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Selective Harmonic Elimination Technique using Transformer Connection for PV fed Inverters

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***Abstract*— This paper discusses a harmonic reduction technique implementation for both 1-Φ and 3-Φ PV fed system .PV system have become very prominent now a days for both standalone and grid connected system. When PV is used for AC loads an inverter is used for conversion of DC-AC. The major drawback found among inverter is the harmful effect of harmonics. The major harmonics present are 3rd harmonic and 5th harmonic. Instead of using multilevel inverter or any complex technique, the method of selective harmonic elimination helps eliminate a particular harmonic whose effect is more without any mundane formulation. The selective harmonics elimination technique is analyzed for 1-Φand 3-Φ inverters their results are plotted in MATLAB/Simulink environment.**

Keywords*—SHE(Selective Harmonic Elimination), Harmonic, Inverter, MPPT(Maximum Power Point Tracking), PV(Photovoltaic), INC(Incremental Conductance).

I. INTRODUCTION

The rise in cost, deterioration of conventional have led to considerable attention to the non-conventional energy sources. As solar energy is free and abundant in most parts of the world, it has proven to be a challenging source of energy. PV cell converters the solar energy incident on it to electrical energy. To connect the PV arrays to any utility, some converters need to be included in the system to convert the dc voltage into ac voltage, boost the voltage and also ensure maximum power utilization for connection in any grid connected as standalone systems, the inverter is a very critical component. It converts the dc voltage from the boost converter to a clean sinusoidal voltage to be given to any electrical equipment. To obtain low harmonic distortion. Several new multilevel inverter topologies have been proposed. But the bad effects of these harmonics can be eliminated by using simple techniques to discard some harmonics.

The conventional PWM techniques like sinusoidal pulse width modulation (SPWM), space vector modulation (SVM), are applied to reduce the harmonics content and also achieved the desired output voltage. The PWM technique fail in suppressing the lower order harmonics. Selective harmonic elimination method is used to eliminate the lower order harmonics. The paper proposes a methodology of selective harmonic elimination where the output voltage of two or more inverters is combined by means of transfer connection to reduce the dominate harmonics. The dominate harmonics in any system are 3rd and 5th harmonics. The switching angles are computed using transcendental equations characteristics harmonics.

Section II deals with the system description. Section III deals with modelling of PV panel. Section IV deals with MPPT. Section V details on the selective harmonics technique for 1-Φ and 3-Φ inverter. Section VI presents the results and discussions. The conclusion are in section VII.

II. SYSTEM DESCRIPTION

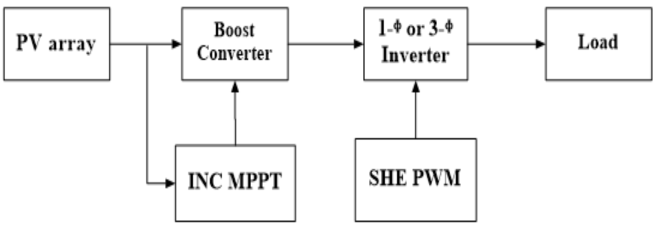

Figure 1. Block Diagram of overall system

The output of the PV panel is given to the input of the boost converter. The inputs of the INC MPPT controller are voltage and current from the PV panel. The pulses from the INC MPPT are given to the boost converter to make the PV panel operate at its peak power. The DC voltage from the boost converter is given as input to the inverter and the AC Output is given to the load.

III. MODELLING OF PV PANEL

Conversion of light energy to electrical energy is the basic function of the photo voltaic cell. The PV panel needs to be modelled mathematically to analyze the characteristics. The PV cells can be realized as a current source in parallel to a diode. The internal resistance is represented by a series resistance Rs in the equivalent circuit. The mathematical equations of the PV panel can be written as follows

$$I = I_{PV} - I_O\left[e^{\frac{q(V+IR_s)}{akT}} - 1\right] - \left[\frac{V+IR_s}{R_p}\right] \quad (1)$$

Where,

I_{pv}= photo voltaic current

I_o=saturation current of the diode
q=electron charge in coulombs
=$1.602*10^{-19}$C
K=Boltzmann constant
=$1.380*10^{-23}$ J/K
a=diode ideality factor
R_s=series resistance
R_p=parallel resistance
T=Temperature in Kelvin

