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Simulation of Load Variation Impacts on a Delta Modulated Inverter

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SIMULATION OF LOAD VARIATION IMPACTS ON A DELTA MODULATED INVERTER

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Simulation of Load Variation Impacts on a Delta Modulated Inverter

Imran Azim [α] & Habibur Rahman [σ]

Abstract - A new concept of identifying the most preferable load to be connected in a single phase full bridge inverter undergoing delta modulation has been provided in this paper. The best load is selected depending on the minimized Total Harmonic Distortion (THD) that depicts the presence of little amount of harmonics at the output response of the inverter as it is undisputedly the case that harmonics cause some perilous effects including unbalance and excessive neutral currents, interference in nearby communication networks and disturbance to other consumers, torque pulsations in electric motors and so forth. This paper reveals that a full bridge inverter operates more precisely with RC load having only 0.4084% THD as compared to RLC load and RL load. As a consequence, based on this, RC load has been considered as the most likely used load.

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I. Introduction

Inverter can be referred to dc-to-ac converter which changes a dc voltage to a symmetric ac output voltage of desired magnitude and frequency [1].

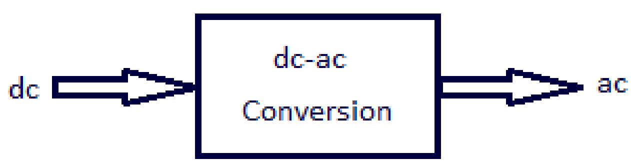

Figure 1 : General Block Diagram of Inversion Process

Inverters can be broadly classified into two types such as single phase inverters and three phase inverters. The output voltage could be fixed or variable at a fixed or variable frequency. A variable output can be obtained by varying the input dc voltage and maintaining the gain of the inverter constant. The output waveforms of an ideal inverter should be sinusoidal. However, the waveforms of practical inverters are non-sinusoidal and contain certain harmonics which can be seen with ease in frequency domain. Due to the availability of high speed power semiconductor devices, the harmonic contents of output voltage can be minimized or reduced significantly by switching technique. BJTs, MOSFETs or IGBTs can be used as ideal switches to explain the power conversion techniques. But IGBT is more popular as it combines the advantages of BJTs and MOSFETs. An IGBT has high input impedance, like MOSFETs, and low on state conduction losses like BJTs.

Some typical applications in which inverters may pay a pioneering role are variable speed ac drives, induction heating, standby power supplies, uninterruptible power supplies(UPS), traction, HVDC and so on. [2].

Delta modulation also known as hysteresis current control is a kind of instantaneous feedback control model. The basic idea is to compare the given current signal which is detected by the converter with actual inverter current signal [3].

Total Harmonic distortion (THD) can be defined as the ratio of the RMS value of all odd number of non fundamental frequency terms to the RMS value of the fundamental.

Mathematically

$$THD = \sqrt{\frac{\mathrm{Im}^2 - \mathrm{Im}_1{}^2}{\mathrm{Im}^2{}_1}} \qquad (1)$$

Where, Im_1 is the RMS value of fundamental current component and I'm is the RMS value of current components.

It goes without saying that THD measures closeness in shape between an original current waveform and the assumed fundamental current component [4].

First Fourier Transform (FFT) is a linear algorithm that can take a time domain signal into the frequency domain and back. Fourier analysis allows a more intuitive look at an unknown signal in frequency domain helping to perceive the fundamental component and the harmonic components without cumbersome [5].

II. Single Phase Full Bridge Inverter

A single phase full bridge voltage source inverter shown in Figure 2. consists of four choppers. When transistors Q_1 and Q_4 are turned on simultaneously, the input voltage V_i appears across the load. If Q_2 and Q_3 are turned on at the same time, the voltage across the load is reversed and is $-V_i$. Again, when Q_1 and Q_2 are on they give 0 voltages across the load. Moreover, the same result is obtained if Q_3 and Q_4 are turned on [6].

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Undoubtedly, there must a dead time between the switches in order to eschew the shorting out of dc source [7].

