IMPROVE THE FILTER OF GRID-TIDE SINGLE-PHASE INVERTER FOR ROOFTOP PHOTOVOLTAIC SYSTEMS

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ABSTRACT

Renewable energy is becoming an alternative to conventional generators in the context of increasing environmental pollution problems. Countries gradually consider photovoltaic application a necessary strategy for the sustainable development of modern power systems. However, to connect the power system or supply power to the load, the energy obtained from PV must convert through inverters. That creates problems during the connection process as frequency synchronization, and harmonics degrade power quality. This study designs a complete grid-tied single-phase inverter model to look for a high-quality inverter that can increase the quality of grid-connected power and minimize harmonics with filters. The results show that the connection voltage is kept stable with the proposed model and the power quality is improved with different harmonic sets analyzed.

CẢI TIẾN BỘ LỌC CHO NGHỊCH LƯU MỘT PHA NỐI LƯỚI TRONG HỆ THỐNG ĐIỆN MẶT TRỜI ÁP MÁI

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TỪ KHÓA

Nối lưới
Bộ lọc LCL
Bộ lọc LLCL
THD
PV áp mái

TÓM TẮT

Năng lượng tái tạo đang trở thành giải pháp thay thế cho các nguồn truyền thống trong bối cảnh vấn đề ô nhiễm môi trường ngày càng gia tăng. Các nước dần coi việc tích hợp quang điện là một chiến lược phát triển bền vững hệ thống điện hiện nay. Tuy nhiên, điện năng từ nguồn năng lượng này cần phải được chuyển đổi thông qua biến tần để có thể nối lưới hoặc cung cấp cho phụ tải. Điều này đòi hỏi cần phải có các giải pháp cải thiện sự đồng bộ của tần số và giảm thiểu sóng hài để đảm bảo chất lượng điện năng. Nghiên cứu này thiết kế mô hình biến tần một pha nối lưới hoàn chỉnh nhằm mục đích nâng cao chất lượng điện năng và giảm thiểu sóng hài thông qua các bộ lọc. Hơn nữa, hiệu quả của các bộ lọc sóng hài cũng được quan tâm nghiên cứu.

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1. Introduction

CO_2 effect reduction requirements are being applied closely with the commitment of countries worldwide. As a result, conventional power sources have to be limited in generating capacity, especially thermal and nuclear power plants, and gradually replaced by new power generation technologies. Along with preferential policies and the urgent need for electricity demand, renewable energy sources (RES) explode in installed and generation capacity. With various installation forms, lower construction costs than other RESs, and many supportive policies, photovoltaic (PV) gradually become essential for the modern electricity system [1]. Moreover, PV is easily accessible to households in the form of the rooftop, which helps to reduce electricity costs paid to power companies and can also earn profits from selling excess electricity [2], [3]. Since then, it has promoted the market share of rooftop PV, accounting for a significant part of the generation rate structure.

Unlike large-capacity PV plants that are often concentrated, rooftop PV is decentralized and connected to the low-voltage electricity grid. That makes coordinating and controlling electricity difficult, significantly when the output power is constantly fluctuating by uncertainties of weather conditions in different areas and times. Furthermore, rooftop PV can be integrated with different phases in the low voltage distribution power system, which can cause the phase to unbalance in the event of a fault. In addition, the power from PV must be converted through an inverter to supply the load, which will create harmonics, causing power quality to degrade [4]. Therefore, many studies have focused on planning and connecting rooftop PV systems to minimize the risk of phase unbalance [5], [6]. Another approach proposes harmonic filters to improve the quality of power obtained from PV, but most focus on isolated inverters [7].

This study proposes a grid-tied inverter model, calculates, and designs filters to improve power quality, operating with stable voltage when connected to the grid. The maximum energy from PV is collected via a DC/DC converter with maximum power point tracking (MPPT) algorithm and then converted through the gird-tied inverter. The harmonic filter types will be reviewed, simulated, and improved with a complete inverter via Matlab/Simulink [8]. From there, an appropriate solution can be given to improve the power quality of rooftop PV systems.