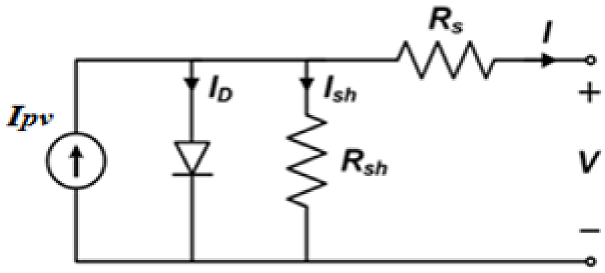

Figure 2. Modeling of PV Cell

The photo voltaic current Ipv is a function of the irradiance (G) and is formulated as:

$$I_{PV} = [I_{PV\_STC} + K_i \Delta T]\frac{G}{G_{STC}} \quad (2)$$

Where;
I_{PV_STC}=light generated current under standard test conditions (STC)
ΔT= T-T_{STC} (in kelvin)
G= surface irradiance of cell (W/m^2)
G_{STC}=1000W/m^2
Irradiance under STC
K_i = short circuit current coefficient
The diode saturation current I_o is given as:

$$I_o = I_{o\_STC}\left(\frac{T}{T_{STC}}\right)^3 exp\left[\frac{qE_g}{ak}\left(\frac{1}{T_{STC}} - \frac{1}{T}\right)\right] \quad (3)$$

Where;
$I_{o,stc}$ = normal saturation current under standard test conditions (STC)
T_{STC}= temperature under standard test conditions
E_g= band gap energy of the semiconductor

IV. INCREMENTAL CONDUCTANCE MPPT

The basic principle for formation of the incremental conductance algorithm is the fact that the slop of the PV array curve is zero at the peak, negative on the right side and positive on the left side.

The INC MPPT can be explained mathematically as in equations [4-8]

$$\frac{dP}{dV}=0 \quad \text{at MPP}$$
$$\frac{dP}{dV}>0 \quad \text{on left side of MPP} \quad (4)$$
$$\frac{dP}{dV}<0 \quad \text{on right side of MPP}$$

The Conductance can be further calculated as:

$$\frac{dP}{dV} = \frac{d(V*I)}{dV} = I + V*\frac{dI}{dV} = 0 \quad (5)$$

Thus, $\frac{dI}{dV} = \frac{-I}{V}$ at MPP

$$\frac{dI}{dV} > \frac{-I}{V} \quad \text{On left of MPP} \quad (6)$$
$$\frac{dI}{dV} < \frac{-I}{V} \quad \text{On right of MPP}$$

As the MPP is reached, the PV panel is operated at this point and is perturbed only if any change in current is obtained due to a variation in Irradiation. The flow chart of the INC MPPT Technique is given in figure 3.

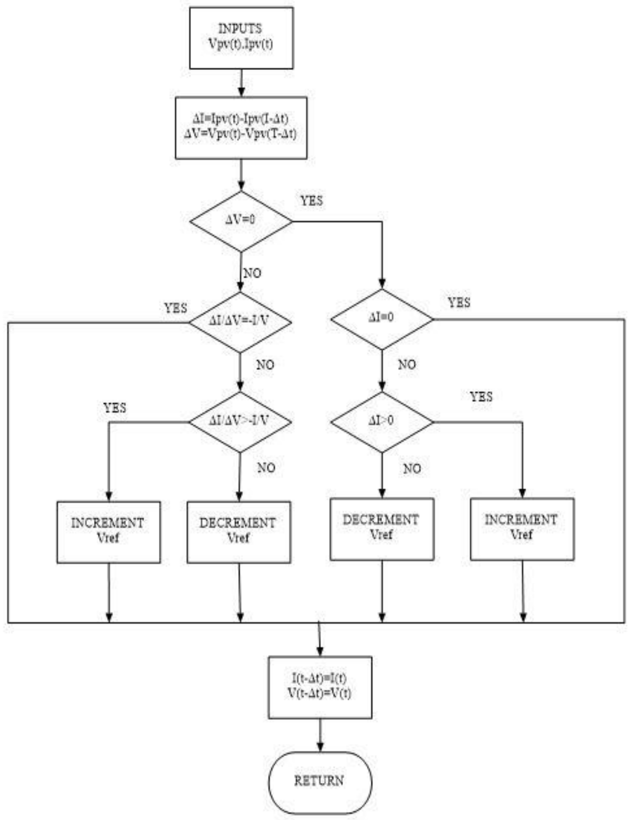

Figure 3. Flow Chart of INC MPPT

The advantage of the incremental conductance MPPT over the P&O algorithm is that, there are less number of steady state oscillations. In the Perturb & Observe algorithm, varying the perturbation size is not very feasible. But, in the INC, the step size can be selected for faster dynamics and reduction in steady state oscillations.