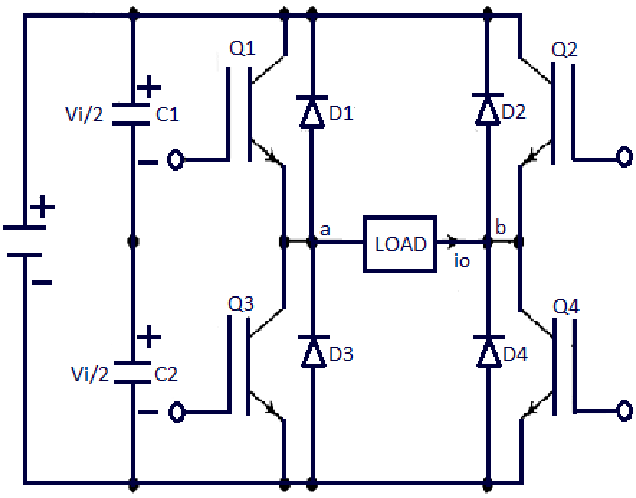

Figure 2 : Circuit Diagram of a Full Bridge Inverter

Instantaneous inverter output current,

$$io = \sum_{n=1}^{\infty} 4 \frac{V_i}{n\pi\sqrt{Z^2}} \sin(nwt - \theta n) \qquad (2)$$

Where, Z is the load impedance and θn is the lagging or leading angle depending upon the connected load.

III. Delta Modulation

Current controlled inverters having delta modulation are used in many low and medium voltage utility applications when the inverter line current is required to track a sinusoidal reference within a specified error margin. Line harmonic generation from those inverters depends principally on the particular switching pattern applied to the valves. The switching pattern of delta modulated inverters is produced through line current feedback and it is not pre-determined unlike the case, for instance, of Sinusoidal Pulse-Width Modulation (SPWM) where the inverter switching function is independent of the instantaneous line current and the inverter harmonics can be obtained from the switching function harmonics.

The inverter line current Io, in Figure 3. Tracks a sinusoidal reference $i_{ref} = \sqrt{2}\, I_{ref} \sin(wt)$ through relay band action and fundamental frequency voltage at the inverter ac terminals when the line current equals the reference current is the reference voltage [8].

The difference between the reference current and the actual output current is called error current illustrated in Figure 3.

Figure 3 : Pictorial Representation of Error Current [8]

If the actual current is more than the given value, then it is decreased by changing the switching state and vice versa. So, the actual current changes around the reference current waveform and delta current control make the deviation within a certain range shown in Figure 4 [9].

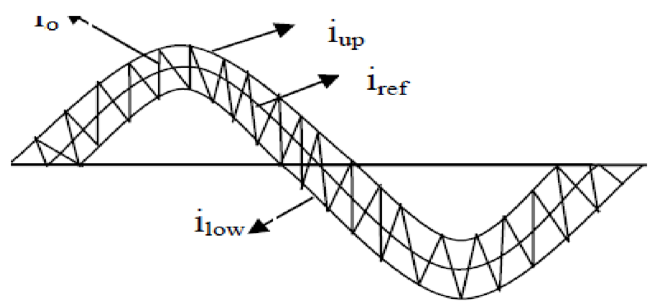

Figure 4 : Delta Modulation Structure [10]

Mathematical expression of Error current is

$$e_o(t) = i_{ref}(t) - i_o(t) \qquad (3)$$

The hysteresis or delta modulation for power electronic converters are preferred for applications, where performance requirements are more demanding such as to achieve good dynamic response, unconditional stability, and wide command-tracking bandwidth [11].

IV. Simulation Under Different Loads

It is assumed that input voltage is 440 V. Other necessary parameters are considered deliberately like R=10 Ohm, L=0.32 H, C=100F and frequency, f=50 Hz with assuming up to 5th harmonics prevalent at the output so as to plot [Equation 2]

a) Resistive Load ($Z^2=R^2$)

To begin with, resistive load is connected ignoring the harmonics. According to the illustration, Figure 5. and Figure 6. Deal with the inverter output voltage in time domain and frequency domain respectively when only resistive load is considered. Due to the absence of harmonics, the output is purely sinusoidal.

