Selective Harmonic Elimination by Programmable Pulse Width Modulation in Inverters

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Abstract- The objective of the electric utility is to deliver sinusoidal voltage at fairly constant magnitude throughout their system. This objective is complicated by the fact that there are loads on the system that produce harmonics currents. These currents result in distorted voltages and currents that can adversely impact the system performance in different ways. When harmonic currents flow through the impedances of the power system they cause corresponding voltage drops and introduce harmonics onto the voltage waveform. If harmonics do cause a problem, it is through the cumulative effect on the power system of numerous harmonic-generating loads. Problems may be experienced within the plant that generates the harmonics, or in other premises fed from the same supply. The main possible effects are: power factor less than unity- i.e current higher than necessary for given power, increased heating of power plant , over-stress of power factor correction plant due to local resonance, noisy bus bars, electrical protection gear etc., over heating of neutral conductors(single –phase loads only).

Harmonics must be reduced in order to reduce the size of filters. PWM technique is one of the energy processing methods used in power electronics. PWM applies a pulse train of fixed amplitude and frequency, only the width of the pulse is varied in proportion to the input voltage so that output voltage is constant but with less wastage of power at the output stage by eliminating harmonics.

Keywords - PWM (pulse width modulation), SHE (selective harmonic elimination), and SVPWM (space vector pulse width modulation).

I. INTRODUCTION

Inverter is usually a device which converts DC power into AC power. In many industrial applications, it is often required to vary output voltage of inverter [1] due to the following reasons: 1.To compensate for the variations in input voltage.2.To compensate for the regulation of inverters.3. To supply some special loads which need variation of voltage with frequency. The various methods for the control of output voltage are:

1. External control of ac output voltage.
2. External control of dc input voltage.
3. Internal control of inverter.

Semiconductor switching devices produce significant harmonic voltages as they abruptly chop voltage waveforms during their transition between conducting and cutoff states. Inverter circuits are notorious for producing harmonics, and are in widespread use today. An adjustable-speed motor drive is one application that makes use of inverter circuits, often using pulse width modulation (PWM) synthesis to produce the AC output voltage. Various synthesis methods produce different harmonic spectra. Regardless of the method used to produce an AC output voltage from a DC input voltage, harmonics will be present on both sides of the inverter and must often be mitigated.

Harmonics will undoubtedly continue to become more of a concern as more equipment that produces them is added to electrical systems. But if adequately considered during the initial design of the system, harmonics can be managed and their detrimental effects avoided.

II. MULTILEVEL INVERTERS FOR HARMONIC ELIMINATION:

A basic inverter has two levels of output voltage either 0,+vdc,-vdc in its pole voltage. Various PWM techniques were developed on two level inverter to reduce harmonic content in the output.

When these techniques are used for high power levels, the switching stress is going to increase. So, a switch which is fast acting and can withstand high switching stress need to be used. Which mayn't be available or even if it is available it is costly.

Multi level inverters offer a great advantage in this area. The fundamental component of the output can be realized as a staircase wave. The number of steps of which depend on the level of inverter and as the level increases the output reaches sine wave.

There are three types of multi level inverters:

1) Diode clamped inverter
2) Capacitor clamped inverter

3) Cascade inverter

III. PWM TECHNIQUES FOR HARMONIC ELIMINATION

PWM techniques are employed to regulate output voltage and to reduce harmonics. Inverters inherently have the property of controlling the output frequency, but the output voltage cannot be varied.To vary output voltage we have to vary supply voltage, which is not always possible. Hence we go for employing PWM techniques.

These techniques serve two purposes:

1) Varying output voltage.
2) Reducing harmonic content (or) improve harmonic profile.

