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

R. O. Anurangi

158011U

Degree of Master of Science

Department of Electrical Engineering

University of Moratuwa
Sri Lanka

August 2018

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

Rambukkanage Omesha Anurangi

158011U

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

Department of Electrical Engineering

University of Moratuwa
Sri Lanka

August 2018

DECLARATION

I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute my thesis, in whole or in part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (such as articles and books).

………………………………. Date:

R. Omesha Anurangi

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

1. Name of the supervisor:

………………………….. Date:

Dr. W. D. A. S. Rodrigo

2. Name of the supervisor:

…………………………... Date:

Dr. (Mrs) U. Jayatunga

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.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVATIONS

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_{THD}	THD of voltage signal
I_{THD}	THD of current signal
V_{THD}%	percentage value of V_{THD}
I_{THD}%	percentage value of I_{THD}
Ipv	output current of the PV array
Vpv	output voltage of the PV array
Vmppt	voltage at MPP
Vin	input voltage
Vout	output voltage
Iload	load current
fsw	switching frequency
L	inductance
R	resistance
C	capacitance
Cin	input capacitance
Cout	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_{dc}	dc voltage
f_g	fundamental frequency
Z_b	base impedance

C_b	base capacitance
ΔI_{Lmax}	maximum current ripple at the inverter output
N	number of customers
Dn	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
Sout	output apparent power of the inverter
Iout	input current signal of the current source
Ppv	output real power of the PV array
Qpv	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^{th} harmonic frequency
V_h	harmonic voltage at h^{th} harmonic frequency
I_h	harmonic current at h^{th} harmonic frequency