Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 6, No.3, June : 2024

HARMONICS MITIGATION AND POWER QUALITY IMPROVEMENT FOR PHOTOVOLTAIC MICROGRID

Mohd Shadab, M.Tech Student, Department of Electrical and Electronics Engineering, Al Falah University, Faridabad, Haryana, India.
Mohd Shahid, Associate Professor, Department of Electrical and Electronics Engineering, Al Falah University, Faridabad, Haryana, India.

ABSTRACT
The modeling of a grid-connected solar photovoltaic system with voltage source converter control and LCL filter design is presented in this study. PV Array, Boost Converter, Voltage Source Inverter, LCL Filter, Utility Grid, and Loads are the components of the system model. Variable input DC is converted to constant output DC by the Boost converter. DC boost voltage is converted to three-phase AC electricity using a voltage source inverter. A control unit made up of the outer and inner control loops has been in charge of controlling the VSC switching using the PWM approach. The power electronics components and non-linear loads that are linked to the system are the sources of the harmonics, and the existence of these harmonics in the system has decreased the power quality and system functionality. PLL has been used to synchronize the inverter's three-phase output with the grid. The system has been modeled in MATLAB, and the steady state of the grid voltage, current, and inverter current will be subjected to a THD analysis. Additionally, a comparison of the THD of the grid currents at two distinct sun irradiance levels has been conducted. An LCL filter has been used to reduce voltage and current THD below IEEE standards and to improve the power quality of the system by mitigating harmonics.

Keywords:
LCL Filter, Harmonics, Voltage Source Inverter (VSI), Total Harmonic Distortion (THD) and Boost Converter.

I- Introduction
The need for renewable energy has increased along with the demand for power in recent years. These sources of energy are plentiful in nature and may be obtained at a low cost to meet the high demand. The world's need for renewable energy sources is growing as traditional energy resources become more scarce. Because solar energy is so widely available, requires little maintenance because it has fewer moving parts, produces less noise, and has less wear and tear overall, it is the ideal renewable energy source for tropical climates[1]. When solar PV electricity is connected to the grid, it can be used more effectively; nevertheless, there are certain issues with solar power systems, such as voltage unbalancing, voltage sag and rise, low power factor, and harmonics in current and voltage. Due to harmonics in the VSC converter output, the main issue with the solar integrated grid system is the power quality in both the grid and the voltage source inverter.The grid is connected to the VSC output, thus it must be synced[2]. Additionally, the harmonics of the VSC output current must be minimized. For this model, an LCL filter with damping resistance has been utilized to decrease the harmonics of the VSC's output current. The dampening resistance lessens the system's resonance issue. Some harmonics are also produced in the system by the non-linear loads in the model[3-4]. The solar PV array with its Perturb and Observe MPPT algorithm, the utility grid, the voltage source converter with its dual loop control circuit, the DC-DC Boost converter regulated by duty cycle through P&O algorithm, the LCL filter, and both linear and non-linear loads are all included in the modeled system. The THD of the grid's voltage, current, and inverter current is computed both with and without an LCL filter. Additionally, the THD of the grid's current with an LCL filter has been compared for two distinct irradiance values. Since conventional L and LC filters are larger, heavier, and less effective in

attenuating harmonics, the LCL filter has shown to be the most effective passive filter among all the filters used in grid-connected solar systems[5] .Because of all the benefits they offer for increasing energy efficiency and reliability while lowering carbon emissions, governments, businesses, and academic institutions throughout the world have become more interested in renewable energy (RE) sources in recent years [6]. Because renewable energy sources (REs) have minimal environmental impact, are sustainable, require no fuel, have low plant operating costs, and produce electricity without producing pollution, they are widely used for power generation at the grid level [7]. There are advantages to solar photovoltaic energy over wind power, including its quiet operation and ease of harvesting in residential settings.Its primary drawbacks are that it is unavailable at night and that its output varies depending on the time of day [8]. The integration of renewable energy sources (RE) into the utility grid raises both technical and financial concerns about power quality (PQ), harmonics, voltage stability, control, and protection. Frequency control and reserve allocation are further impacted by the extensive integration of RE sources into the electric grid [9]. Due to these sources' erratic behavior, integrating PV into the grid results in operational issues. It impacts the utility network's frequency/load control, voltage and current balancing, load following, and unbalancing of levels. PQ issues like low power factor, voltage disturbance, flicker, and harmonic distortions are also brought on by it [10].