Types of PWM:

1) Single PWM
2) Multiple PWM
3) Sinusoidal PWM

In single PWM we get output voltage when Vref>Vcar. In square wave single pulse and multiple pulse PWM inverters the lower order harmonics are 3,5,7 for 1-phase and 5,7,9 for 3-phase,but in multiple phase the energy in lower order harmonics is transferred to higher order, thereby it is easy to filter out and in sinusoidal PWM the lowest order harmonic present is Mf.Where Mf is called frequency modulation index

Mf=Fc/Fref

IV. SPACE VECTOR PULSE WIDTH MODULATION

Space vector modulation is a PWM control algorithm [2] for multi-phase AC generation, in which the reference signal is sampled regularly; after each sample, non-zero active switching vectors adjacent to the reference vector and one or more of the zero switching vectors are selected for the appropriate fraction of the sampling period in order to synthesize the reference signal as the average of the used vectors. The topology of a three-leg voltage source inverter is Because of the constraint that the input lines must never be shorted and the output current must always be continuous a voltage source inverter can assume only eight distinct topologies. Six out of these eight topologies produce a nonzero output voltage and are known as non-zero switching states and the remaining two topologies produce zero output voltage and are known as zero switching states.

V. SELECTIVE HARMONIC ELIMINATION BY PROGRAMMABLE PULSE WIDTH MODULATION IN INVERTERS

In the Sinusoidal PWM technique, a large number of switching's are required, with the consequent associated switching losses. With the method of Selective Harmonic Elimination, only selected harmonics are eliminated with the smallest number of switching's. This methodhowever can be difficult to implement on-line due to computation and memory requirements.For a two level PWM waveform with odd and halfwave symmetries and n chops per quarter cycle as shown in Fig6.1, the peak magnitude of the harmonic components including the fundamental, are given by Eqn:

$$h_1 = \left(4 \cdot \frac{E}{\pi}\right) \cdot [1 - 2\cos\alpha_1 + 2\cos\alpha_2 - 2\cos\alpha_3 \ldots 2\cos\alpha_n]$$

$$h_3 = \left(4 \cdot \frac{E}{3\pi}\right) \cdot [1 - 2\cos 3\alpha_1 + 2\cos 3\alpha_2 - 2\cos 3\alpha_3 \ldots 2\cos 3\alpha_n]$$

$$\vdots$$

$$h_k = \left(4 \cdot \frac{E}{k\pi}\right) \cdot [1 - 2\cos k\alpha_1 + 2\cos k\alpha_2 - 2\cos k\alpha_3 \ldots 2\cos k\alpha_n]$$

Here hi is the magnitude of the ith harmonic and αj is the jth primary switching angle. Even harmonics do not show up because of the half-wave symmetry.

The n chops in the waveform afford n degrees of freedom. Several control options are thus possible. For example n selected harmonics can be eliminated. Another option which is used here is to eliminate n-1 selected harmonics and use the remaining degree of freedom to control the fundamental frequency ac voltage. To find the α's required to achieve this objective, it is sufficient to set the corresponding h's in the above equations to the desired values (0 for the n-1 harmonics to be eliminated and the desired per-unit ac magnitude for the fundamental) and solve for the α's.

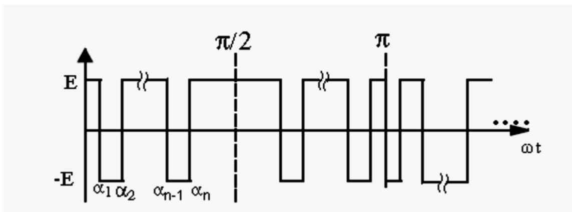

Fig.5.1.A two-level PWM waveform with odd and half wave symmetry.

Equation 1 can be readily proved by finding the Fourier coefficients of the waveform shown in Fig. 5.1. In general, for a periodic waveform with period 2π , the Fourier Cosine and Sine Coefficients are given by:

$$a0 = 1/2\pi \int_0^{2\pi} f(\theta)\, d\theta$$

$$ak = 1/\pi \int_0^{2\pi} f(k\theta) \cos(k\theta)\, d\theta$$

$$bk = 1/\pi \int_0^{2\pi} f(k\theta) \sin(k\theta)\, d\theta \quad \ldots\ldots\ldots 5.1$$

