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Simulation Of Filter And Load Influence On Single Phase Inverter Against Voltage And Current Harmonic

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***Abstract*—The inverter using for power supply provides constant voltage, current and frequency generation advantage although there are changes in the load. However, inverter has weakness too. It will generate large harmonic. To get a high efficiency from an inverter, a sinusoidal voltage output is needed and total harmonic distortion (THD) is minimized. Several factors influence the harmonic magnitude on 1 phase inverter, namely load type and presence of filter. This study discussed about simulation of 1 phase inverter with and without LC filters, using R and RL series load type against voltage (V) and current (I) THD. The study results with LC filter and series RL load indicated THD reduction. The LC filter installation did not only affects harmonic reduction only but also output voltage and current of load.**

Keywords—single phase inverter, harmonic, LC filters, R and RL series load

I. Introduction

Now days, the utilization of inverter cannot be separated from several types of power sources. One of them is Uninterruptible Power Supply (UPS) [1]. UPS is widely used to back up important and critical loads [2]. UPS is a backup power source that its power comes from batteries. In UPS, DC voltage from battery is converted to AC voltage through inverter. So that, it can replace the power supply from grid [3].

Comparing with electrical supply from grid, inverter for power supply provides a number of advantages. These advantages are constant voltage, current and frequency even though any changes in load. But a new problem arises, the emergence of bigger harmonic when compared with grid.

High-efficiency inverters require a sinusoidal output voltage and minimal total harmonic distortion (THD). The ideal inverter output voltage is pure sinusoidal waves. The high efficiency of an inverter will affect its output voltage. The power quality of the inverter itself is affected by harmonics. Harmonics are affected by the load. Therefore, the effect of harmonics must be taken into account in maintaining the quality of power output.

There are several control methods for performance improvement of inverter. One of them is Pulse Width Modulation (PWM). The implementation of PWM control is pulse signal generation form. In addition, harmonic reduction can also be conducted through harmonic filters [4]. Based on the description above, this study was conducted with aim to determine load effect on harmonics and design a passive filter to reduce harmonics on single phase inverter.

II. Theory

Inverter is an electronic device that can convert DC voltage into AC voltage with adjustable voltage and frequency. Today, inverters have an important role in the conversion of energy from renewable sources. Inverters cannot be separated from distributed generation (DG) system based on renewable energy sources [5]. Distributed generation includes small generators which are directly connected to the load [6,7,8]. The inverter topology can be half or full bridge. For a full H-bridge, it has two legs. Each legs consists of two power semiconductor switches namely MOSFET or IGBT [9].

PWM is widely implemented in variable speed drives at industry. Sinusoidal Pulse Width Modulation (SPWM) is the most commonly used PWM method in voltage source inverters. In SPWM generation process can use two types of signals, sinewave signals and triangular signals. In the process, the amplitude ratio between of the two signals is done [10]

MOSFET has similar characteristics with transistors. MOSFET has three terminals named Source (S), Drain (D), and Gate (G) [3]. Unlike the transistor, commutation controlling of MOSFET through the gate voltage (V_{GS}). While the transistor through the base current (I_b).

Harmonics are disturbances that occur in an electrical system due to distorting current and voltage waves. If the basic frequency of an electric power system is 50 Hz, the second, third and next harmonics have a frequency with 100 Hz, 150 Hz and its multiples [11]. The harmonics wave hitched a ride on original wave so that it produced a defective wave.

