal, dengan menggunakan sumber voltan yang berasingan atau yang disambung secara belakang ke

belakang. Untuk mendapatkan kuasa yang dikehendaki, terutama ketika mempertimbangkan ketepatan, kebolehpercayaan dan ekonomi, penyongsang berbilang-aras merupakan pilihan yang memanfaatkan. Ia menunjukkan kemampuan untuk mengawal jumlah voltan dan arus elektrik yang lebih tinggi, THD rendah, kecekapan dan kos yang boleh diterima, kaedah kawalan yang mudah, kepadatan dan kebolehpercayaan.

Setelah menunjukkan kelebihan dalam penukaran kuasa elektronik, struktur tertentu sebelum ini telah menunjukkan beberapa halangan yang berisiko mengurangkan ciri-ciri positif yang ada. Seperti pelaksanaan suis berhubung bersiri (lata), faktor kurang kecekapan, penjanaan haba operasi dan tidak boleh dipercayai. Struktur lata menetapkan dua halangan penting terhadap sistem: ia hadkan kecekapan dengan meningkatkan pelepasan kuasa keadaan hidup pada penukar (converter). ia hadkan kebolehpercayaan. Dalam sistem lata, suis gagal dalam litar terbuka atau litar pintas bererti berhenti atau ketidakstabilan pada output yang berdasarkan kepada tatasusunan suis yang tidak boleh diterima.

Pemilihan penyongsang berbilang-aras yang efisien, berdasarkan ciri-ciri berganda boleh dibuat melalui pengiraan matematik diod-terkapit, jambatan-H dan kecekapan penyongsang yang dicadangkan untuk suis simpang p-n dan MOSFET. Perhitungan ini

bergantung pada suis voltan rosak, jumlah aras, voltan output puncak, turunan voltan keadaan-hidup pada suis simpang p-n, rintangan pengaliran MOSFET dan magnitud langkah voltan.

Menggunakan transformer pelbagai lilitan, penyongsang DC-AC-AC berbilang aras frekuensi rendah telah dipersembahkan dan terbukti menjadi pilihan yang menguntungkan. Kelebihan yang paling penting dari penyongsang ini adalah, hanya empat suis mengalir elektrik pada setiap langkah. Ini bererti ia beroperasi dengan pelepasan kuasa keadaan hidup yang lebih rendah. Kebolehpercayaan tinggi ketika suis gagal dalam litar terbuka dan perilaku litar pintas adalah kelebihan lain struktur penyongsang ini. Sistem ini dikawal dengan mikropengawal murah. Prototaip 5-kW tahap 47 menunjukkan 97.4% ± 0.2% kecekapan puncak dan THD lebih rendah daripada 7.5%.

ACKNOWLEDGEMENTS

This dissertation would not have been possible without the guidance and the help of several individuals who in one way or another contributed and extended their valuable assistance in the preparation and completion of this study.

First, my utmost gratitude to Prof. Dr. Ir. Norman Bin Mariun, for his valuable supervision, encouragement and unselfish and unfailing support throughout the whole work and being my inspiration as I hurdled all the obstacles in the completion this research work.

I am also grateful to my co-supervisor, Associate Prof. Dr. Mohammad Hamiruce Marhaban, for his encouragement, valuable discussions and support.

I would also like to thank Prof. Dr. Azmi Zakaria for his valuable contribution to this work.

I wish to express my gratitude to the staff and colleagues of Electrical and Electronic department for their friendship, encouragement and support to complete this study.

My colleagues and staff in the Electrical Engineering Departments for the use of facilities especially in the power electronic lab.

University Putra Malaysia, for financial support of this work under Grant No.91852.

I wish to express my gratitude to the president of the Islamic Azad University, Majlesi Branch; Dr. Hasan Gheysarian for his financial and moral supports during this study.

Last but not the least, my family, my wife; Somaieh, my parents, Abbasali and Zahra and the one above all of us, the omnipresent God, for answering my prayers for giving me the strength to plod on despite my constitution wanting to give up and throw in the towel, thank you so much Dear Lord.

EHSAN ESFANDIARI

APPROVAL

I certify that a Thesis Examination Committee has met on 15/September/2011 to conduct the final examination of **Ehsan Esfandiari** on his thesis entitled "**DEVELOPMENT OF STAIRCASE-OUTPUT MULTILEVEL INVERTER**" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the **PhD**.

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APPROVAL

Saya mengesahkan bahawa satu Jawatankuasa Peperiksaan Tesis telah berjumpa pada 15/September/2011 untuk menjalankan peperiksaan akhir bagi **Ehsan Esfandiari** bagi menilai tesis beliau yang bertajuk "**DEVELOPMENT OF STAIRCASE-OUTPUT MULTILEVEL INVERTER**" mengikut Akta Universiti dan Kolej Universiti 1971 dan Perlembagaan Universiti Putra Malaysia [P.U.(A) 106] 15 Mac 1998. Jawatankuasa tersebut telah memperakukan bahawa calon ini layak dianugerahi ijazah **PhD**.

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Tarikh:

This thesis was submitted to the Senate of University Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of Supervisory Committee were as follows:

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DECLARATION

I declare that the thesis is my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any institution.

Signature

EHSAN ESFANDIARI

Date:15/September/2011

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