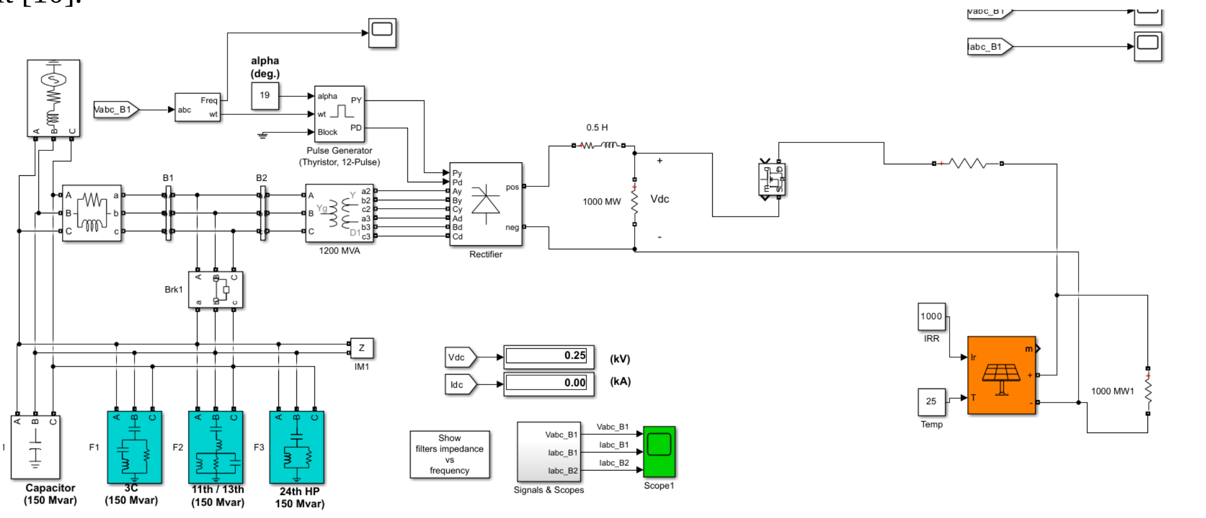

Fig-1 MATLAB simulink of proposed design

II- Proposed design:

A PV cell model with a single diode has been taken into consideration for the design of PV modules. Since the solar power is assumed to be 100 KW and the solar cell's power is 305 W, a parallel and series connection is established. To maximize the power of the sun, the solar modules are selected taking into account the geographical region. An MPPT is required to help harness the varying power throughout the day because the solar irradiance fluctuates throughout the day. Additionally, the variable DC voltage from the solar module needs to be boosted in order to feed into the inverter. Thus, in order to obtain a constant output voltage from a changing DC voltage, we must use the MPPT algorithm to alter the duty cycle[11]. Because of the ramp input type solar irradiance, which causes variations in output current and voltage over a brief period of time, the solar output voltage and current are changeable in this instance. The sun irradiation fluctuates at first, but then it becomes constant and is measured at 1000 W/m2. Filter LCL In the grid-connected PV system, the third-order LCL passive filter is highly effective in reducing voltage and current harmonics (shown in fig 2)[12]. By eliminating the high frequency harmonics, fewer passive components are needed, which results in a smaller filter and lower cost. Its benefit is that switching harmonics are eliminated, but its drawback is that resonance is produced because of the circuit's need for reactive power. In addition to a capacitor, a damper resistance is required to reduce the resonance phenomenon.The following is the flow chart for the LCL filter computations, where P stands for grid power, V for the inverter connecting grid voltage, fg for grid frequency, and fsw for switch frequency (Figure 3). Fig. 1 displays a MATLAB-based model featuring three-phase passive filters. Figure 6, 7 displays the voltage and current waveform status when the model is operating under load and with installed harmonic filters.The installation of harmonic filters causes the voltage and current waveforms to become smoother.