The Total Harmonic Distortion (THD) can be analyzed using Fourier series approach. The voltage and current in time function are formulated through (1) and (2) below.

$$v(t) = V_0 + \sum_{n=1}^{\infty} V_n \cos(n\omega t + \theta_n) \quad (1)$$

$$i(t) = V_0 + \sum_{n=1}^{\infty} I_n \cos(n\omega t + \theta_n) \quad (2)$$

The rms voltage and current of sinusoidal wave is wave peak value divided by $\sqrt{2}$ as shown in (3) and (4).

$$V_{rms} = V_0^2 + \sqrt{\sum_{n=1}^{\infty} (\frac{V_n}{\sqrt{2}})^2} \quad (3)$$

$$I_{rms} = V_0^2 + \sqrt{\sum_{n=1}^{\infty} (\frac{I_n}{\sqrt{2}})^2} \quad (4)$$

The value of THD can be found using the following equation in (5).

$$THD = \frac{\sqrt{\sum_{h>1}^{h\,max} M_h^2}}{M_1} x100 \quad (5)$$

M_h is the rms value of harmonic h of the quantity M [11].

The main components of passive filter are inductor (L) and capacitor (C), both connected in series or parallel. At certain frequency, filter circuit can be tuned. Passive filter which is used as harmonic filter serves to reduce amplitude of one or more specific frequencies of voltage or current.

To determine the value of inductor and capacitor components, the cut-off frequency value must be determined previously. The multiplying result of system basic frequency with the n^{th} harmonic will produce a cut-off frequency. Meanwhile, the resonance frequency of the AC circuit is determined by (6) as shown below [12].

$$f_r = \frac{1}{\sqrt{LC}} Hz \quad (6)$$

In non-linear loads, the output waveform is not same with input waveform. This is due to absorption of current waves that are not sinusoidal. Examples of linear loads include rectifiers, inverters, chargers and variable speed drives [12].

III. Simulation Data

The data for simulation in this research are:

1. The input voltage is 100 Vdc.
2. The parameter of PWM block are modulation index of 1 with 10 kHz carrier frequency of and 50 Hz output frequency.
3. Resistive loads are 50 ohm, 100 ohm and 1000 ohm.
4. Inductive loads are 2.3 mH, 10 mH and 50 mH installed in series with 50 ohm resistive load.
5. The design of LC filters accordance with the harmonic characteristics is starting with determination of cut-off frequency based on the results of the filterless simulation, then determining capacitor and inductor values based on (6).

The fundamental frequency for harmonic analysis is 50 Hz. The parameters that have been determined and tested through a simulation. The result is compared to gain a good filter for harmonics reduction.

IV. Models

The diagram block of single phase inverter simulation to determine the load effect and utilization of filter against harmonic is shown in Fig. 1 below.

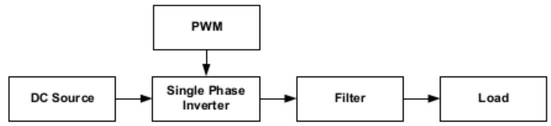

Fig. 1. Diagram block of simulation

The inverter circuit used in this research is a full bridge. The input is DC voltage source. The inverter uses 4 MOSFETs with switching function to produce an output signal. This simulation design uses PWM with SPWM technique. The simulation circuit without and with LC filter is shown in Fig. 2 and Fig. 3, respectively.

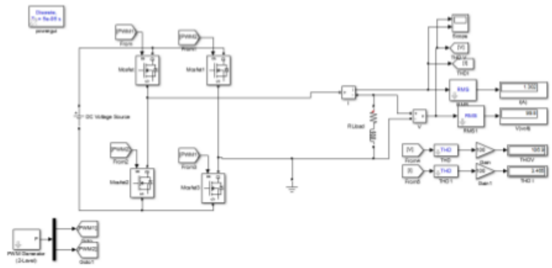

Fig. 2. Model of inverter without LC filter

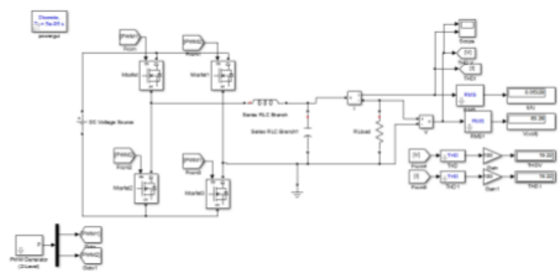

Fig. 3. Model of inverter with LC filter

V. Simulation Result Without Filter

A. R Load

The result for simulation with resistive load is shown as Table I below.