V. SELECTIVE HARMONIC ELIMINATION

In the method of selective harmonic elimination, the output voltage of two or more inverters are combined by means of transformer connection and the resultant output consists of reduced harmonic content when compared to individual inverter output voltage. The block diagram of the system is shown in Figure 4.

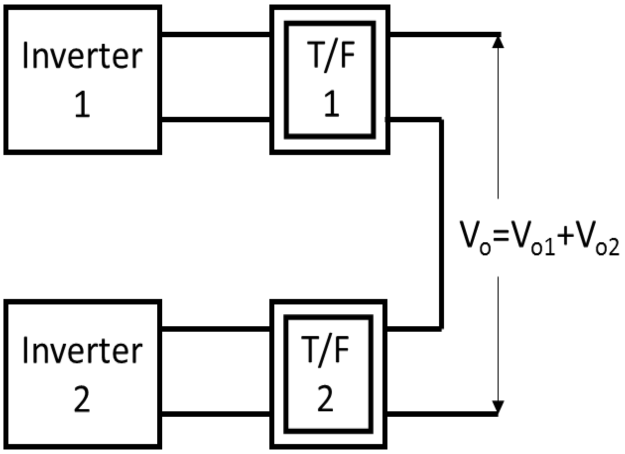

Figure 4. Circuit Diagram of Selective Harmonic Elimination

The condition that must be satisfied in order to avail this SHE is the output voltages of the two inverters must be similar but phase shifted from each other. The voltages v_{01} and v_{02} for the two inverters are obtained. The v_{02} waveform is phase shifted by Π/3 radians with respect to v_{01}. The resultant output voltage will have the amplitude which is summation of two inverter voltages. The equations pertaining to the inverter voltages and the net voltage are shown below.

$$V_{01} = \frac{4Vs}{\Pi}\left[\sin\omega t + \frac{\sin 3\omega t}{3} + \frac{\sin 5\omega t}{5} + \frac{\sin 7\omega t}{7} + ...\right] \quad (7)$$

$$V_{02} = \frac{4Vs}{\Pi}\left[\begin{array}{l}\sin\left(\omega t - \frac{\Pi}{3}\right) + \sin 3\left(\omega t - \frac{\Pi}{3}\right)/3 \\ + \sin 5\left(\omega t - \frac{\Pi}{3}\right)/5 + \sin 7\left(\omega t - \frac{\Pi}{3}\right)/7 + ..\end{array}\right] \quad (8)$$

$$V_0 = V_{01} + V_{02}$$

$$= \frac{4\sqrt{3}Vs}{\Pi}\left[\begin{array}{l}\sin\left(\omega t - \frac{\Pi}{6}\right) + \frac{1}{5}\sin\left(5\omega t + \frac{\Pi}{6}\right) \\ + \frac{1}{7}\sin\left(7\omega t - \frac{\Pi}{6}\right) + ...\end{array}\right] \quad (9)$$

From the figure it can be seen that v_{02} lags v_{01} by 60^0 for fundamental frequency. By examining the expressions resultant of v_{01} and v_{02} must be $\sqrt{3}$ times v_{01} and at same time resultant lags v_{01} by 30^0. Therefore net value of fundamental frequency voltage be associated with $\sqrt{3}\ \sin(\omega t - \Pi/6)$.For third harmonic, v_{02} lags v_{01} by 180^0, so the resultant is zero. In the same manner it follows for remaining 5^{th}, 7^{th} and 9^{th} and so on. As the inverter voltages are quasi square wave in shape, the effect of even harmonics will become zero. The analysis has been performed on 1-Φ and 3-Φ inverters to eliminate 3^{rd} and 5^{th} harmonics and the results have been discussed in Section VI.

VI. RESULTS AND DISCUSSIONS

A. *Single Phase Inverter*

The output Voltage of 1-Φ inverter is shown in Figure 5. The Figure 6 shows the harmonic spectrum of the system without employing Selective Harmonic Elimination.

