Performance Analysis of different Line filters for Single Phase Grid Connected Photovoltaic System in Secondary Distribution Network

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Abstract—**Grid-tied distributed generation systems (DG) are becoming more and more necessary to meet customer demands. In a low voltage distribution network, line filters are crucial for connecting solar photovoltaic (PV) installations to the utility grid. The IEEE1547 standard states that power injection from the inverter system to the utility grid shall have a unity power factor and few harmonics. In order to link single phase solar PV inverter systems in the low voltage (LV) distribution network, several line filters are provided. For example, these filters are used to remove harmonics from the inverter output waveform. This research estimates the Total Harmonic Distortion (THD) of the injected current by the PV inverters in the suggested system with various kinds of line filters and analyses the power factor in these scenarios. MATLAB/SIMULINK has been used to implement the system.**

Index Terms—**Distributed generation, Single phase solar PV systems, Line filter, Harmonics, THD, Power factor, Low voltage Distribution network MATLAB/SIMULINK.**

I. INTRODUCTION

Renewable energy technology and power conversion devices for solar and wind power systems have advanced more quickly in the current century [1]. These days, PV systems are more common because they don't produce pollution and are less expensive to operate and maintain. However, they deal with a number of anomalies, including distortion caused by power conversion devices, erratic weather, problems with integration, problems with power quality, etc. [2]. The use of inductance in power conversion devices reduces these harmonics in a traditional manner since the (THD) generated by these devices is a crucial

factor in the system design stage [3]. However, greater system capacity necessitates high inductance levels. Furthermore, despite their high cost and poor dynamic responses, practical filters are not very difficult to operate [4]. To reduce the switching frequency harmonics generated by grid-connected PV inverter systems in the low voltage distribution network, a L filter, LC filter, or LCL filter is typically positioned between the inverter and the utility grid [5]–[6]. Despite this, the LCL filter outperforms the L filter in terms of both dynamic responsiveness and attenuation capacity. The undesirable resonance situation causes certain stability issues for the LCL filter. Therefore, a passive component like a resistor connected in series with a filter capacitor may be a useful way to address the aforementioned problem [7]. LCLR filter implementation in PV generation systems is straightforward, very dependable, and requires compliance with IEEE 1547 [8]–[9].

Numerous studies on line filter design have been published. In this research, we present a platform for solar PV systems that carry less THD of the current injected into the utility grid by the PV systems throughout the low voltage distribution network using various line filters. In addition to a comparative study of several line filters used in conjunction with grid-tied solar PV systems, this research presents a new design technique for LCLR filters.

The paper is organized as follows. The system model and line filter design are explained in Section II. Section III contains the results of the simulation model. Section IV has the conclusion.

II. SYSTEM MODEL

Due to the quicker development of power electronics devices and new power conversion technologies, distributed generating systems are evolving quickly in the modern power system. A typical distribution network with several PV inverters and an R/X ratio of 1 is taken into consideration in this analysis, as shown in Fig. 1. The three nodes that make up the system are separated by section impedance of 1+j1 ohm. Each node carries solar PV generators of 500 Watts, 1000 Watts and 1500 Watts respectively along with the low voltage distribution line having domestic load.
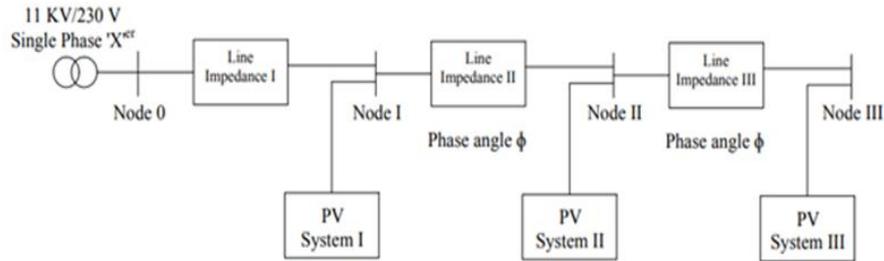

