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A simple variable THD load emulation technique for performance evaluation of power supply equipment

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Using load emulation, the performance of source side converters can be easily evaluated and improved without the need for actual load. Due to the increase in use of power electronic converters and SMPS based systems, the harmonic levels in load side has increased considerably. Hence emulation of variable THD load is very important in analysing the performance of source side converters and ensure the performance efficiency and power quality under such loads. Here a novel method of obtaining variable load using PWM control explained. The PWM is controlled in a rainbow sinusoidal fashion to obtain clipped waveform across a resistor so that harmonics is introduced in the Load. The power factor can also be varied in the system by paralleling it with leading and lagging converter circuits. The working principle, modelling and simulation are presented along with the results. Proposed technique provides accurate modulation of load THD and effect of harmonics loads on sources converter are also analysed using this.

Keywords: *Load Emulation, harmonic loads, current clipping*

1.0 INTRODUCTION

Use of power electronic converters and SMPS on utility side increases the amount of harmonics in the power system. When it comes to standalone applications like solar PV or wind generators, these harmonic loads reduces the performance of the system to a great extent. In order to avoid this, such systems should be tested under nonlinear loads and suitable design modifications should be made. If a particular source to be used for specific applications like pump load or electric vehicles their performance should be always tested under that load particular characteristics, so that maximum efficiency and optimized performance can be obtained. Load emulation is a very effective technique which can be used for this purpose.

Emulation is the process by which actual load is replaced by a flexible system which is mechanical Electrical or electronic in nature. For stand alone renewable energy sources Power Electronics load emulation is the most suitable one due to the issue of control and flexibility. Using the existing models of back to back converter it is difficult to obtain variable THD load along with power factor variation. Total harmonic distortion is the amount of disturbance in the sinusoidal waveform due to the manipulation of current indifferent electrical equipments. This will cause malfunctioning of source side converters, reduced efficiency, unwanted heating etc. This can be avoided by design modification of source converters using variable THD load emulation.

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This paper presents a novel method for emulation of Harmonic load mainly for testing and performance improvement of source side converters. The theory of calculation of THD from wave shape is explained in section 2. The concept of load emulation and development of the proposed variable THD load emulation are explained in section 3. Section 4 and 5 give the simulation studies and analysis of results respectively.

2.0 TOTAL HARMONIC DISTORTION

Ideal voltage and current waveforms in alternating quantity are sinusoidal functions. When there is dispersion in the sinusoidal function the repeating waveform can be represented as a combination fundamental sinusoidal wave and n number of sinusoidal waves with frequency of integral multiple of fundamental waveform. These components are called harmonics, and the magnitude of each harmonic component depends upon the amount of distortion from the originals sinusoidal wave. Total harmonic distortion, or THD, can be defined as the summation of all harmonic components of the voltage or current waveform with respect to the fundamental component of the voltage or current wave.

$$THD = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + \ldots}}{V_1} \quad \ldots.(1)$$

Where V_1 is the fundamental frequency component and V_2, V_3, V_4… are 2nd, 3rd, 4th harmonics and so on.

THD is mainly caused by non linear loads which modulate the current shape like,

- Electronic lighting ballasts/Controls
- Adjustable speed Motor-Drives
- Solid state Industrial Rectifiers
- Industrial Process Control Systems
- Uninterruptible Power Supplies(ups)systems
- Inductors or Transformers under saturation
- Computer Networks

2.1 Calculation of THD

The harmonic components and THD of a repeating sequence is obtained by developing the Fourier series of the same as follows.

If the repeating sequence f(t) has time period T, frequency f, then Fourier series

$$f(t) = \frac{1}{2}a_0 + \sum_{n=1}^{\infty}\{a_n \cos(n\omega t) + b_n \sin(n\omega t)\} \quad \ldots.(2)$$

For n=1,2,3…∞

Where,

$$a_n = \frac{1}{\pi}\int_0^{2\pi} f(t)\cos(n\omega t)d(\omega t) \quad n=0,1,2,\ldots\infty \quad \ldots.(3)$$

$$b_n = \frac{1}{\pi}\int_0^{2\pi} f(t)\sin(n\omega t)d(\omega t) \quad n=0,1,2,\ldots\infty \quad \ldots.(4)$$

$$a_0 = \frac{1}{2\pi}\int_0^{2\pi} f(t)dt \quad \ldots.(5)$$

For each value of n, a sinusoidal wave of frequency n times the fundamental frequency is obtained. This is called the nth harmonic of the sequence. Figure 1 shows a square wave as a sum of sine waves with fundamental frequency and multiples of fundamental frequency.