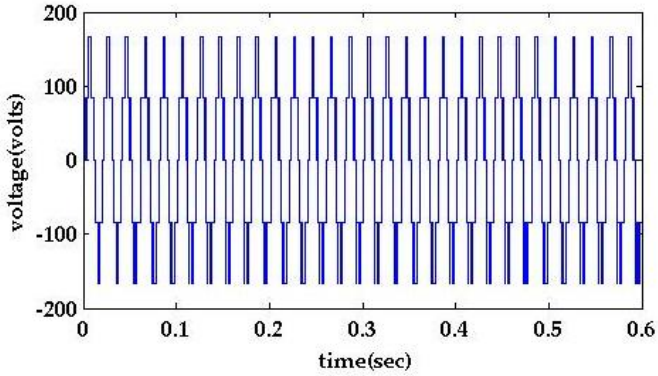

Figure 5. Output Voltage of single phase inverter

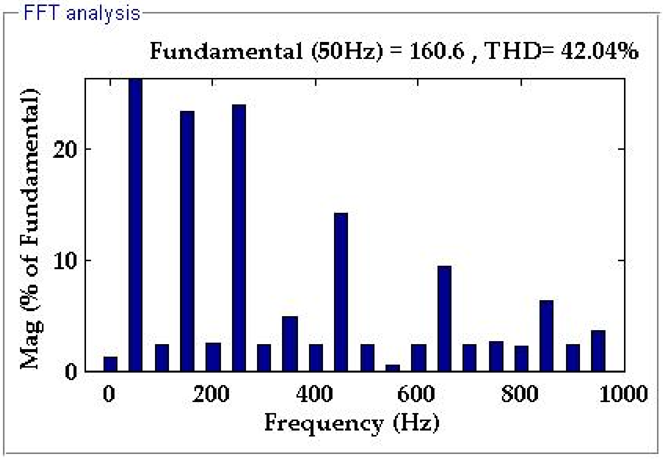

Figure 6. Harmonic Spectrum without employing SHE

The figure 7 shows the harmonic spectrum of the system with employing selective harmonic elimination for 3^{rd} harmonic. The figure 8shows the harmonic spectrum of the system with employing selective harmonic elimination for 5^{th} harmonic.

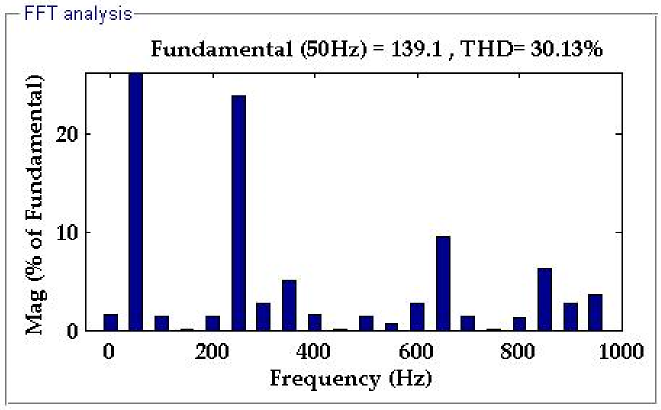

Figure 7. Harmonic Spectrum with employing SHE for 3^{rd} harmonic

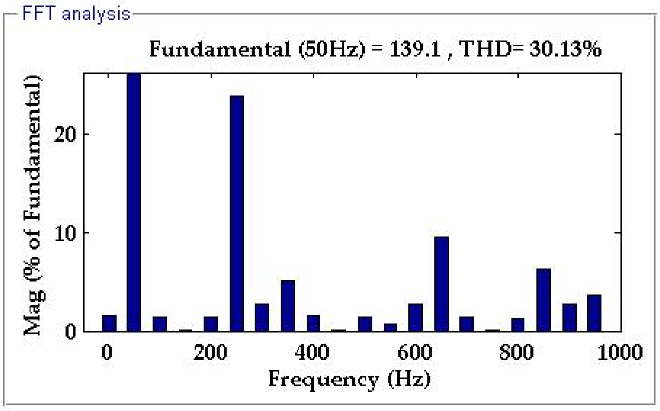

Figure 8. Harmonic Spectrum with employing SHE for 3rd harmonic

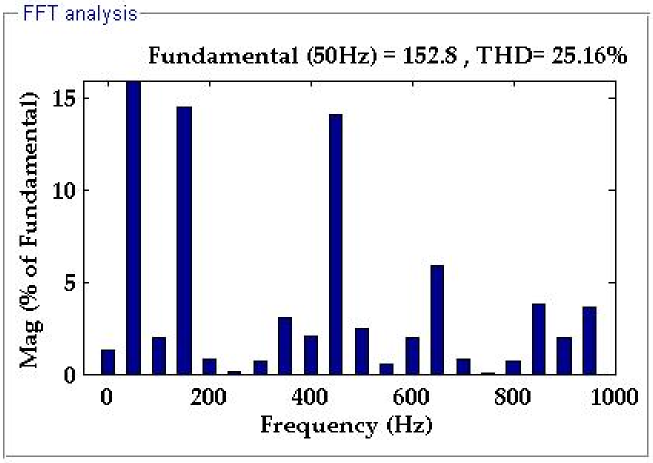

Figure 9. Harmonic Spectrum with employing SHE for 5th harmonic

A single phase full bridge inverter has been simulated and the harmonics are reduced using transformer connection employing sinusoidal pulse width modulation. The third and fifth harmonics have been effectively reduced by giving a phase delay of π/3 and π/5 respectively.