TABLE I. RESULT WITH R LOAD

No	R (ohm)	Vo (V)	Io (A)	THDV (%)	THDI (%)
1	50	99.6	1.922	106.6	106.6
2	100	99.8	0.988	106.6	106.6
3	1000	99.8	0.0998	106.6	106.6

The simulation results show that THDV and THDI values are same, 106.6%. The load changes did not affect the THD value, but affect to output voltage and current. For resistive load R=50, 100 and 1000 ohm, the highest harmonics percentage at the third order (frequency = 150 Hz), which is 3.35% for THDV and THDI.

B. RL Load

The result for simulation with RL load is shown as Table II below.

TABLE II. RESULT WITH RL LOAD

No	L (mH)	Vo (V)	Io (A)	THDV (%)	THDI (%)
1	2.3	99.70	1.415	106.9	27.85
2	10	99.79	1.365	106.9	8.553
3	50	99.80	1.302	106.9	3.465

For series RL loads, the values of THDV and THDI are not same. The value of THDV does not change even though any changes of inductance load value. THDI value changes similar with the value change of inductance load. The highest percentage of harmonics with a series RL load occurs in third order (frequency = 150 Hz), which is 3.35% for THDV and 3.35% for THDI

C. Comparison of THDI between R Load and RL Load

The comparison of THDI and THDV between R and RL load is shown nin Fig. 4 and Fig 4, respectively. The graphs show the influence of load to THDI and THDV. The graphs shows that THDI with a series RL load is lower than the R load

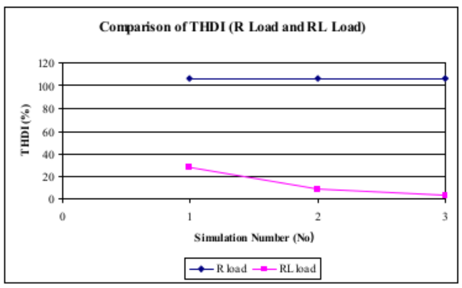

Fig. 4. Comparison of THDI (%) with R Load and RL Load

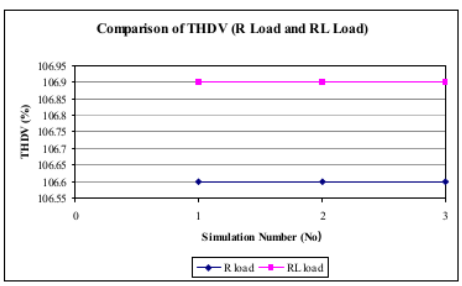

Fig. 5. Comparison of THDV (%) with R load and RL load

VI. SIMULATION RESULT WITH LC FILTER

From the test conducted without a filter, it was concluded that the cut-off frequency was 150 Hz. The LC filter value is shown at Table III below.

TABLE III. LC FILTER VALUE

No	L(mH)	C(µF)
1	80	14
2	100	11
3	150	7

A. With R Load

The result for simulation with resistive load is shown as Table IV below.

TABLE IV. RESULT OF THE INVERTER WITH FILTER

No	R (ohm)	Vo (V)	Io (A)	THDV (%)	THDI (%)
L= 80 mH and C = 14 µF					
1	50	66.74	1.335	2.477	2.477
2	100	73.91	0.7391	4.286	4.286
3	1000	81.95	0.08195	37.21	37.21
L= 100 mH and C = 11 µF					
1	50	62.54	1.251	2.14	2.14
2	100	72.27	0.7227	3.557	3.557
3	1000	80.13	0.08013	30,43	30,43
L= 150 mH and C = 7 µF					
1	50	52.48	1.050	1.728	1.728
2	100	67.44	0.6744	2.610	2.610
3	1000	77.59	0.07759	19.24	19.24

From the results, it can be seen that the LC filter is able to reduce THDV and THDI to 1.728% at load R = 50 ohms with filter values L = 150 mH and C = 7µF. The results also show that with LC filters, load value affects the harmonics. If load value increase, harmonics value also increase too (for the same LC filter).