In the following sections of this paper, the grid-harmonized inverter model will be mentioned in part 2. Then, the harmonic filters will be calculated in part 3. Finally, the comparison and evaluation results can be presented in section 4, and the conclusions are considered in section 5.

2. Grid-tied Inverter Model

The single-phase grid-connected inverter model is combined from DC/DC and DC/AC converters. Firstly, the PFSB DC/DC converter ensures 2 functions of changing the switching frequency of the semiconductor valves to bring the unstable DC voltage of the renewable energy back to a stable DC voltage at 700V and integrates the MPPT algorithm to optimize the power obtained from PV. The H-bridge inverter consists of 4 IGBT control keys that convert the DC gain voltage into AC voltage. The IGBT opens and closes, synchronizes energy with the grid voltage and frequency, and goes through a filter to reduce harmonics, creating the best quality power before connecting to the low voltage distribution power system. The overview model is shown in Figure 1 [5], [6], with the specification as Table 1. The converter simulation model in Matlab is shown in Figure 2 [8].

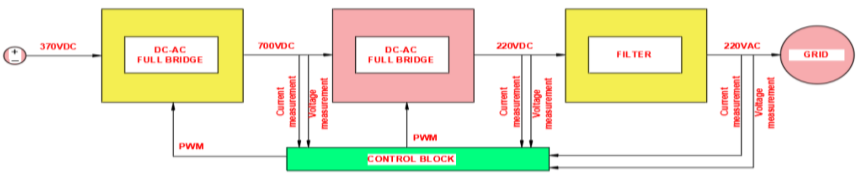

Figure 1. *Block diagram of grid-connected inverter* [5], [6]

Table 1. *System specification*

Factor	Specification	Rated value
1	DC/DC input voltage	350-450VDC
2	DC/DC out voltage	700VDC (600 -800VAC)
3	DC/AC input voltage	220VAC
4	Rated power	6kW
5	DC/DC switch frequency	17kHz
6	DC/AC switch frequency	35kHz
7	Grid frequency	50Hz
8	AC rated current	27,27 A
9	DC rated current	8,57A

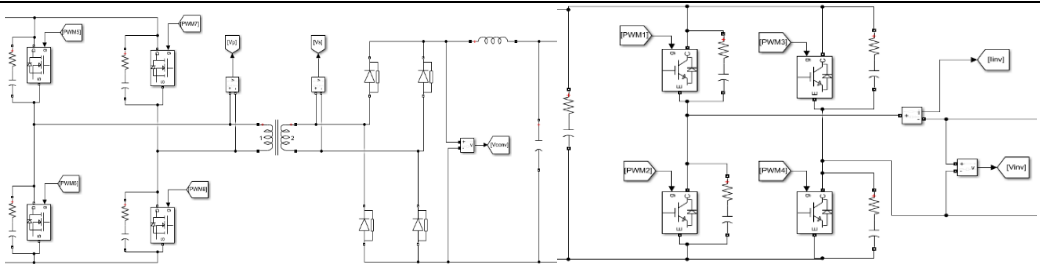

Figure 2. *Modeling of DC/DC PSFB combined Full-Bridge inverter unit in Simulink*

3. Integrated Filters for Grid-Tied Inverter

3.1. LCL type

The LCL type filter is designed as Figure 3 with the total inductance of the two inductors, L_1 and L_2, should be less than 10% of the base inductor of the system to avoid large voltage drop [9], [10]. The current fluctuation I_{Ripple} is limited to 20% of rated current, from which inverter side inductor L_1 is selected based on a maximum allowable ripple of ΔI_{Ripple} current as in equation (1):

$$L_1 = \frac{V_{in}}{4\times f_s \times \Delta I_{Ripple}} = \frac{V_{in}}{4\times f_s \times 20\% I_{in}} \quad (1)$$

Where: V_{in} and I_{in} are the rated input voltage and current of the inverter, respectively; f_s is the sampling frequency, also known as the switching frequency of the semiconductor valve.