The total THD is: Before transformer connection: 42.07%
After transformer connection: 30.13%
3rd harmonic: Before transformer connection: 23.38%
After transformer connection: 0.13%
5th harmonic: Before transformer connection: 23.56%
After transformer connection: 0.10%

B. Three Phase Inverter

The Output Voltage of 3-Φ inverter is shown in Figure 10. The Figure 11 shows the harmonic spectrum of the system without employing Selective Harmonic Elimination.

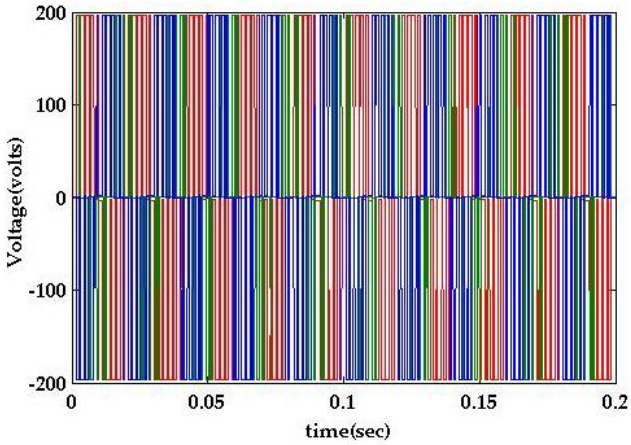

Figure10. Output Voltage of 3-Φ inverter

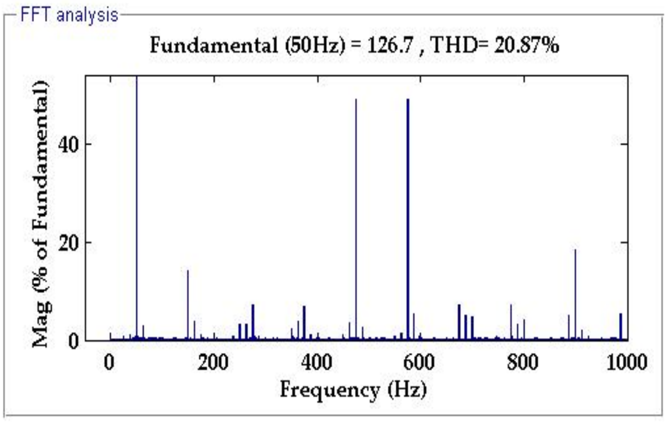

Figure 11. Harmonic Spectrum without employing SHE

It can be observed from the Figure 10 that 3rd harmonics are absent in the output Voltage of a 3-Φ inverter. Thus, the technique has been employed to illustrate its effectiveness on the 5th harmonic. The harmonic spectrum of the output voltage with the SHE employed on the 5th harmonic is shown in figure 12.

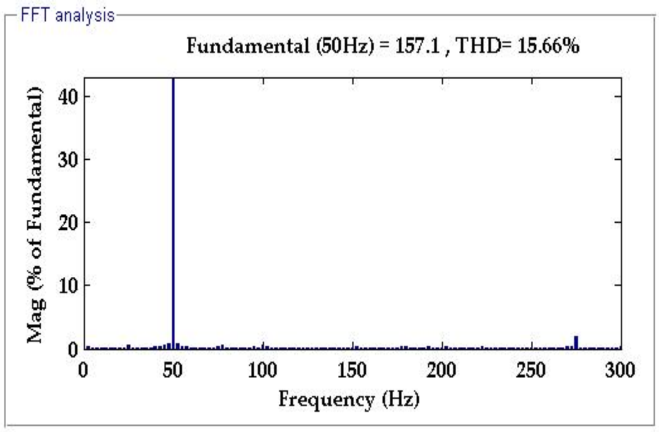

Figure 12 Harmonic Spectrum with employing SHE for 5th harmonic

VII. CONCLUSION

The methodology and implementation of the Selective Harmonic Elimination using Transformer connection has been discussed in the paper using PV as a source. The results have been obtained through simulation using MATLAB/ Simulink environment. The dominant harmonics in the single phase inverter being 3rd and 5th harmonic are eliminated successfully using this technique. The dominant harmonic in the three phase inverter being 5th harmonic is successfully eliminated using the technique. Further work can be carried out by exploring other novel techniques of selective harmonic elimination.

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