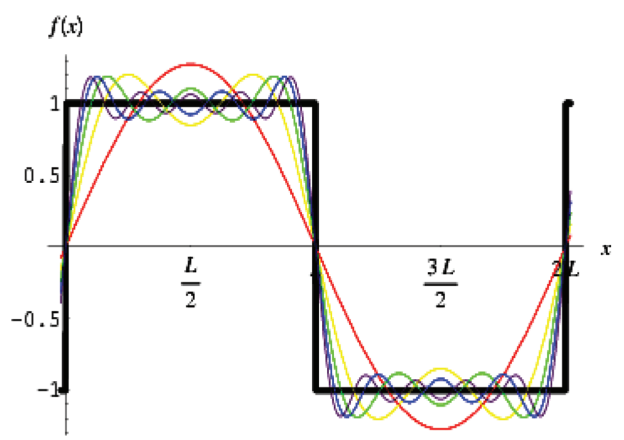

FIG. 1 THD IN SQUARE WAVEFORM

2.2 Effect of Harmonic loads

Figure 2 shows typical input and output Voltage and current waveforms on an inverter under test. The input current is supposed to be pure DC but distortion is due to the converter operation [3].

- Overheating and failure transformers parts.
- Increasing iron and copper losses
- Mechanical oscillations in the motor-loads
- False operation of circuit breakers.
- Power factor correction capacitor failure
- Change in impedance of capacitor bank
- Malfunctioning of voltage regulator.
- Dielectric failure or rupture the power factor correction capacitors
- Error in readings of meters
- Malfunctioning and reduction of efficiency in source side converters. Figure 2 shows the reduction in efficiency of solar PV inverter under non-linear load of 20% THD obtained by experimental analysis on 1 kVA inverter.

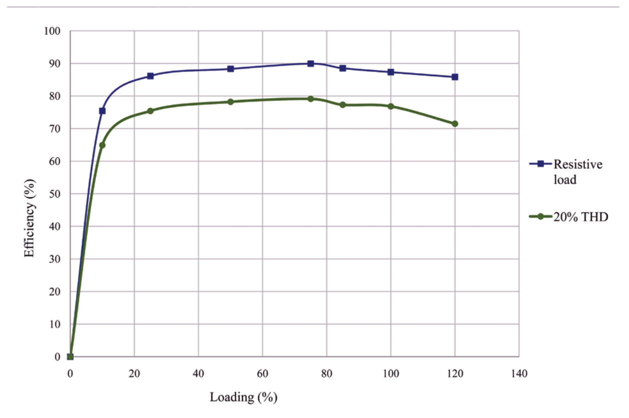

FIG. 2 EFFECT OF HARMONIC LOAD ON PERFORMANCE OF ELECTRICAL EQUIPMENT

3.0 EMULATION OF THD LOAD

3.1 Load Emulation

In load emulation, a controllable system which can behave as actual load is used for loading, mainly for testing and design of source side equipments. Using load emulation, the energy drawn by the load can be regenerated, there by avoiding large amount of energy wastage. The concept of load emulation is shown in Figure 3. The combination of load emulator and regenerative converter was initially implemented using motor generator set, which was later replaced by solid state converters. The load emulator converter manipulates the input current to obtain the required current characteristics and regenerative converter converse just energy and supplies it back to the Grid