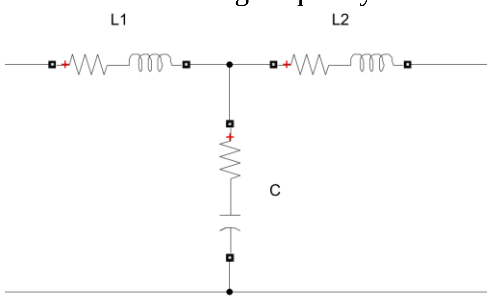

Figure 3. *LCL filter in Simulink*

The total inductance value of the filter is determined by equation (2) based on the condition of the maximum voltage drop across the inductor, which is limited to about 10% of the rated grid voltage V_{grid}:

$$L_1 + L_2 = \frac{10\% V_{grid}}{2\pi \times I_{out} \times f} = \frac{10\% V_{grid}}{2\pi \times \dfrac{S}{V_{grid}} \times f} = \frac{10\% V_{grid}^2}{2\pi \times S \times f} \quad (2)$$

Where: S and I_{out} are the output power and current of the inverter, respectively, with the grid frequency f.

From there, the value of inductor L_2 is determined:

$$L_2 = \frac{10\% V_{grid}^2}{2\pi \times S \times f} - L_1 \tag{3}$$

The filter capacitor is designed to limit the variation of the reactive source. The reactive power absorbed by the filter capacitor is limited to 5%*S*. A small capacitance will reduce the attenuation of the LCL filter, while a high value leads to resonance in the inverter. This value is calculated from (4):

$$C = \frac{Q}{2\pi \times V_{grid}^2 \times f} = \frac{0,05S}{2\pi \times V_{grid}^2 \times f} \tag{4}$$

During the calculation, the resonant frequency of the LCL filter is calculated using equation (5) and should be in the range (6). The L_2 side inductor value should only be a part of L_1 to ensure stability and limit, according to IEEE 519 [11]. The parasitic resistance of inductors and capacitors can be ignored since their values in the filter are relatively small and do not affect too much energy loss and voltage drop. In addition, the selection of element values must satisfy the resonant frequency value as (5):

$$f_{res} = \frac{1}{2\pi}\sqrt{\frac{L_1 + L_2}{L_1 \times L_2 \times C}} \tag{5}$$

$$10 f_g \langle f_{res} \langle 0,5 f_s \tag{6}$$

LCL filters may contain a shock-reducing resistor R_d to avoid resonances and have a value of one-third of the impedance of the filter capacitor. Shock absorbing resistors are placed in parallel or series with the filter capacitor.

$$R_d = \frac{1}{3} \times \frac{1}{2\pi \times f_{res} \times C} \tag{7}$$

3.2. LLCL Type

A high-performance source filter topology for mains voltage power inverters is called LLCL to improve high-order harmonics rejection [12], [13]. Based on the traditional LCL filter, a small inductor is added into the branch loop of the capacitor, as shown in figure 4, creating a series resonant circuit at the switching frequency fres. This filter model can better attenuate switching frequency current ripple components than the LCL filter.

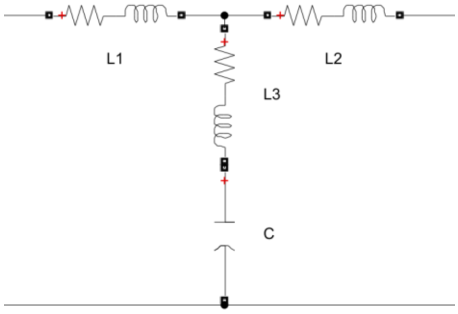

Figure 4. *LLCL filter in Simulink*

The constraints of the LCL and LLCL filters are the same [8]. So the values of L_1, L_2, and C are chosen to be the same with LCL. Reactive power limit corresponding to equations (1), (2), (3), and (4). There is one more inductor L_3 connected in series with capacitor C, the resonant frequency fres in equation (5) is calculated as:

$$f_{res} = \frac{1}{2\pi}\sqrt{\frac{L_1 + L_2}{L_1 \times L_2 \times C}} = \frac{1}{2\pi\sqrt{L_3 \times C}} \tag{8}$$