Fig 1 Single Line Diagram of the proposed system

A Maximum Power Point Tracking (MPPT) controller, a boost DC/DC converter, and a solar panel make up each consumer-side system. A DC/AC inverter and line filter are used to connect the DC/DC converter's output to the grid. Each solar system is linked to an MPPT charge controller, which uses the perturb and observe method to harvest the most power from the panel. Phase Locked Loop (PLL) and αβ to dq transformation are used to build DC/AC inverter control logic. To lessen the harmonics in the PV system's output wave form, various kinds of line filters are created and applied. MATLAB 2017 is used to model the entire system. Fig 2 and Fig 3 show the modelling guidelines of different subsystems and the overall system is given in Fig 4
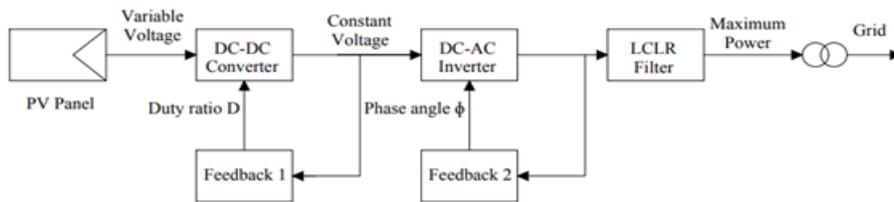

Fig 2 Modelling of system with solar panel and DC/DC boost converter
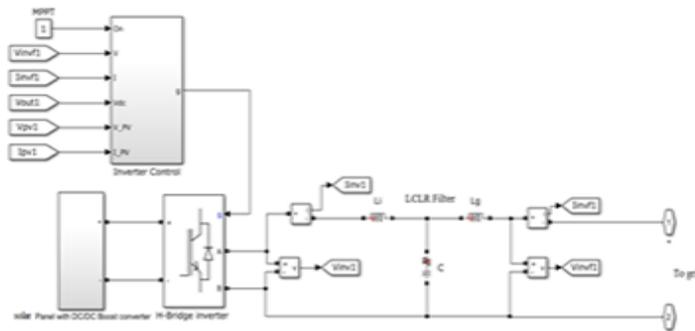

Fig 3 Modelling of system containing Inverter control, solar panel with boost converter and LCLR filter
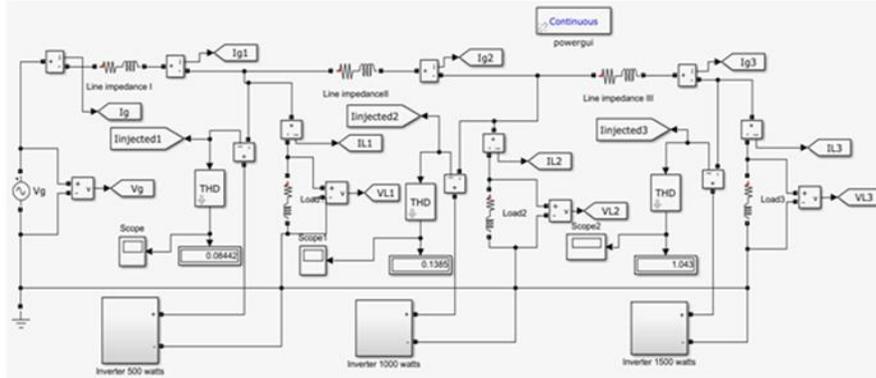
Fig 4 Developed Simulation circuit

Design of LCL Filter:
We can design Line filter (LCLR) by following the given below design procedure,

Current through capacitor filter is given
$$I_{cf} \leq 0.05 * P_0/V_0 \quad (1)$$
Where P_o is the inverter output power and V_o is the rated grid voltage.

