Harmonics Analysis of Nine Phase Inverter Drive Using Buck Boost Regulator for Renewable Energy Applications

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Abstract : Most of the power generation depends on the fossil fuel energy resources like coal and oil which is a big challenge for limited storage and global warming. Renewable natural energy sources are the best option to overcome these challenges. Renewable energy sources like wind and solar energy highly depends on climatic conditions results fluctuating power generation. Dc to Dc converters are suitable for the fluctuating power generations and inverters are suitable for the motor speed control devices. Multy/poly phase motor drives and inverters are the better solution for high torque density and heavy loads. Hence buck boost regulators and inverters play's a major role in the field of motor drives. Electronics devices are feed by nonlinear frequencies through voltage and current called Harmonics, these nonlinear frequencies are higher than fundamental frequencies causes harmonic distortion, which increases the rms current and generates more heat. Presented paper focused on the Harmonics analysis of nine phase inverter drive using buck boost regulator for renewable energy application carried out by Matlab/Simulink.

IndexTerms - Buck Boost Regulator, Harmonics, LCL Filter, Nine phase Inverter, Nine phase Induction Motor, Matlab/Simulink.

I. INTRODUCTION

'Electricity' is a human developed energy source plays a vital role in the modern world. All over world most of the power generation depends on fossil fuels like coal, oil and natural gases. Fossil fuels are nonrenewable and limited, generates the need for natural energy sources which are constantly replenished and will never run out like water (hydro energy), Air (wind Energy), Sunlight (Solar Energy), Biomass Energy, Hydrogen Energy etc. These natural resources highly depend on climate conditions and a big challenge for a constant power generation [1]-[3]. Dc to Dc converter gives constant output voltage with respect to variable input voltage also called as 'Choppers'. These regulators step up voltage supply with Boost regulator and step-down voltage supply with Buck regulator. Hence Buck Boost Regulators are the best option for the self-regulating power supply [5]-[6]. Three phase drives are generally used for low torque density, if three phase drives are replaced with multiphase drives; it is more advantageous for the high torque density and heavy loads [4]. Since, most of the power supply is limited with the three phase, if multiphase motor drives are feed by multi-phase inverters, multiphase drives are the best examples for the high torque motor drives like aviation, hybrid electric cars, traction and battery-operated electric vehicles [8]-[9].

Presented paper focuses on the constant output voltage supply with respect to self-variable input voltage supply and reduction of Total Harmonics Distortion (THD) in renewable energy sources using Buck Boost Regulator and Nine Phase Inverter for motor drives load. Building blocks are as shown in Fig.1.

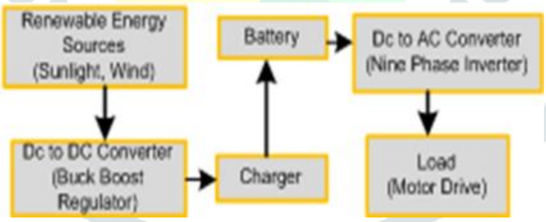

Figure.1. Building Block of Buck Boost Regulator using Nine Phase Inverter Drive

II. BUCK BOOST REGULATORS

Buck Boost converters are the DC to DC converters where, output voltage can be step up or step down with respect to input voltage hence also called as step up and step down converters. This fundamental operation of buck boost converter gives major importance in the field renewable energy power generation. Where buck boost converters overcome the challenge of fluctuations in power supply due variable climate conditions and gives self regulating power supply [4].

Dc to Dc converters are mainly divided into three types are:

1. Buck Converter: where,
   - Vinput>Voutput,
   - Iinput<Ioutput,

   Duty cycle < 50% and voltage equation is;

$$vo = vin\mathrm{D}\ . \qquad (1)$$

2. Boost Converter: where,
   - $V_{input} < V_{output}$,
   - $I_{input} > I_{output}$,

   Duty cycle > 50% and voltage equation is;

$$vo = vin\frac{1}{(1-D)}\ . \qquad (2)$$

3. Buck Boost Converter: where,

- V_{input}(variable) = $-V_{output}$(constant)

Duty cycle = 50% and Ratio of output voltage with respect to input voltage equation is;

$$\frac{Vo}{Vin} = -\frac{D}{(1-D)}. \qquad (3)$$

Where, 'Vo' is output voltage, 'Vin' is input voltage and 'D' is duty cycle.

The main working principle of Buck Boost converter is as shown in Fig.2. and Fig.3.

