

**IMPACT OF HIGH PENETRATION OF SOLAR PVS ON  
HARMONICS IN LV DISTRIBUTION NETWORKS**

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**August 2018**

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Thesis submitted in partial fulfillment of the requirements for the degree of Master of  
Science in Electrical Engineering

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August 2018

## DECLARATION

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The above candidate has carried out research for the Masters Dissertation under our supervision

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## **ABSTRACT**

Present trend of using solar photovoltaic (PV) technology for generating electricity has marked a rapid growth in the number of grid connected solar PV systems which has been reported to make a considerable impact on the power quality in the grid. With comparison of power quality (PQ) problems such as voltage unbalance, local voltage rise and voltage fluctuations, the increase of network harmonic levels has been identified as a potential PQ concern with the grid connected solar PVs. PV inverters are source of harmonics that produces low order and high order harmonics at the switching frequency and its side bands. Low order harmonics present at the inverter output due to the inability of producing pure sinusoidal waveform. Varying solar irradiance, inverter characteristics, inverter capacity, multi-inverter interactions and background harmonic level are examples of factors which influence the amount of harmonic generation of a PV system.

This research focuses on the effect of high levels of harmonic injection and propagation of current harmonics in distribution network with solar PV integrations. A methodology is discussed in this thesis to achieve the aforementioned matter with the detailed modeling of PV inverters in a typical distribution network using PSCAD/EMTDC simulation platform. From the analysis of simulation results, the current harmonics injected by single phase inverters has been found substantial and influential with regard to the energy transmission and increase losses with compared to the three phase inverters. Unbalance occurred due to single phase inverters results in triplen harmonics to propagate to the upstream grid via the distribution transformer. Moreover, current harmonics superimposition were recorded as a result of multi-inverter operation. It was found that the Point of connection (POC) of the PV inverter affects the voltage harmonic levels at the inverter output.

Keywords - Harmonics; Photovoltaic inverters; Distribution Network; THD; Power Quality

## **ACKNOWLEDGEMENT**

My sincere gratitude must go out to my supervisor Dr. Asanka S. Rodrigo, senior lecturer of the department of Electrical Engineering, University of Moratuwa. This achievement would not have been possible without the courage, guidance and assistance given to me throughout my research work.

My heartiest gratitude goes to my supervisor, Dr. (Mrs) Upuli Jayatunga, senior lecturer of the department of Electrical Engineering, University of Moratuwa in giving guidance, assistance and necessary resources focusing on the subject area.

Further, I would like to convey my grateful thank to Prof. J. P. Karunadasa for the assistance and encouragement given in this research which aided immensely in completing the study.

A special note of thank goes to my colleagues for their valuable assistance and support given to me which strengthened my work massively.

Finally, my unfeigned appreciation should go to my family, my beloved husband for his encouragement and support provided.

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## LIST OF ABBREVIATIONS

|        |   |
|--------|---|
| NRE    | non-renewable energy                              |
| RE     | renewable energy                                  |
| RER    | renewable energy resource                         |
| CDM    | clean development mechanism                       |
| ECF    | energy conservation fund                          |
| NCRE   | non-conventional energy resources                 |
| PV     | photovoltaic                                      |
| PQ     | power quality                                     |
| DC     | direct current                                    |
| AC     | alternating current                               |
| THD    | total harmonic distortion                         |
| IHD    | individual harmonic distortion                    |
| THD%   | percentage value of THD                           |
| SPWM   | sinusoidal pulse width modulation                 |
| POC    | point of connection                               |
| CSI    | current source inverter                           |
| LV     | low voltage                                       |
| MPP    | maximum power point                               |
| MPPT   | maximum power point tracking                      |
| STC    | standard test condition                           |
| InC    | incremental conductance                           |
| PI     | proportional-integral                             |
| IGBT   | insulated gate bipolar transistor                 |
| ESR    | effective series resistance                       |
| ESL    | effective series inductance                       |
| MOSFET | metal oxide semiconductor field effect transistor |
| GTO    | gate turn off                                     |

|       |   |
|-------|---|
| BJT   | bipolar junction transistor                 |
| rms   | root-mean-square                            |
| CEB   | Ceylon Electricity Board                    |
| IPP   | independent power producer                  |
| SPP   | small power producer                        |
| LECO  | Lanka Electricity Company (Private) Limited |
| OH    | overhead                                    |
| UG    | underground                                 |
| PSS   | primary sub station                         |
| FDS   | fuse disconnect switch                      |
| T-OFF | tap off                                     |
| ABC   | Aerial Bundled Cable                        |
| ADMD  | after diversity maximum demand              |