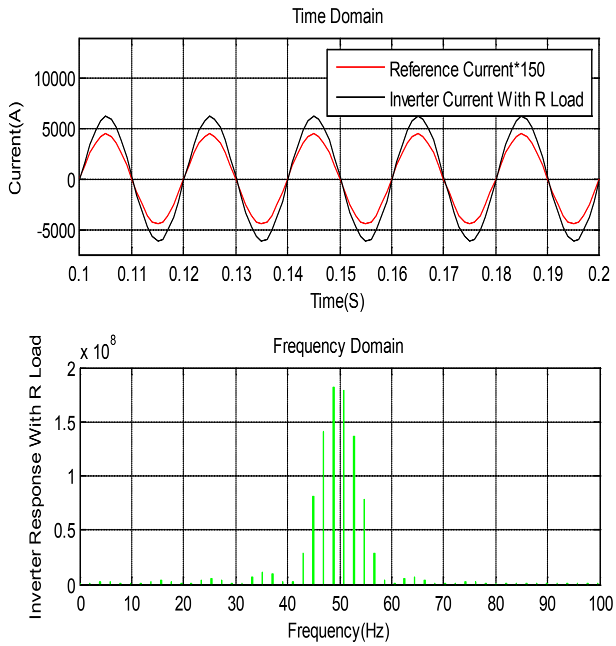

Figure 5 : Inverter Response with R Load

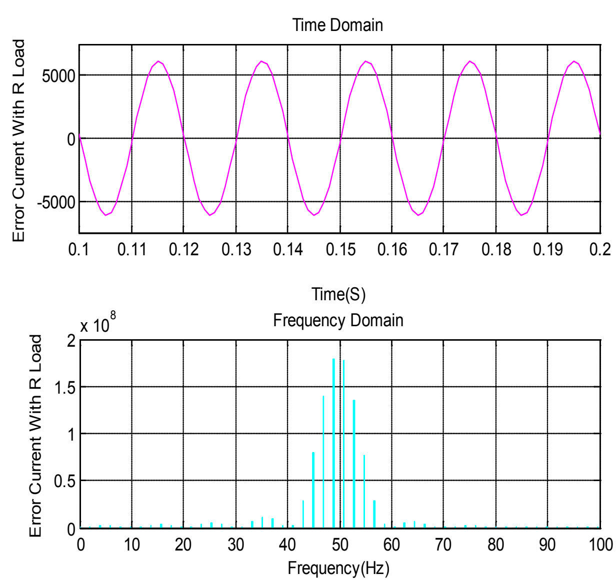

Figure 6 : Error Current With R Load

From [Equation 1] Calculated THD= 0%
Therefore, it resembles to the ideal case.

b) RL Load($Z^2=R^2+(nwL)^2$)

Secondly, RL load is connected so as to observe the response under harmonic components. Figure 7. and Figure 8. reveal the response of delta modulated current controlled inverter with RL load meaning thar the considered harmonics are present. Using [Equation 1] under these circumstances THD is evaluated and is found 39.7053% which is not satisfactory at all. Therefore, it is needless to say that the avoidance of harmonics is rquisite for better performance.