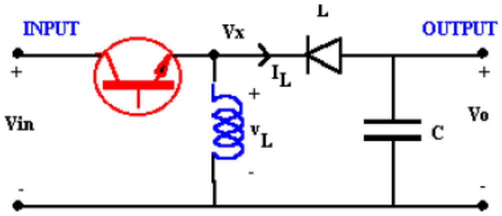

Figure.2. Circuit diagram of Buck Boost converter

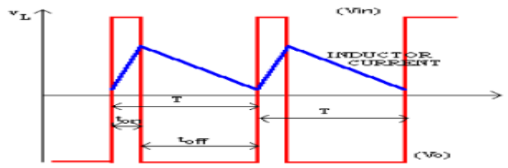

Figure.3. Conduction period of Buck Boost converter

An inductor in the input circuit resists sudden variations in input current. When switch ((MOSFET) is ON an inductor stores energy from the input in the form of magnetic energy and discharges it when switch is OFF. In Buck mode output voltage is less than input voltage where, duty cycle is less than 50% for ON and OFF operation of switch. In Boost mode output voltage is more than input voltage where, duty cycle is more than 50% for ON and OFF operation of switch. In an ideal mode output voltage is equal to input voltage where, duty cycle is equal to 50% for ON and OFF operation of switch. The capacitor in the output circuit is assumed large enough that the time constant of RC circuit in the output stage is high. The large time constant compared to switching period ensures that in steady state a constant output voltage Vin = -Vo(t) exists across load terminals [4]-[5].

III. NINE PHASE PWM INVERTERS

Topology of Nine phase inverter constructed with nine legs and eighteen switches is as shown in Fig.4.

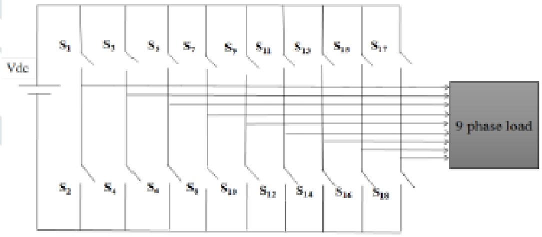

Figure.4. Topology of Nine Phase Inverter

An inverter is most commonly used for motor drive applications in industries, speed of the induction motor can be varied by using voltage to frequency method and most of the inverters use semiconductor switching devices. An inverter topology uses two switches connected in series as one inverter leg which perform the ON and OFF operation with upper and lower switch alternatively. The number of inverter leg depends on number of phases [10]-[12].

Switching Cycles and switching period of inverter legs with 180^0conduction mode is as shown in Fig.5. and Fig.6.

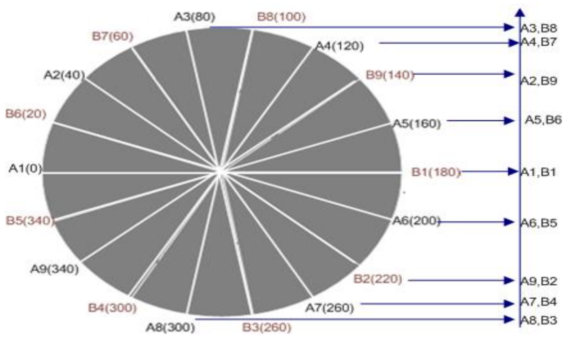

Figure. 5. Switching cycles of Inverter legs with $180^{0.}$ Conduction mode

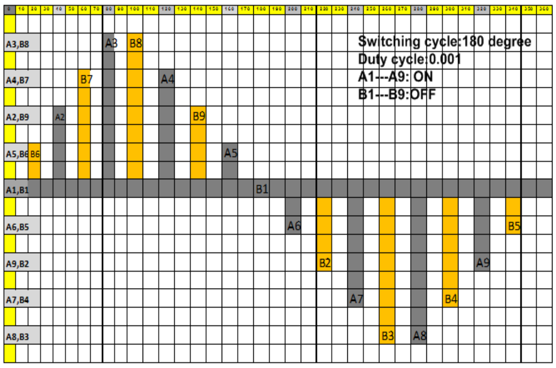

Figure. 6. Switching Sequences of Inverter legs with 180^{0}. Conduction mode

Motor drive is fed by nine phase inverter presented in Fig.4. There are nine push pull drives, the control signals to the inverter switches are generated through pulse generators with pulse width modulation (PWM), which are 40° out of phase with each other. The PWM trigger signals drive IGBT (Insulated-Gate Bipolar Transistor) switches. All the switches operate for a period of 180^{0}. The amplitude of the generated pulse decides the modulation index, as the modulation index reaches unity harmonics can be reduced. Harmonics distortion is the major factor responsible for the poor efficiency in power electronics systems [7]-[8].

IV. Total Harmonics Distortion

Voltage or current waveform of (a) Sine Waveform of Linear Load (b) scattered waveform of Nonlinear load is as shown in Fig.5.