Because of the half-cycle symmetry of the waveform of Fig.3.1, only odd order harmonics exist. Also, it is easy to see that the Fourier Cosine coefficients disappear with the choice of coordinate axes used. Utilizing the quarter cycle symmetry, the Fourier Sine coefficients become:

bk=$4/\pi \int_0^{2\pi} f(k\theta)\sin(k\theta)d\theta$………5.2

Substituting the two-valued PWM waveform for f(θ),

bn=$4e/n\pi[1-2cosn\alpha1+2cosk\alpha2-2cosk\alpha3 \ldots ..2coskan]$…….5.3

A. Total harmonic distortion:

The most commonly used measure for harmonics is total harmonic distortion [3] (THD), also known as distortion factor. It is applied to both voltage and current.THD is defined as the RMS value of the harmonics above fundamental, divided by RMS value of fundamental**.**

THD=$(\sqrt{\sum_{N=2}^{\infty} In^2})/I1$

B. Power factor:

To examine the impact of harmonics on power factor, it is important to consider the true power factor, which is defined as [4]

Pftrue=Pavg/(Vrms*Irms)

- Where the average power Pavg=(V1 *I1)/2[cos($\boldsymbol{\varphi 2-\varphi 1}$)]
- Harmonics always increase the RMS value
- Harmonics don't necessarily increase average power.
- Increased RMS values means increased losses.

C. Fourier series representation of output voltage of inverter:

By Fourier series, the output voltage of inverter is given by

Vk=$\frac{\boldsymbol{4Vdc}}{\boldsymbol{n\pi}}(\boldsymbol{1-2cosk\alpha1+2cosk\alpha2-2cosk\alpha3+2cosk\alpha4-2cosk\alpha5+\cdots.})$
where Vk is the kth harmonic voltage magnitude.

For fundamental voltage k=1 and

V1=$\frac{\boldsymbol{4Vdc}}{\boldsymbol{n\pi}}(\boldsymbol{1-2cosk\alpha1+2cosk\alpha2-2cosk\alpha3})$

To eliminate 3,5,7,9 harmonics the values of V3,V5,V7,V9 are equated to zero.

V1=$\frac{\boldsymbol{4Vdc}}{\boldsymbol{n\pi}}(\boldsymbol{1-2cos\alpha1+2cos\alpha2-2cos\alpha3+2cos\alpha4-2cos\alpha5})$
V3=$\frac{\boldsymbol{4Vdc}}{\boldsymbol{n\pi}}(\boldsymbol{1-2cos\alpha31+2cos\alpha32-2cos3\alpha3+2cos3\alpha4-2cos3\alpha5})$=0

V5=$\frac{\boldsymbol{4Vdc}}{\boldsymbol{n\pi}}(\boldsymbol{1-2cos5\alpha1+2cos5\alpha2-2cos5\alpha3+2cos5\alpha4-2cos5\alpha5})\boldsymbol{=0}$

V7=$\frac{\boldsymbol{4Vdc}}{\boldsymbol{n\pi}}(\boldsymbol{1-2cos7\alpha1+2cos7\alpha2-2cos7\alpha3+2cos7\alpha4-2cos7\alpha5})$=0

V9=$\frac{\boldsymbol{4Vdc}}{\boldsymbol{n\pi}}(\boldsymbol{1-2cos9\alpha1+2cos9\alpha2-2cos9\alpha3+2cos9\alpha4-2cos9\alpha5})$=0

The equations V1,V3,V5,V7,V9 are solved to obtain the angles $\boldsymbol{\alpha1}$, $\boldsymbol{\alpha2}$, $\boldsymbol{\alpha3}$, $\boldsymbol{\alpha4}$, **and** $\boldsymbol{\alpha5}$ to eliminate 3,5,7 and 9 harmonics.

These angles are used to generate pulses so that the particular lower order harmonics are eliminated from the inverter output voltage.

VI. SIMULATION OF BASIC INVERTER MODEL

The basic model of inverter was first simulated without incorporating angles and THD of the output was found.

The below figure shows the basic model of inverter without incorporating angles. The input voltage given to the inverter is 230V.The pulses are generated in the sub system and these are given to the gate terminal of the inverter. The output voltage was measured by voltage measurement block connected across the load.