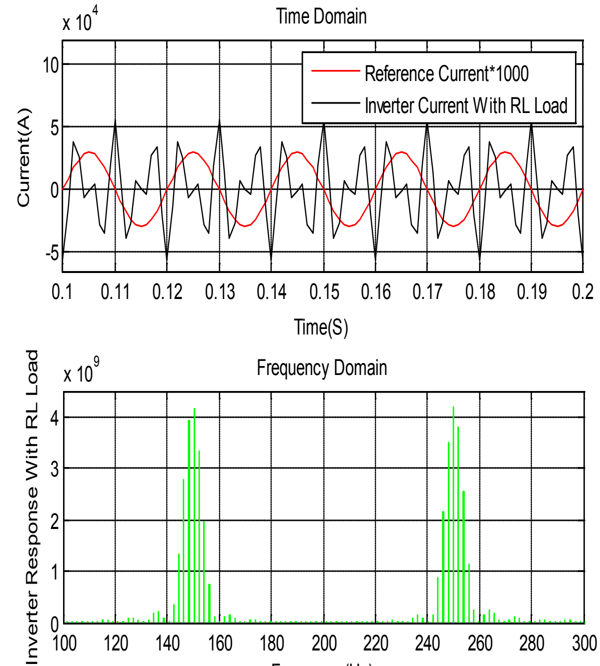

Figure 7 : Inverter Response with RL Load

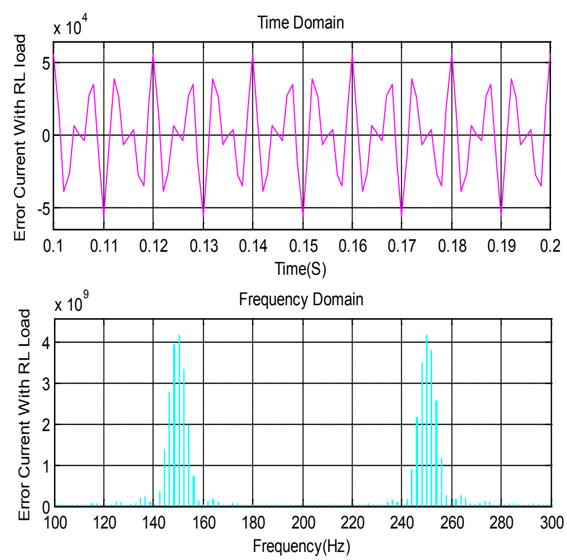

Figure 8 : Error Current With RL Load

c) RLC Load($Z^2=R^2+(nwL-1/nwC)^2$)

Afterwards, the implementation of an RLC load having LC at the inverter ac terminals could trigger a parallel resonance which tends to amplify the harmonic voltages and currents in ac network leading, in some cases, to potential harmonic instabilities owing to the fact that the capacitance has a profound impact on the harmonic performance. This capacitance brings the harmonics into a lower state [12].

As far as Figure 9. and Figure 10. are concerned, not only close to sinusoidal time domain output response is obtained but also the received error current response is nearly sinusoidal and in each case it is noticed that the fundamental component has the highest amplitude.

[Equation 1] is once again utilized and calculated THD is 2.0416%. So, without a hint of doubt a vast improvement has been noticed.

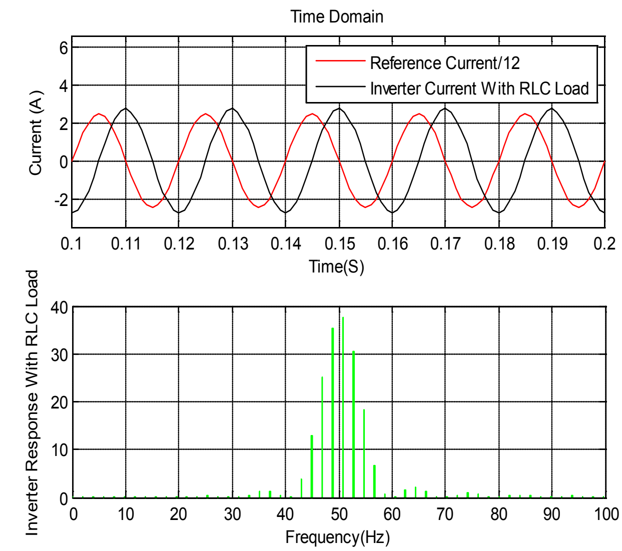

Figure 9 : Inverter Response with RLC Load

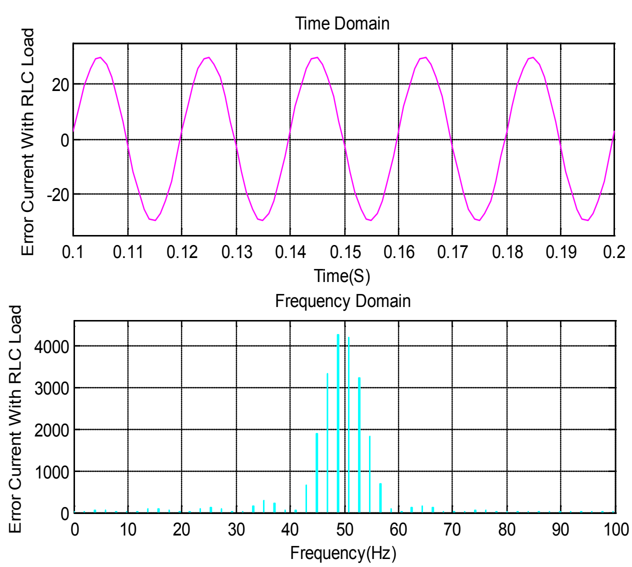

Figure 10 : Error Current with RLC Load

d) RC Load($Z^2=R^{2+}(-1/nwC)^2$)

To end with, for visualizing the effects of load capacitance in more precise and flawless manner, RC load is appended across the inverter terminal.