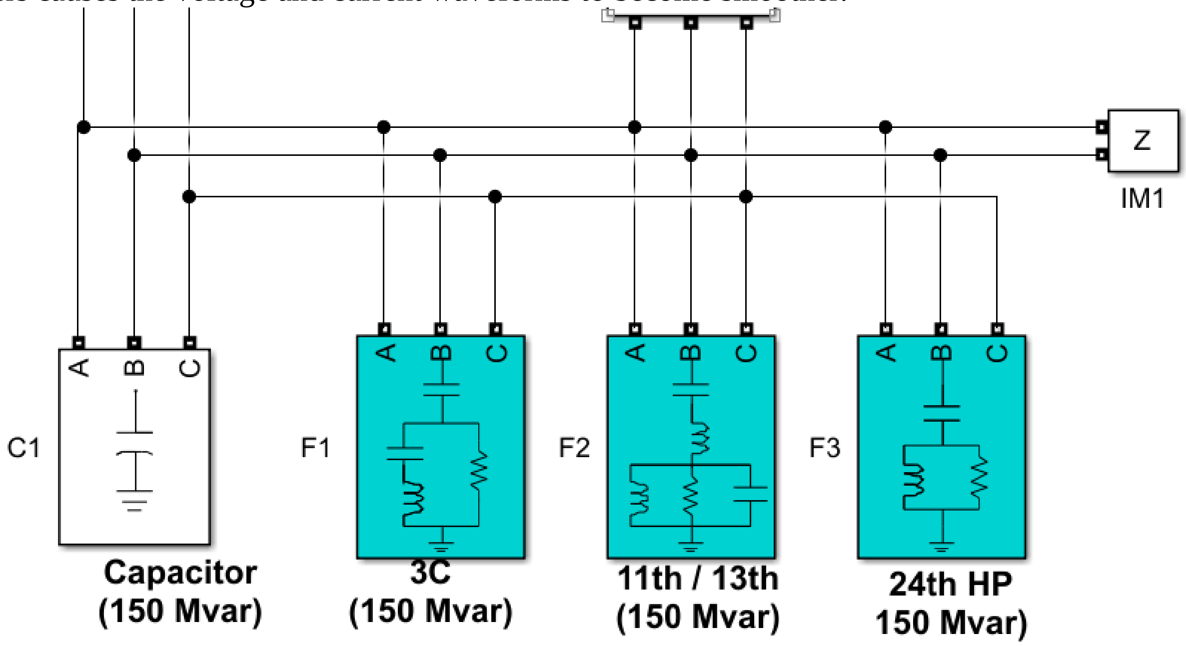

Fig-2 Three-phase harmonic filters

III- Repetitive Controller: The repetitive controller is another controller structure that is utilized in the inner controllers of the primary controller. To lower the THD of voltage in an islanded microgrid, a compensator based on repetitive and deadbeat control is proposed; a discrete time mathematical model of the proposed controller is presented and used. In addition, a comparison of the PI and RC controllers shows that, despite the RC's longer settling time, it reduces voltage THD far more effectively than the PI controller[13]. To lower specific harmonics and PCC THD in a single-phase grid-connected photovoltaic system, a repetitive VAR controller based on a finite-impulse response digital filter is suggested. A group of electrical components called a static VAR compensator, or "SVC" for short, is utilized in transmission networks to supply quick-acting reactive power. The SVCs are a class of devices used in flexible AC transmission systems that stabilize the system and control voltage, power factor, and harmonics. SVC stands for shunt-connected static variable-absorption regulator. Its output can be tuned to interchange inductive or capacitive current in order to regulate or maintain certain electrical power system parameters. Thyristors without a gate turn-off feature are the foundation of SVC[14].

The thyristors' operating characteristics indicate that the SVC's reactive impedance is changeable. It consists of two main parts, which are the thyristor-switched capacitor (TSC) and the thyristor-controlled and thyristor-switched reactor (TCR & TSR). Reactive power in SVC rises when TSC is turned on. This demonstrates how the AC power source receives reactive power from SVC. In a similar vein, reactive power in SVC rises when TCR firing angle decreases. This suggests that as AC power sources' reactive power is absorbed by SVC, it increases[15]. The least resistance channel to the harmonic current at tuning frequency is provided by the shunt connection of passive filters with the power supply. Series filters require over current protection devices since they are meant to handle full load current, unlike shunt filters. A portion of the series filter current is carried by the shunt passive filter. Because the shunt passive filter is less expensive than the series filter, it is frequently utilized as a harmonic filter. Moreover, it offers reactive power at the frequency at which the system operates[16].