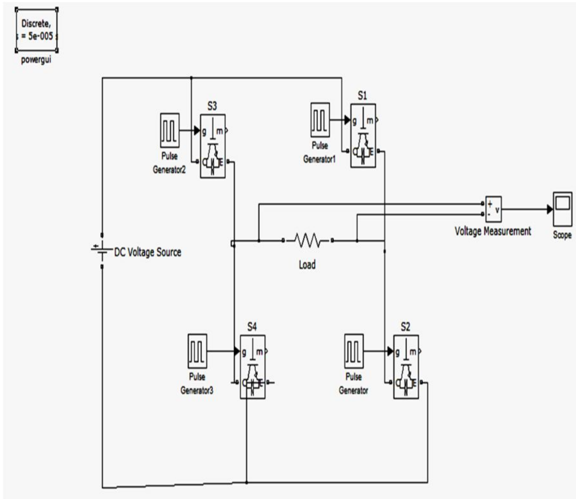

Fig.6.1 Basic model of inverter.

The below wave form shows the output voltage wave form of the inverter that is obtained across the load.

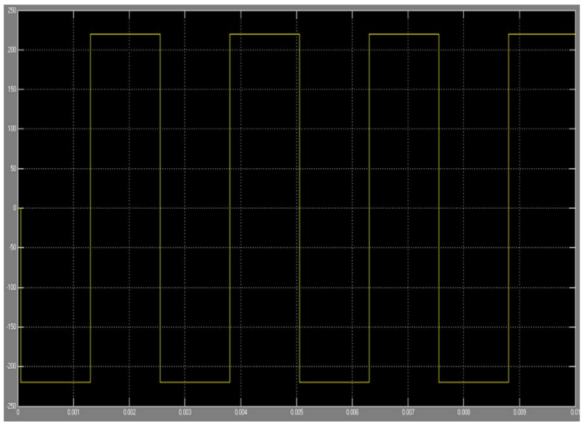

Fig.6.2.A two-level PWM waveform with odd and half wave symmetry.

The THD was found using FFT analysis tool of the power gui block. Due to symmetry only odd harmonics exist and even harmonics doesn’t exist. The THD found was 42.77%.