B. With RL load

The simulation is performed using LC filters with L and C values according to Table III. The R load is 50 ohms, series with L load. The simulation results are shown in Table V below.

TABLE V. RESULT OF THE INVERTER WITH FILTER

No	L (mH)	Vo (V)	Io (A)	THDV (%)	THDI (%)
L=80 mH and C = 14 µF					
1	2,3	66.33	1.326	2.507	2.504
2	10	65.06	1.299	2.665	2.604
3	50	60.44	1.153	4.619	3.143
L=100 mH and C = 11 µF					
1	2,3	62.12	1.242	2.168	2.165
2	10	60.82	1.214	2.315	2.258
3	50	56.26	1.073	4.447	2.911
L=150 mH and C = 7 µF					
1	2,3	52.11	1.042	1.752	1.749
2	10	50.97	1.017	1.874	1.821
3	50	47.21	0.9004	3.717	2.347

From the research result, it can be seen that a good value of filter to reduce harmonic at RL series load is L = 150mH and C = 7 µF

VII. COMPARISON OF THDI AND SIGNAL OUTPUT WITHOUT FILTER AND WITH FILTER

The Fig. 6 and Fig. 7 show the comparison of THDI dan THDV (with and without filter). The value of L = 150 mH and C = 7 µF on RL series load.

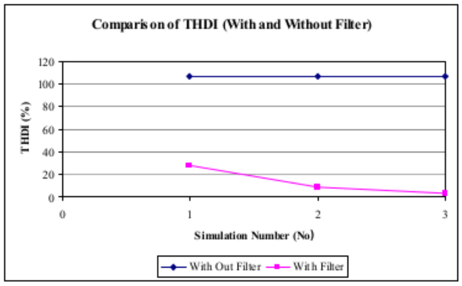

Fig. 6. Comparison of THDI (%) without filter and with filter

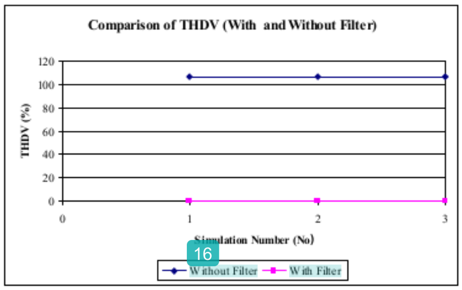

Fig. 7. Comparison of THDV(%) without filter and with filter

The Fig. 8 and Fig. 9 show the waveform comparison of output voltage and current (with and without filter). From the two figures it can be seen that the output signal with filter approaches sinusoidal while the output signal without filter is still in the form of boxes.

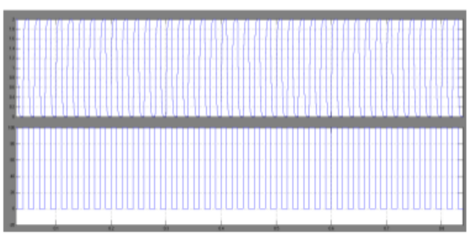

Fig. 8. Output voltage and current waveform of the inverter without filter

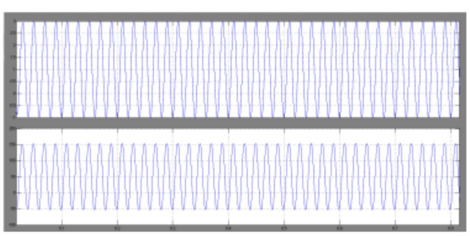

Fig. 9. Output voltage and current waveform of the inverter with filter

VIII. CONCLUSION

Based on result research that has been conducted, it can be concluded that type of loads is very influential on the amount of THD. Inductor load will make the THDI decrease. The installation of passive LC filters can reduce harmonic significantly.

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