IV- FFT ANALYSIS: Total harmonic distortion is the product of the root mean square of the harmonic content and the rms value of the fundamental quantity, represented as a percentage of the fundamental. For numerous applications, the total harmonic distortion, or THD, is a highly helpful metric. It can give a fairly accurate estimate of the additional heat that will be generated when a distorted voltage is placed across a resistive load. Additionally, it can indicate any additional losses brought on by current passing through the conductor[17]. Figure 10 below illustrates the total harmonic distortion, or THD, of the voltage on bus B1 without a passive filter, which is 29.28%.

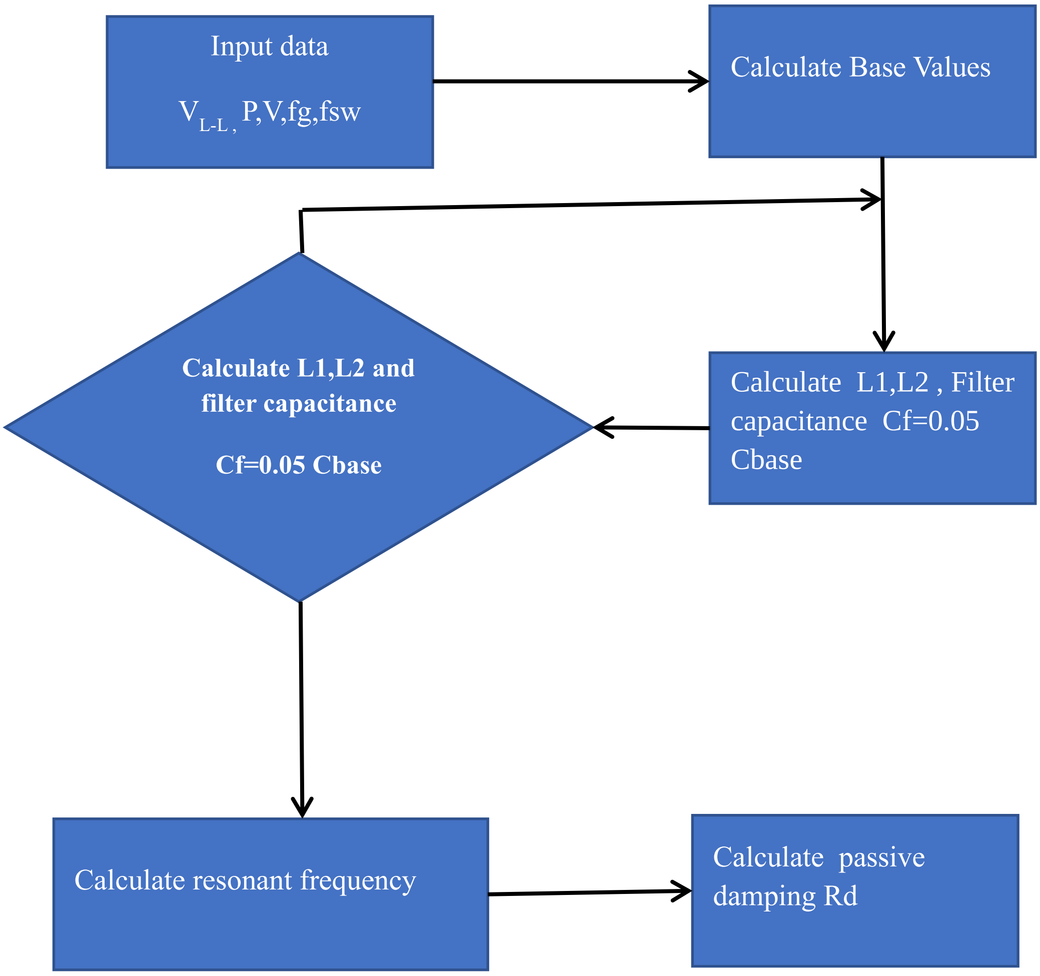

Fig-3 Flowchart of LCL filter calculation

The modeled system's MATLAB simulation results, both with and without an LCL filter, are displayed below. Figures 6 and 7 display the waveform of the grid voltage and current. The findings of the Fourier analysis are displayed in the corresponding figures below. As seen in Figures 8,9, shows the overall harmonic distortion grid voltage and current filter is 3.7 and 1%, respectively.