Impedance of the filter capacitor, $Z_{cf} = V_{cf}/ \quad (2)$
Thus filter capacitor C_f is given by $C_f = 1/(w_1 * Z_{cf}) \quad (3)$

Impedance of the inductor at inverter side can calculate using the below equation,
$$Z_{LI} = 0.05 * (V_0{}^2 / P_0) \quad (4)$$

Inductance at inverter side is given by
$L_I = Z_{LI}/ w_1 \quad (5)$

Resonant frequency w_{res} can be selected in such a manner that
$$10 * w_1 \leq w_{res} \leq 0.5 w_s \quad (6)$$
Where w_1 is the natural frequency and w_s is the switching frequency.

Inductance at the grid side L_f can be calculated as below,

$w_{res} = sqrt (L_{I+} L_f) /(L_{I*} L_{f*} C_f).(7)$

Equation for damping resistor is given by,
$$R_d = 1/(3 * w_{res} * C_f) \quad (8)$$
In this manner line filter parameters can be calculated for the single-phase solar PV inverter systems. System description is listed below in Table1.

Table 1 System Description

Solar PV system	1000W,500W and 1500W
Local load	900+j435.88 VA at each node
Sending end voltage	$230 < 0^0$ V
Line Impedance	1+j1 between nodes
Boost DC/DC Converter	
Inductors and capacitors	0.25 mH,220 µF (500 VA PV Inverter)
	0.5 mH,470 µF (1000 VA PV Inverter)
	0.1 mH,47 µF (1500 VA PV Inverter)
L/LC/LCL/ LCLR Filter parameters (designed for resonant frequency=5000Hz)	
Inverter side inductance	16.8mH (500 VA PV Inverter)
	8mH (1000 VA PV Inverter)
	4 mH (1500 VA PV Inverter)
Capacitance	0.25 µF (500 VA PV Inverter)
	1 µF (1000 VA PV Inverter)
	1.50 µF (1500 VA PV Inverter)
Damping resistor	20Ω (500 VA PV Inverter)
	30 Ω (1000 VA PV Inverter)
	40Ω (1500 VA PV Inverter)
Grid side inductance	45.4mH (500 VA PV Inverter)
	23mH (1000 VA PV Inverter)
	9mH (1500 VA PV Inverter)

III. SIMULATION RESULTS

Tables 2 and 3 list the estimated total harmonic distortion (THD) and power factor of the injected current waveform. Additionally, they have analysed various line filters, such as L, LC, LCL, and LCLR,

with constant irradiation of 1000 w/m2 at 100% load. According to the simulation results, a 500 W inverter with an LCLR filter has a lower THD value of 0.9%, while an LCL filter without a resistor has a higher THD value of roughly 11.32%. Additionally, it is seen that the 1500 W inverter's power factor increases to 0.9955 when using an LCLR filter and to roughly 0.9943 when using an LC filter. During the minimum load condition with lower THD values, excess power from the solar PV systems is supplied back to the utility grid at unity power factor. When compared to other filters, the LCLR filter shows significantly lower THD (less than 1%) and a better power factor (nearly closer to unity).

Table 2 Estimation of THD for 100% Load at 1000w/m^2 irradiation for different line filters

Line filter	THD of the injected current by the inverter		
	500 W	1000 W	1500 W
L	0.0524	0.03779	0.03691
LC	0.1695	0.06992	0.02695
LCL	0.1132	0.01253	0.04217
LCLR	0.009718	0.007393	0.01951

Table 3 Estimation of Power factor for 100% Load at 1000w/m^2 irradiation for different line filters

Line filter	Power Factor		
	500 W	1000 W	1500 W
L	0.8732	0.8937	0.854
LC	0.9282	0.9926	0.9943
LCL	0.9709	0.9889	0.991
LCLR	0.978	0.9896	0.9955

IV. CONCLUSION

In this research, a low voltage distribution network and a single-phase grid-connected PV inverter system are integrated with a novel LCLR filter design methodology. In this case, excess power is given back to the grid with significantly lower THD when the load is at its lowest, and the injected current is in phase with the grid voltage. The system's injected power's THD and power factor are calculated and contrasted using various line filters. For various load scenarios, proposed method using an LCLR line filter demonstrated the superior dynamic responsiveness.

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