2006

# Harmonic impact of photovoltaic inverter systems on low and medium voltage distribution systems

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# Harmonic Impact of Photovoltaic Inverter Systems on Low and Medium Voltage Distribution Systems

A thesis submitted in fulfilment of the
requirements for the award of the degree

Masters of Electrical Engineering

from

UNIVERSITY OF WOLLONGONG

by

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Bachelor of Engineering (Hons)

SCHOOL OF ELECTRICAL, COMPUTER
AND TELECOMMUNICATIONS ENGINEERING
2006

# Abstract

As residential customers become more energy conscious and environmentally aware, the installation of grid connected photovoltaic solar panels for small-scale electricity generation is expected to increase. However, the issue of quality of the electrical supply is as equally important as adopting sustainable energy. This thesis proposes a method to determine the quality of electrical supply based on the acceptable level of harmonic current that can be injected from a typical grid connected residential type photovoltaic inverter system (PVIS). The acceptable number of PVISs is based on not exceeding the recommended harmonic voltage levels in medium voltage (MV–11kV) and low voltage (LV–415V) distribution systems given in standard AS/NZS 61000.3.6-2001 and its application guide HB 264-2003.

To undertake this study, an acceptable frequency domain model of a typical power system is developed, an appropriate model of a typical inverter spectrum is proposed and a method for allocating harmonic voltage distortion levels for PVIS in MV and LV systems by incorporating background distortion is suggested. The harmonic voltage distortion levels caused by the residential type PVIS are calculated based on conventional methods such as nodal analysis applied over the distribution network.

A typical residential power system is adapted from the available literature. The LV distributors of the power system were modelled based on residential load and PVIS aggregation, and MV feeders are modelled based on distribution transformer aggregation. The distributors selected for LV systems study are based on overhead open–wire conductor, aerial bundled conductor and underground cabling types and the MV system feeders are based on an open–wire overhead conductor system. Residential load for harmonic studies is modelled based on the duration of equipment usage (with typical household ratings) during the power generation (active time) of the PVIS. Active time of the PVIS is estimated from field measurement data.

Since the LV system is of multiple earth neutral (MEN) construction, an additional system study is required to investigate the effective neutral harmonic impedance. This study revealed the significance of the zero sequence impedance of the system to show the importance of representing the neutral current within the study. Consequently, the acceptable number of PVIS units is limited by triplen harmonic voltage magnitudes suggested by recommended harmonic voltage levels.

Studying the available literature revealed that the development of a harmonic current spectrum to represent a typical photovoltaic inverter's line current is required. Hence, an adequate harmonic current spectrum was developed being selected from three distinct methods. The PVIS spectrums were modelled up to $40^{th}$ harmonic, and an appropriate model was selected from among the three proposed models based on their compliance to recommended harmonic current emission levels, both individual and total, as suggested by standards. Examining the harmonic range up to $40^{th}$ revealed that recent LV distribution network harmonic studies associated with PVIS are not wide enough in harmonic range to show some important network wide harmonic issues.

Allocation of harmonic voltage distortion levels for the LV PVIS was based on the background distortion level and recommended harmonic voltage planning levels and the suggestion in standards to incorporate sufficient diversity for the MV and LV distribution systems contribution. Background harmonic voltage distortion levels were calculated based on published data related to field measurements from dedicated residential feeders in distribution systems.

This study has proposed and identified a method to assess the harmonic distortion levels in MV and LV distribution systems, and related key issues, to assist the harmonic management of these systems due to grid connected PVIS.

# Statement of Originality

This is to certify that the work described in this thesis is entirely my own, except where due reference is made in the text.

No work in this thesis has been submitted for a degree to any other university or institution.

Signed

Ahmed Ahsan Latheef

December, 2006

# Acknowledgments

I would like to thank my parents for their constant support given to me throughout the time of my studies, their encouragement for me to move forward with my studies during the most depressed times is invaluable. I would also like to thank my wife and my son for their patience and understanding, when long hours were spent on studies instead of being with them.

I am very grateful to those who assisted me in this work; my supervisor Dr Vic Smith for constant support and his contribution to publications from this study, Prof Vic Gosbell for his continuous technical support and guidance from the early stage of this work to the submission of this thesis, Dr Duane Robinson for his supervision during the initial stage of this work and Integral Energy for their assistance in providing with technical data. I am honoured to have worked with a team of extremely high technical knowledge and experience in the field.

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# List of Abbreviations

| | |
|---|---|
| PV | Photovoltaic |
| PVIS | Photo-Voltaic Inverter System |
| MV | Medium Voltage |
| LV | Low Voltage |
| THD | Total Harmonic Distortion |
| $V_h$ | Harmonic voltage |
| $V_{THD}$ | Voltage Total harmonic Distortion |
| PQ | Power Quality |
| $I_h$ | Inverter Harmonic Current |
| $h$ | Represents the harmonic number (Multiple of the fundamental, 50Hz) |
| $L_{415,h}$ | Harmonic Voltage Planning Level for 415V system [10] |
| $L_{11,h}$ | Harmonic Voltage Planning Level for 11kV system [10] |
| $L_{33,h}$ | Harmonic Voltage Planning Level for 33kV system [10] |
| $L_{O,415,h}$ | Distortion contribution due to existing 415V system equipment |
| $L_{415,PVIS,h}$ | Allowable $V_h$ contribution to PVIS for the 415V system |
| $L_{11,PVIS,h}$ | Allowable $V_h$ contribution to PVIS for the 11kV system |
| $L_{11,415,h}$ | Distortion contribution due to existing 415V system equipment in 11kV system |
| $x_{s,tx,h}$ | Impedance of the Transformer and Upstream at h$^{th}$ harmonic |
| $x_{tx}$ | Transformer impedance |
| $\alpha$ | Harmonic Summation exponent [10] |
| $\beta_h$ | Background Harmonic allocation factor at h$^{th}$ harmonic |
| GMD | Geometric Mean Distance |

| | |
|---|---|
| $\mathrm{L}_{PVIS}$ | Allowable distortion Limit for the PVIS |
| PCC | Point of Common Coupling |
| IEEE | Institute of Electrical and Electronics Engineers, Inc |
| IEC | International Electrotechnical Commission |
| ABC | Aerial Bundled Conductor system voltage feeder type |
| OH | Overhead open wire system voltage feeder type |
| UG | Underground system voltage feeder type |
| $S_{INV}$ | Rating of the inverter |
| $V_{INV}$ | Voltage at the point of grid connection of the inverter system |
| AAC | Aluminum Alloy Conductor |
| UG | Underground Cabling |
| ABC | Aerial Bundled Conductor |
| $V_{BUS}$ | Voltage at the transformer side of a MV feeder or LV distributor |
| $V_{MID}$ | Voltage at the mid-point of a MV feeder or LV distributor |
| $V_{END}$ | Voltage at the end of a MV feeder or LV distributor |
| $Z_{load}$ | Residential load impedance |