V- Results:

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 6, No.3, June : 2024

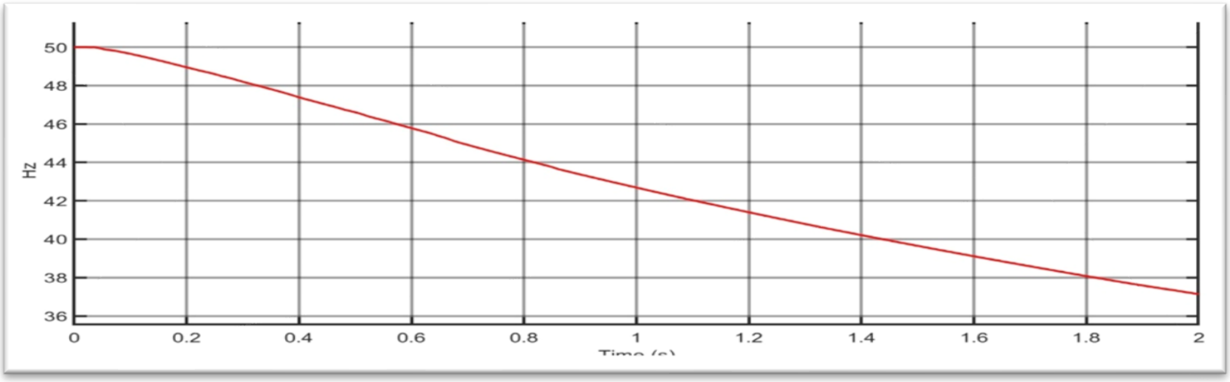

Fig-4 Grid frequency without Capacitor bank

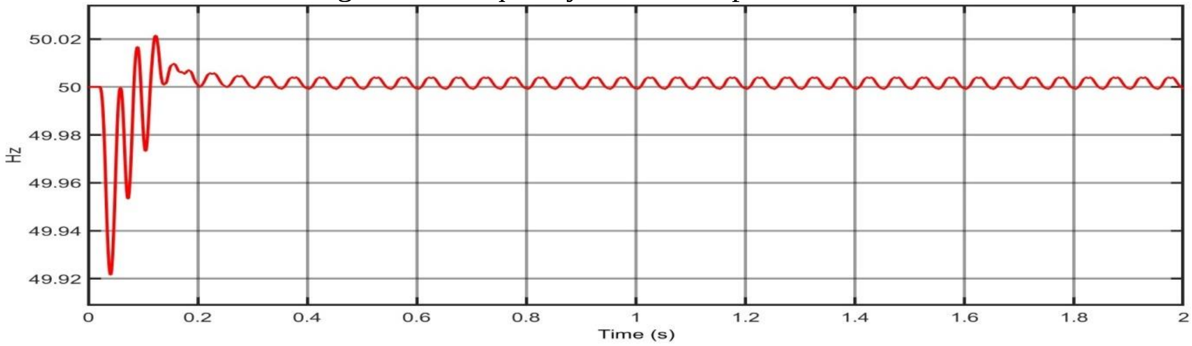

Fig-5 Grid frequency with Capacitor bank

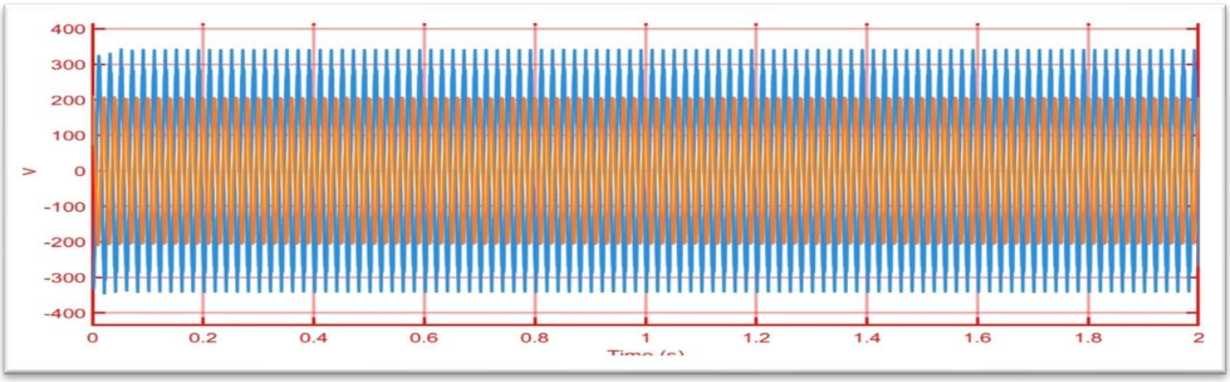

Fig-6 Grid Voltage

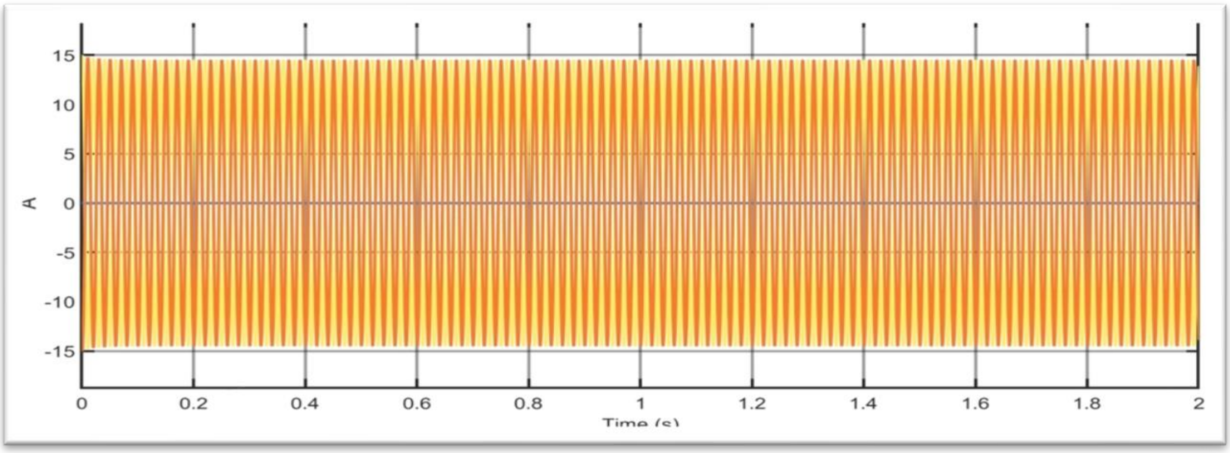

Fig-7 Grid Current

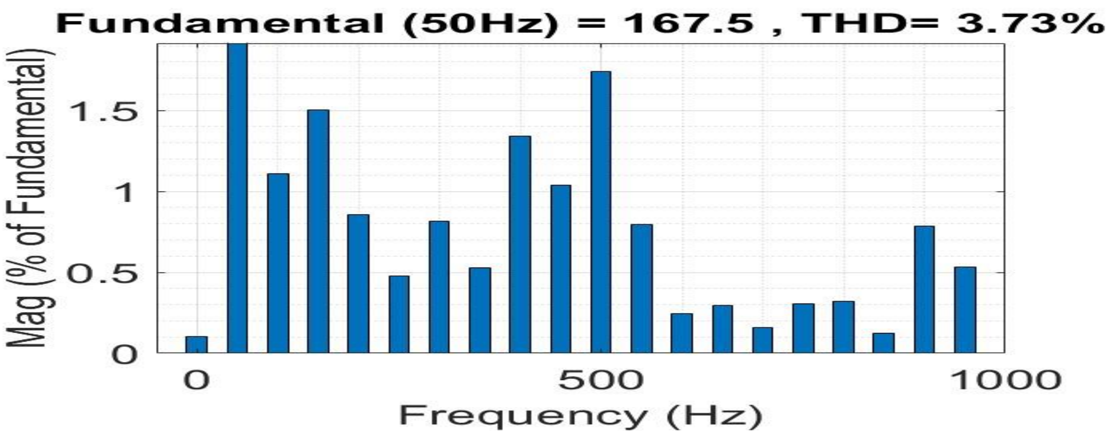

Fig – 8 THD in load voltage