The inductance value L_3 is found based on (9):

$$L_3 = \frac{1}{(2\pi \times f_{res})^2 \times C} \tag{9}$$

The total resonant frequency of the filter of LICL type is shown in (10):

$$f_{res\_total} = \frac{1}{2\pi\sqrt{\frac{L_1 \times L_2}{L_1 + L_2} \times L_3 \times C}} \tag{10}$$

Similar to the LCL filter, the shock damping resistance R_d of the LLCL filter is determined:

$$R_d = \frac{1}{3} \times \frac{1}{2\pi \times f_{res\_total} \times C} \tag{11}$$

4. Simulation Results

To accurately evaluate the filter efficiency, the calculation and simulation are guaranteed to be performed under the same conditions summarized in Table 2.

Table 2. *Filter parameters*

Factor	LCL	LLCL
L1	648.5 μH	648.5 μH
L2	3.08 μH	3.08 μH
C	19.73 μF	19.73 μF
Fres	1584 Hz	1584 Hz
L3	/	511.69 μH
Fres'	/	1120 Hz
Rd	1.7Ω	2.4Ω

For the LCL filter type, results of the output current waveform are shown in Figure 5. The current can be seen before passing through the filter corresponding to the green line with high flicker due to the wave components. That is because harmonics have not been removed and can hardly be supplied to the load. After power has passed via the filter, the red response shows that most of the higher-order harmonics have been eliminated, but the peak is still distorted due to the inability to remove all the harmonics.

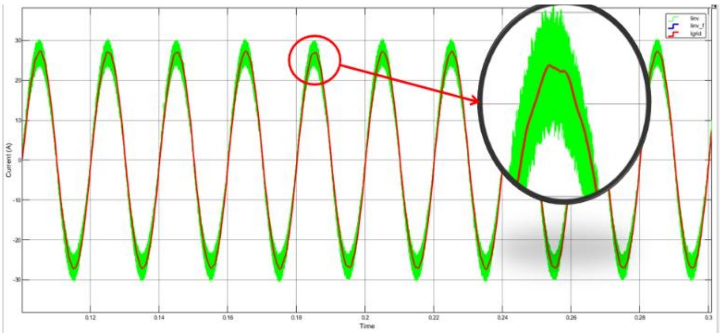

Figure 5. *Output current waveform of inverter with LCL filter*

Similarly, with the LLCL filter, when the current has not passed, the green current wave represents the result before filtering, and the red response is the current after passing the harmonic filter in the figure 6. The output waveform is obtained as close to the standard sine. At the same time, the wave peak does not have as significant distortion as the LCL filter.

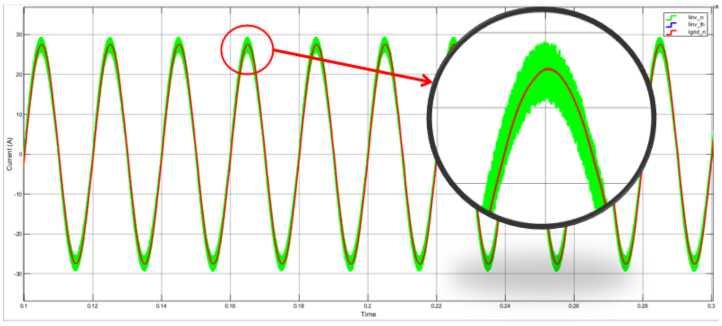

Figure 6. *Output current waveform of inverter with LLCL filter*

The difference in output response between the two filters is shown in figure 7 determines the effective filtering level of LLCL compared with LCL. Green response in case of using LLCL filter near the standard response in blue line and the deviation is almost zero. Meanwhile, the red response of the LCL filter, whose amplitude is lower than the standard value in unison, can see the wave deflection of the current to be able to see in more detail. The distribution of harmonic components (THD) can be observed in figure 8.