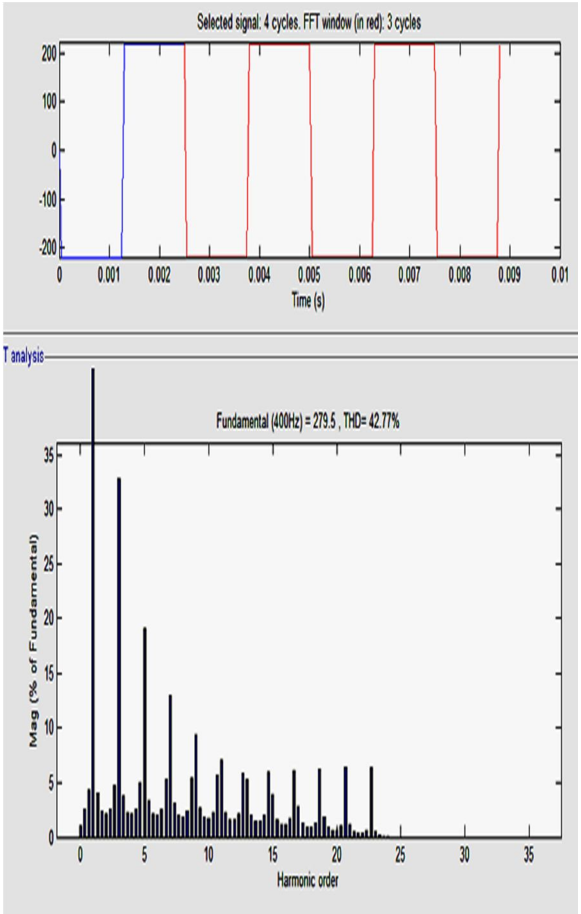

Fig.6.3Determination of THD by FFT analysis

VII. MATLAB program for elimination of 3,5,7&9 harmonics:

```
function N=spwm2211(x);
i=[3 5 7 9];
k=[1 11 13 17 19];j=1;
m=1;xstart=[14.2 24 47 51 88];
while(m>0)&(m<=1)
options=optimset('display','iter');
[x,fval,output,iter]=fsolve(@smpwm2211,xstart,options);
x_1(j,:)=x(1)';x_2(j,:)=x(2)';x_3(j,:)=x(3)';x_4(j,:)=x(4)';x_5(j,:)=x(5)';M(j,:)=m';
   N(k)=509.2958*(1-(2*cos(k*x(1)))+(2*cos(k*x(2)))-(2*cos(k*x(3)))+(2*cos(k*x(4)))-(2*cos(k*x(5))));
T(j,:)=(((N(7)^2)+(N(11)^2)+(N(13)^2)+(N(17)^2)+(N(19)^2))^(1/2))/N(1);
xstart=x';
   m=m-0.1;j=j+1;
end
evals=j-1;
fprintf('x_1\t\t   x_2\t\t    x_3\t\t   x_4\t\t   x_5\t\t      M\n');
fid=fopen('epwm2211.txt','w');
fprintf(fid,'x_1\t\t   x_2\t\t    x_3\t\t   x_4\t\t   x_5\t\t    M\t\t THD\n');
for j=1:(evals)
fprintf('%6.4f\t   %6.4f\t   %6.4f\t   %6.4f\t   %6.4f\t %4.2f\n',x_1(j,:),x_2(j,:),x_3(j,:),x_4(j,:),x_5(j,:),M(j,:));
y=[x_1(j,:);x_2(j,:);x_3(j,:);x_4(j,:);x_5(j,:);M(j,:);T(j,:)];
fprintf(fid,'%6.4f\t%6.4f\t%6.4f\t%6.4f\t%6.4f\t%4.2f\t %6.4f\n',y);
   j=j+1;
end
fclose(fid);function F=smpwm2211(x);
F(1)=(1-(2*cos(x(1)))+(2*cos(x(2)))-(2*cos(x(3)))+(2*cos(x(4)))-(2*cos(x(5)))-m);
F(i)=(1-(2*cos(i*x(1)))+(2*cos(i*x(2)))-(2*cos(i*x(3)))+(2*cos(i*x(4)))-(2*cos(i*x(5))));
end
end
```

The output of the above program where the five angles to eliminate 3[rd],5[th],7[th] and 9[th] harmonics are

X_1	X_2	X_3	X_4	X_5	M
14.10	23.53	46.51	51.35	88.88	1.00
14.10	23.53	46.51	51.35	88.88	0.90
14.10	23.53	46.51	51.35	88.88	0.80
14.10	23.53	46.51	51.35	88.88	0.70

14.10	23.53	46.51	51.35	88.88	0.60
14.10	23.53	46.51	51.35	88.88	0.50
14.10	23.53	46.51	51.35	88.88	0.40
14.10	23.53	46.51	51.35	88.88	0.30
14.10	23.53	46.51	51.35	88.88	0.20
14.10	23.53	46.51	51.35	88.88	0.10
14.10	23.53	46.51	51.35	88.88	0.00

Table 4.1 Angles to eliminate 3rd,5th,7th and 9th harmonics

VIII. SIMULATION OF INVERTER MODEL AFTER INCORPORATION OF ANGLES:

The below model is the simulink model of the inverter to eliminate 3rd,5th,7th and 9th harmonics, where the above found angles are incorporated to eliminate four harmonics[5].

Here also the input DC voltage to the inverter is 230V.The pulses given to the inverter are generated in the subsystem. The output voltage is measured at the load using voltage measurement block. The THD is found by using the power gui block.