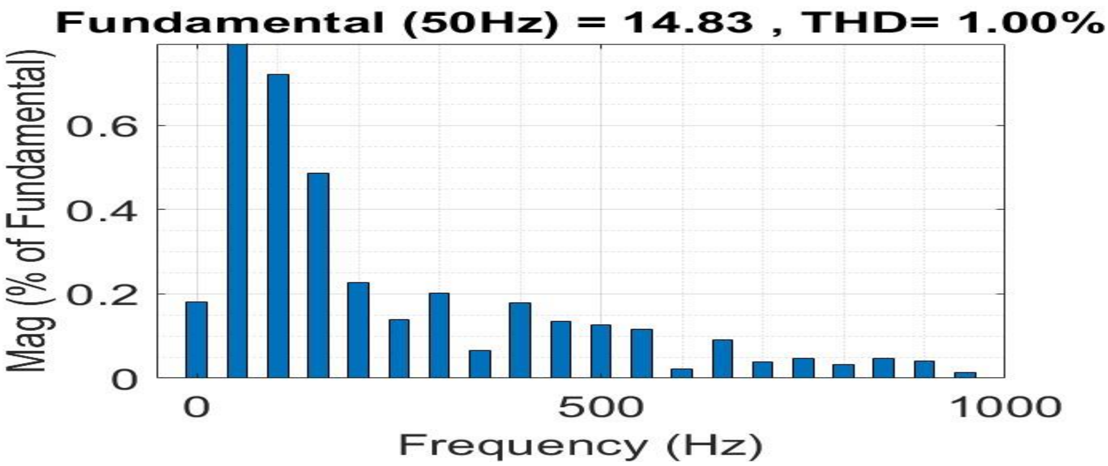

Fig – 9 THD in load Current

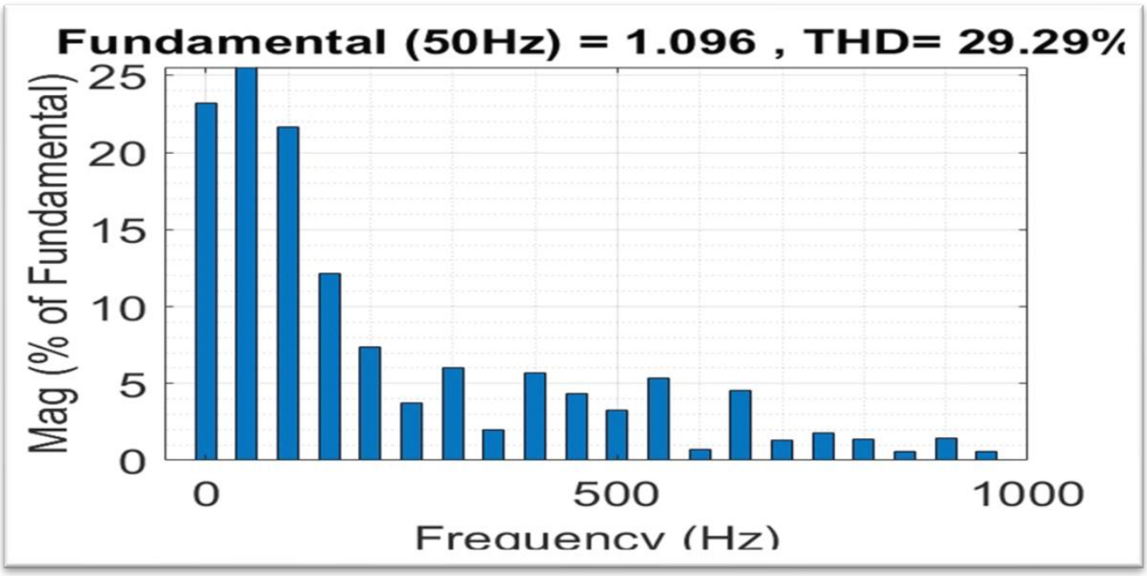

Fig-10 THD, of the voltage on bus B1 without a passive filter

VI- Conclusion:

The 100 Kw grid-connected LCL filter PV system model with dual loop control produces THD values within tolerances without resonance issues, indicating that the modeling design is operating within tolerances. After analyzing the system under study both with and without filters, it is clear that, in the event that the inverter's control scheme is unable to completely eliminate harmonics, a filter is essential for harmonic mitigation. Only the lower order harmonics might be reduced by this control system; the higher order harmonics are eliminated by the LCL filter with resistance damping and the ideal values of the inductor and capacitor. The Fourier analysis of the inverter current with LCL filter demonstrates how the solar irradiation also influences the THD.