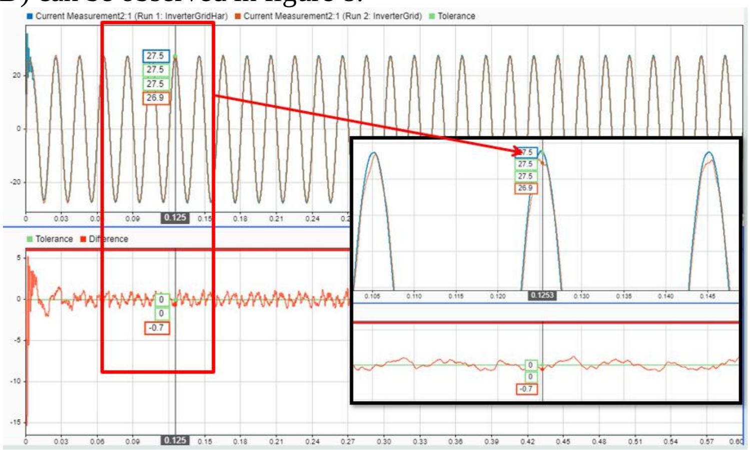

Figure 7. *Differential output current value before and after filter improvement*

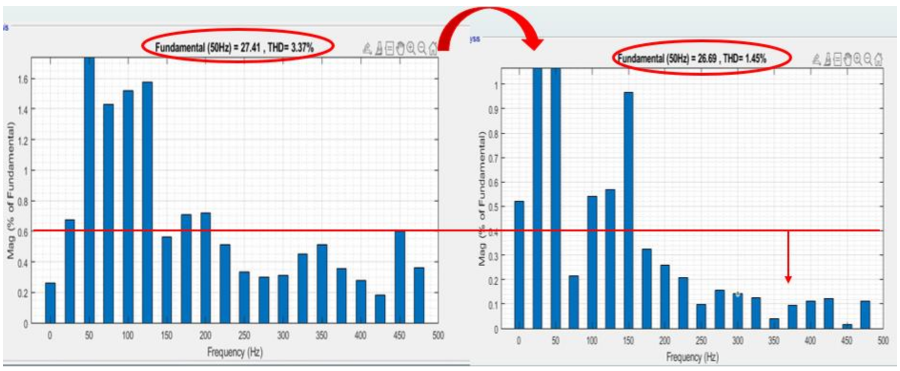

Figure 8. *THD comparison between LCL and LLCL filters*

The harmonic distribution again shows the filtering quality of the LLCL. THD level achieved is 1.45% compared to 3.37% of the LCL. Considering IEEE 519-1992 and IEC 61000 [11]-[14], the allowable THD level for voltages below 1kV is 5% and below 69kV is 3%. However, many countries still require the 3% limit. With this condition, the grid-tied inverter with the LCL filter can hardly meet the requirements for grid-connected power quality. In addition, with the 2nd harmonic, the most dangerous component for the system, LLCL gives better filter quality and other harmonic orders.

5. Conclusion

This paper has designed a grid-tied single-phase inverter model using Matlab/Simulink integrating different types of harmonic filters for rooftop PV systems. With rooftop PVs always affected by unpredictable weather conditions that make the energy output dynamic, the construction model maintains voltage and current stability through the converter.

The careful selection of the filter element and the simulation results have shown that the performance of the proposed LLCL filter is improved from the LCL filter. The level of waveform distortion caused by harmonics is almost eliminated, and the TDH value meets IEEE/ANSI and IEC grid connection standards. However, research to improve power quality for installed PV systems needs to be further developed in terms of inverter control and considering three-phase inverters for applications with larger power sources.

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