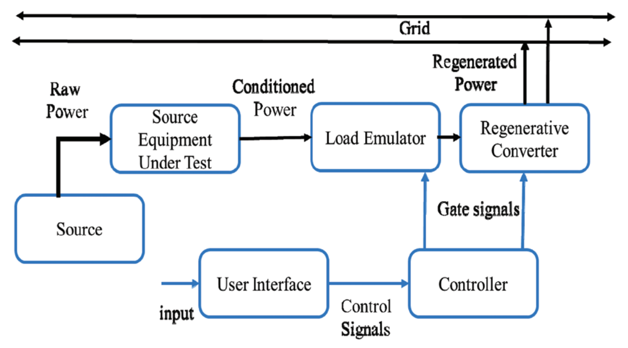

FIG. 3 CONCEPT OF LOAD EMULATION

3.2 Creation of harmonic load

Here, in order to emulate harmonic load, the current waveform chopped at an angle such that, the required THD is induced in the load. Figure 4 shows the block diagram of the proposed model. The lagging and leading components are obtained using inductor and capacitors and the main focus here is on the harmonic load. AC regulator configuration is used for current control converter, where positive how cycle is controlled by one switch and negative half cycle is controlled by another switch.

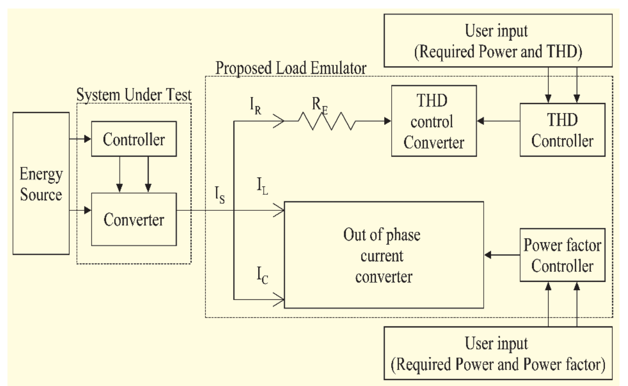

FIG. 4 PROPOSED MODEL FOR HARMONIC LOAD EMULATION

If $I_{R\ rated}$ is the rated current through resistor R, and I_R is the require load current, then a PWM signal of duty cycle I_R/I_{RRated} gives a sinusoidal current of value I_R flowing through resistance. If this current is to be clipped at an angle $_\varphi$, then and Inverse sinusoidal pwm is applied between angle $_\varphi$ and 90 - $_\varphi$ as shown in Figure 5. This results in clipping of current from angles $_\varphi$ to 90 - $_\varphi$, there by inducing harmonic distortion in the load current. The required angle file is calculated from the relationship between THD and clipped sinusoidal waveform. Thus the PWM for obtaining clipped waveform can be represented by the following equations.

$$PWM_{THD} = PWM_1$$

for $0 < \omega t < \varphi$ and $(90 - \varphi) < \omega t < 90$

$$PWM_{THD} = \frac{PWM_1}{I_R(\omega t)} I_\phi$$

$$\text{for } \varphi \leq \omega t \leq 90 \qquad ....(6)$$

Where PWM_1 has duty cycle $I_R/I_{RRated.}$ And I_φ is the value of sinusoidal current IR at angle $_\varphi$. $I_R(wt)$ is the instantaneous value of sinusoidal current I_R

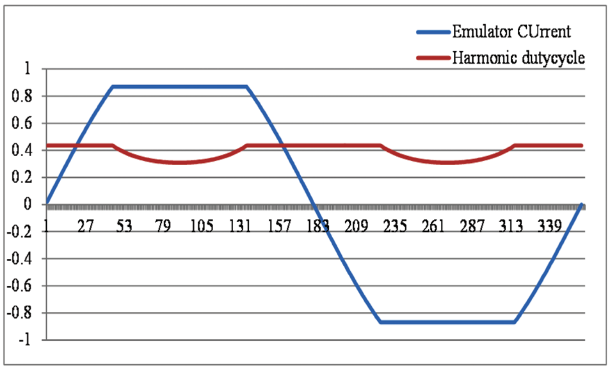

FIG. 5 VOLTAGE AND CURRENT WAVEFORM AND PWM VARIATION FOR VARIABLE THD LOAD

4.0 SIMULATION STUDIES

The over all simulation model of the proposed system the shown in Figure 6 implemented in MATLAB/SIMULINK^{TM} platform. The current through the resistive component is regulated by a bidirectional converter which was controlled as per the PWM generated by THD control subsystem. The required THD and required amount of load are given as inputs to the controller. For the purpose of converter analysis inbuilt in built source model is used for simulation