Reference:

[1] T. Ackermann, G. Andersson and L. Söder, "Distributed generation: A definition", *Electric Power Systems Research*, vol. 57, pp. 195-204, 2001.
[2] V. Kumar, A. S. Pandey and S. K. Sinha, "Grid integration and power quality issues of wind and solar energy system: A review", *2016 International Conference on Emerging Trends in Electrical Electronics Sustainable Energy Systems (ICETEESES)*, pp. 71-80, March 2016.
[3] N. G. Hingorani, "Introducing custom power", *IEEE Spectrum*, vol. 32, no. 6, pp. 41-48, June 1995.
[4] H. Fujita and H. Akagi, "The unified power quality conditioner: the integration of series and shunt-active filters", *IEEE Transactions on Power Electronics*, vol. 13, no. 2, pp. 315-322, Mar 1998.
[5] S. Biricik, S. Redif, S. K. Khadem and M. Basu, "Control of the single phase parallel active filter under weak grid voltages", *2014 IEEE 5th International Symposium on Power Electronics for Distributed Generation Systems (PEDG)*, pp. 1-5, June 2014.
[6] J. Balcells and P. Bogonez-Franco, "Voltage control in a lv microgrid by means of an svc", *Industrial Electronics Society IECON 2013-39th Annual Conference of the IEEE.*, pp. 6027-6030, 2013.
[7] B. P. Nayak and A. Shaw, "Reduction of harmonics and voltage sag compensation by series active power filter", *2017 International Conference on Data Management Analytics and Innovation (ICDMAI)*, pp. 52-57, Feb 2017.
[8] M. Gayatri, A. M. Parimi and A. P. Kumar, "Microgrid reactive power compensation using upqc with common dc link energy restored by pv array", *Emerging Trends in Engineering Technology and Science (ICETETS) International Conference on. IEEE*, pp. 1-8, 2016.
[9] M. T. L. Gayatri, A. M. Parimi and A. V. P. Kumar, "Application of dynamic voltage restorer in microgrid for voltage sag/swell mitigation", *2015 IEEE Power Communication and Information Technology Conference (PCITC)*, pp. 750-755, Oct 2015.
[10] A. Hirsch, Y. Parag, and J. Guerrero, “Microgrids: a review of technologies, key drivers, and outstanring issues,” Renew. and Sustain. Energy Rev., vol. 90, pp. 402–411, 2018.
[11] M. F. Akorede, H. Hizam, and E. Pouresmaeil, “Distributed energy resources and benefits to the environment,” Renew. and Sustain. Energy Rev., vol. 14, no. 2, pp. 724–734, 2010.
[12] U. B. Tayab, M. A. B. Roslan, L. J. Hwai, and M. Kashif, “A review of droop control techniques for microgrid,” Renew. and Sustain. Energy Rev., vol. 76, pp. 717–727, 2017.
[13] F. Katiraei, R. Iravani, N. Hatziargyriou, and A. Dimeas, “Microgrids management,” IEEE Power and Energy Mag., vol. 6, no. 3, pp. 54–65, 2008.
[14] G. Pepermans, J. Driesen, D. Haeseldonckx, R. Belmans, and W. Dhaeseleer, “Distributed generation: Definition, benefits and issues,” Energy Policy, vol. 33, no. 6, pp. 787–798, 2005.
[15] K. Alanne and A. Saari, “Distributed energy generation and sustain. development,” Renew. and Sustain. Energy Rev., vol. 10, no. 6, pp. 539–558, 2006.
[16] D. E. Olivares, A. Mehrizi-Sani, A. H. Etemadi, C. A. Canizares, ˜ R. Iravani, M. Kazerani, A. H. Hajimiragha, O. Gomis-Bellmunt, M. Saeedifard, R. Palma-Behnke et al., “Trends in microgrid control,” IEEE Trans. on Smart Grid, vol. 5, no. 4, pp. 1905–1919, 2014.
[17] T. Ackermann, G. Andersson, and L. Soder, “Distributed generation: ¨ A definition,” Electric Power Syst. Res., vol. 57, no. 3, pp. 195–204, 2001.