## LIST OF SYMBOLS

|                    |  |
|--------------------|--|
| $V_{\text{THD}}$   | THD of voltage signal                                      |
| $I_{\text{THD}}$   | THD of current signal                                      |
| $V_{\text{THD}\%}$ | percentage value of $V_{\text{THD}}$                       |
| $I_{\text{THD}\%}$ | percentage value of $I_{\text{THD}}$                       |
| $I_{\text{pv}}$    | output current of the PV array                             |
| $V_{\text{pv}}$    | output voltage of the PV array                             |
| $V_{\text{mppt}}$  | voltage at MPP   |
| $V_{\text{in}}$    | input voltage  |
| $V_{\text{out}}$   | output voltage   |
| $I_{\text{load}}$  | load current   |
| $f_{\text{sw}}$    | switching frequency  |
| $L$                | inductance   |
| $R$                | resistance   |
| $C$                | capacitance  |
| $C_{\text{in}}$    | input capacitance  |
| $C_{\text{out}}$   | output capacitance   |
| $L_1$              | inductance of the inverter side inductor of the LCL filter |
| $R_1$              | resistance of the inverter side inductor of the LCL filter |
| $L_2$              | inductance of the grid side inductor of the LCL filter     |
| $R_2$              | resistance of the grid side inductor of the LCL filter     |
| $C_f$              | capacitance of the capacitor of the LCL filter             |
| $R_f$              | damping resistance of the LCL filter                       |
| $E_n$              | inverter output rms voltage                                |
| $P_n$              | rated active power   |
| $V_{\text{dc}}$    | dc voltage   |
| $f_g$              | fundamental frequency                                      |
| $Z_b$              | base impedance   |

|                   |   |
|-------------------|---|
| $C_b$             | base capacitance  |
| $\Delta I_{Lmax}$ | maximum current ripple at the inverter output               |
| $N$               | number of customers   |
| $D_n$             | demand of customer $n$ at the time of system maximum demand |
| $P$               | active power  |
| $Q$               | reactive power  |
| $V$               | magnitude of the bus voltage                                |
| $P_0$             | initial active power  |
| $Q_0$             | initial reactive power                                      |
| $V_0$             | initial value of $V$  |
| $S_{out}$         | output apparent power of the inverter                       |
| $I_{out}$         | input current signal of the current source                  |
| $P_{pv}$          | output real power of the PV array                           |
| $Q_{pv}$          | output reactive power of the PV array                       |
| $T1$              | three phase inverter 1                                      |
| $T2$              | three phase inverter 2                                      |
| $T3$              | three phase inverter 3                                      |
| $S1$              | single phase inverter 1                                     |
| $S2$              | single phase inverter 2                                     |
| $S3$              | single phase inverter 3                                     |
| $F2-2$            | feeder 2 branch 2   |
| $F2-1$            | feeder 2 branch 1   |
| $V_{ab}$          | voltage between node a and b                                |
| $V_{ao}$          | voltage between node a and o                                |
| $V_{bo}$          | voltage between node b and o                                |
| $V_{An}$          | voltage between node A and n                                |
| $V_{Bn}$          | voltage between node B and n                                |
| $V_{Cn}$          | voltage between node C and n                                |
| $V_{Ao}$          | voltage between node A and o                                |

|          |  |
|----------|--|
| $V_{Bo}$ | voltage between node B and o                           |
| $V_{Co}$ | voltage between node C and o                           |
| $h$      | harmonic order   |
| $t_0$    | starting time  |
| $T$      | periodic time  |
| $I_{An}$ | output current of the inverter                         |
| $Z_S$    | source impedance                                       |
| $Z_T$    | transformer impedance                                  |
| $Z_G$    | resultant grid impedance                               |
| $Z_h$    | impedance at $h^{\text{th}}$ harmonic frequency        |
| $V_h$    | harmonic voltage at $h^{\text{th}}$ harmonic frequency |
| $I_h$    | harmonic current at $h^{\text{th}}$ harmonic frequency |