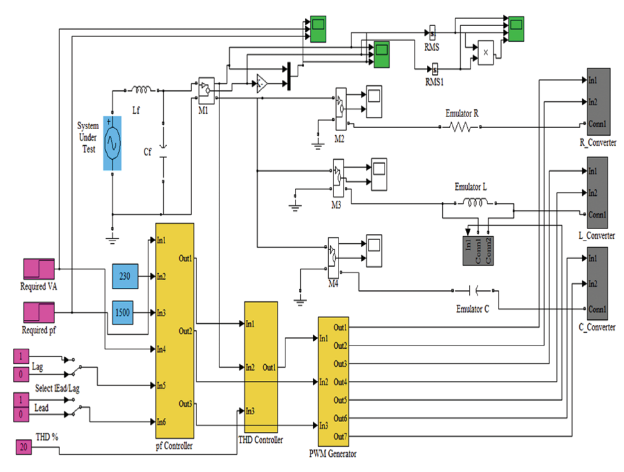

FIG. 6 OVERALL SIMULATION DIAGRAM FOR VARIABLE THD LOAD EMULATION

The algorithm as explained in section 3 is incorporated in the subsystem by using logical blocks and embedded programming as shown in Figure 7. The input subsystem is the angle at which clipping of the way form is to be done in order to obtain the required THD. The output of subsystem if the instantaneous pulse width value. This value is given to PWM generator to obtain the signals required for converter switches

5.0 RESULTS AND ANALYSIS

Figure 8 shows the results of waveforms obtained by simulation of the model shown in Figure 6. It can be seen that when required THD input is increased from zero to 40 % ,the current waveform get clipped at the angle corresponding to this THD. The scaled waveform of current is shown in the figure in order to highlight the change in shape of the waveform.

The model is verified for different THD levels from 0 to 80 % an analytical study is conducted on solar PV inverter in order to study the effect of variable THD load on source performance. Compared to simulations, hardware emulation is more realistic and many physical factors which do not come into picture in simulation studies can be accounted in emulation studies.