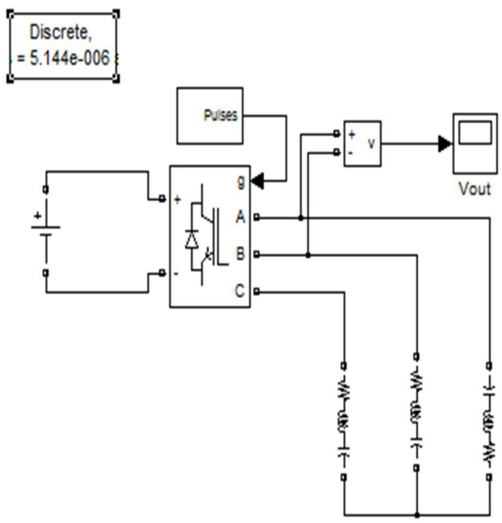

Fig.8.1 Simulink model of inverter after incorporating angles to eliminate 3rd,5th,7th and 9th harmonics

The below wave form shows the output voltage wave form of the inverter that is obtained across the load.

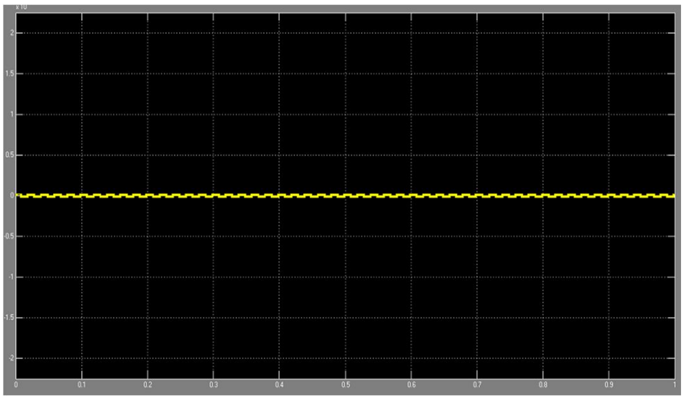

Fig.8.2 Output waveform of inverter after eliminating 3rd,5th,7th &9th harmonics

The THD was found using FFT analysis tool of the power gui block. Due to symmetry only odd harmonics exist and even harmonics doesn't exist. The THD found was 99.15%.

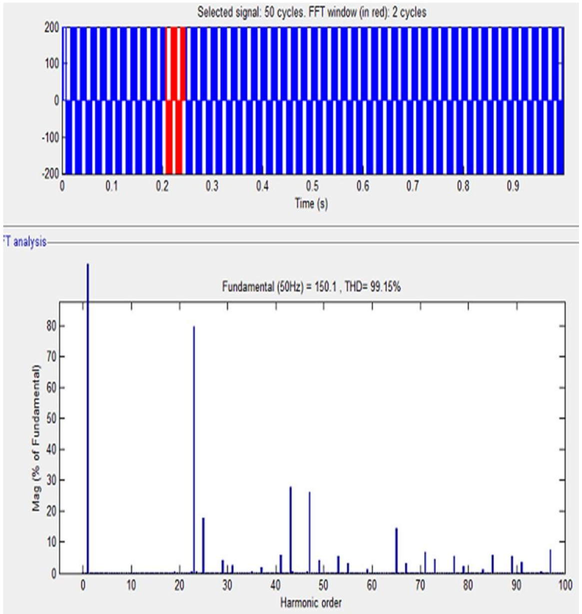

Fig.7.3Determination of THD by FFT analysis and elimination of 3rd,5th,7th & 9th harmonics

IX. CONCLUSION

Through this project we were able to eliminate 3rd, 5th, 7th and 9th harmonics from three phase inverter. By reducing harmonics the size of filters are reduced. PWM technique is one of the energy processing methods used in power electronics. PWM applies a pulse train of fixed amplitude and frequency, only the width of the pulse is varied in proportion to the input voltage so that output voltage is constant but with less wastage of power at the output stage by eliminating harmonics.

X. FUTURE SCOPE

PWM technique requires large number of thyristors (Or) firing circuits, which increases switching losses. Switching speed of thyristors must be high which makes it uneconomical. Firing pulse design is complicatory compared to other techniques.

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BIOGRAPHIES

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