Figure 11: demonstrates the inverter output response whereas error current response has been portrayed in Figure 12. More importantly, almost sinusoidal waveforms have been found in both the cases implying lower existence of the harmonics at the output terminal.

In this circumstance, the evaluated THD is 0.4084% which is satisfactory indeed and this load is simply the most desired one among the loads observed under practical conditions indicating the presence of unwanted components regarded as harmonics.

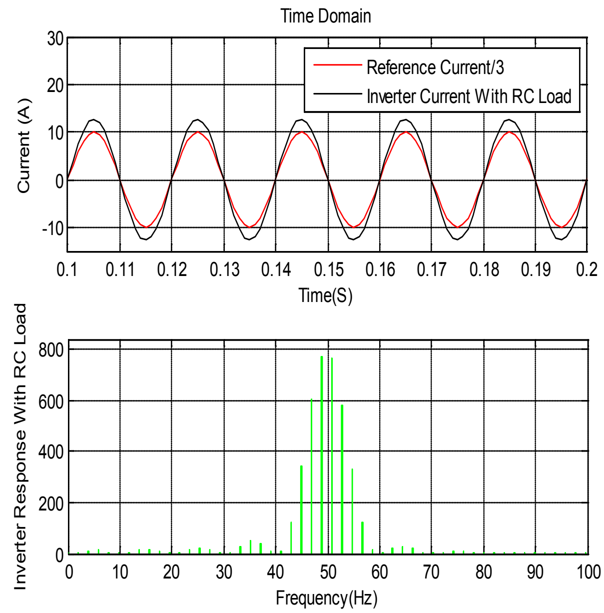

Figure 11 : Inverter Response with RC Load

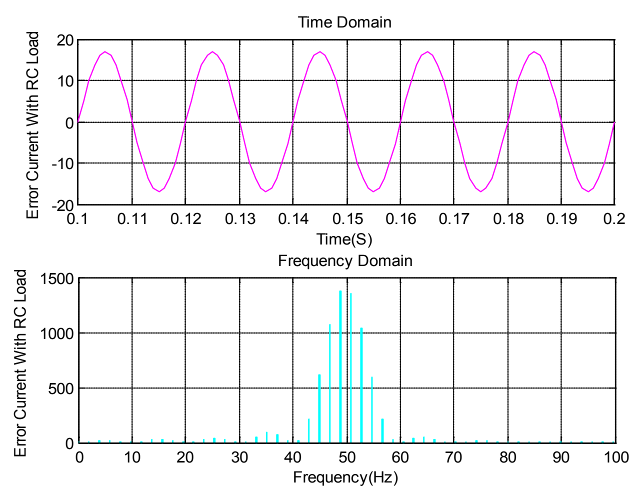

Figure 12 : Error Current with RC Load

V. Result and Discussion

Table I : Performance Comparison

Load	THD	Comment
R	0%	No Harmonics
RL	39.7053%	Harmonics
RLC	2.0416%	Improved
RC	0.4084%	Preferable

As is observed in Table-I, under R load, THD is 0% referring no harmonics but in practical it is not possible. In second case, too much harmonics close to

40% prevail which is not desirable by any means although this has been improved if RLC load is used. Finally, more convincing result has been obtained when it comes to append an RC load. This time THD has been dropped to under 0.5% that can be tolerable in practical case. Thence, there is no denial to say that RC load is the best one in practical case.

In future, besides changing loads, an LC low pass filter can be added if there exists more than accepted amount of harmonics. This is due to the fact that this filter is capable of triggering a parallel resonance tending to amplify the harmonic components in an ac network.

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