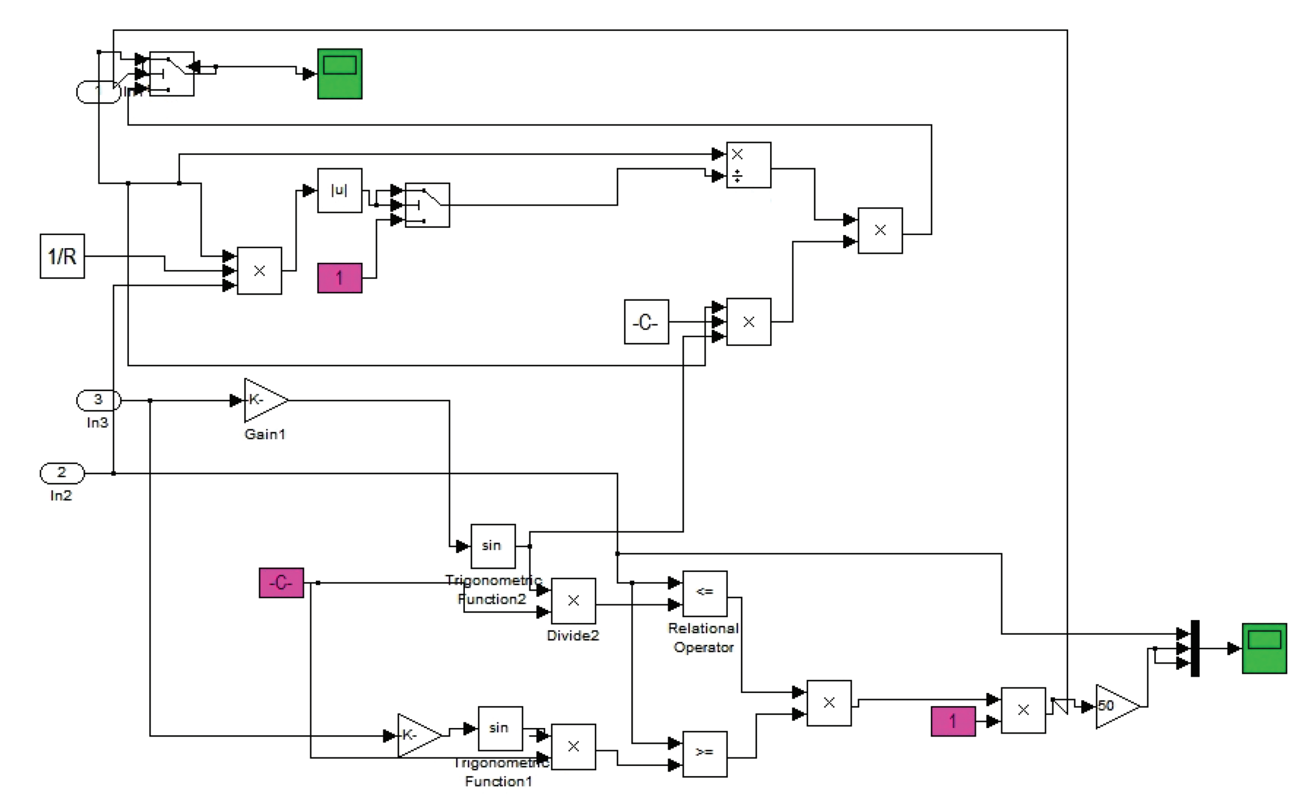

FIG. 7 SUBSYSTEM FOR THD CONTROL

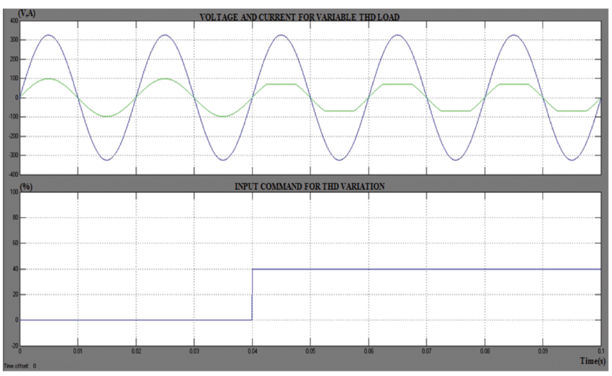

FIG. 8 SIMULATION RESULTS FOR VARIABLE THD LOAD

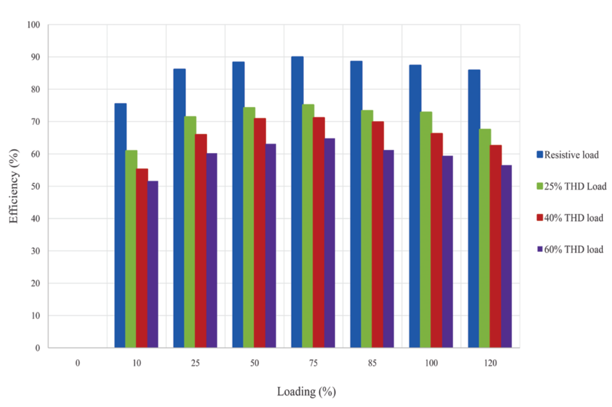

FIG. 9 COMPARISON OF EFFICIENCIES AT DIFFERENT LOAD THD

Figure 9 shows the comparison of efficiency under 4 THD levels, at various loading on solar PV inverter. It can be found that there is considerable reduction in the efficiency with increase in THD. The life of the system also come down because of abnormal temperature rise in various areas

6.0 CONCLUSIONS

This paper presents a novel method for emulation of harmonic loads, which is difficult using conventional method of passive loading. Here the current waveform is clipped at different angles based on the amount of THD required in the load. This clipping is done using a novel method of PWM control in inverse sinusoidal fashion. The angle of clipping is calculated based on the relationship between fourier transform of clipped waveform and THD. From the simulation results it is found that this method gives accurate emulation of harmonic load as per the user requirement. The importance of harmonic emulation is evident from the performance study of solar PV inverter under different THD loads using the developed model. Efficiency is found reduce roughly by 2 % for every 5 % increase in THD

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