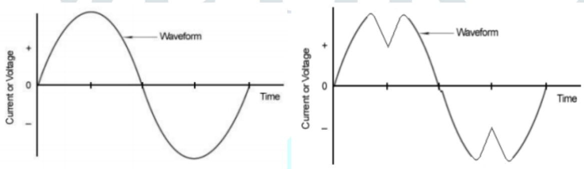

Figure.7. (a) Sine waveform of linear load (b) scattered waveform of nonlinear load

Harmonics are the non-sinusoidal frequencies of voltage and current that are odd integral multiples of fundamental power supply frequency (50HZ or 60HZ), resulting in the distortion of supply waveform due to nonlinear loads. Power applied to harmonic frequencies will not provide any additional energy nor influences any mechanical torque at the output of inverter, but this frequency of harmonics dissipated as heat in the load which affects the power factor and switching losses.

The percentage of harmonics in an AC circuit output waveform is called Total Harmonic Distortion (THD). More percentage of harmonics results scattered waveform as shown in Fig.7(b) which reduced the efficiency of the system. Percent of THD of voltage can be calculated using equation (4). If Voltage is replaced with current or power, same equation is applicable for current and power.

$$THD = \frac{\sqrt{V2^2+V2^3+V2^4+\cdots Vn^2}}{V1} * 100\%. \qquad (4)$$

Where, 'THD' is the Total Harmonic Distortion,'V2' to 'Vn' are number of harmonic component of the voltage, V1 is fundamental component of the voltage.

Energy released by renewable sources like solar or wind are variable and power supply to load is nonlinear hence aim of this work is to maintain constant voltage supply and reduce percentage of THD trough LCL filter and RL load using nine phase inverter. [11-18].

V. Schematic Of Buck Boost Regulator Using Nine Phase Inverter For Variable Voltage

Schematic diagram of PWM nine phase inverter using Buck Boost Regulator with R-load and LCL filter with RL load in each phase is as shown in Fig.8. and Fig.9.

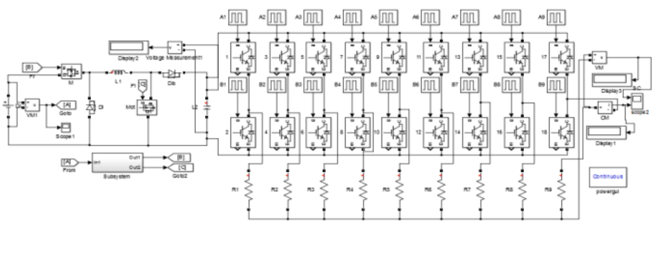

Figure.8. Schematic of Nine Phase Inverter Drive using Buck Boost Regulator with R load

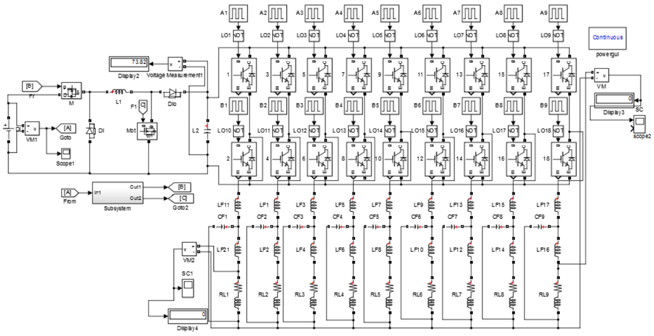

Figure.9. Schematic of Nine Phase Inverter Drive using Buck Boost Regulator with LCL filter and RL load

Presented schematic in Fig8 and Fig9 designed with the Buck Boost Regulator and Nine phase PWM Inverter using LCL filter for R and RL load. In Buck Boost Regulator variable input voltage from 150v to 250v is feed by {A} and constant output voltage of 180v is maintained by switches (MOSFET1and MOSFET2). Buck mode is maintained by MOSFET1 ON and OFF operation with the duty cycle less than 50% by pulse generator {B},Boost mode is maintained by MOSFET2 ON and OFF operation with the duty cycle more than 50% by pulse generator {C} to maintain constant output voltage at 180v. Duty cycle has been taken as per equation (3).

Where, input voltage (Vin) varies from 150v to 250v and the constant output voltage is 180v (Vo). The values Of Inductor and Capacitor calculated accordingly.

In Nine phase PWM Inverter drive, nine push pull drives are triggered by PWM signal, thus there are nine PWM trigger signals which are 40° out of phase with each other. The PWM trigger signals drive IGBT (Insulated-Gate Bipolar Transistor) switches. All the switches operate for a period of 180°.

IGBT switches are fed by LCL filters for RL load, filters arranged with the combination of one capacitor and two inductors. It provides better minimization of harmonics in the nine-phase inverter compare to other filter techniques. Main significance of using the LCL scheme at the inverter output is low distortion in reactive output power and low switching frequency. [13]-[16].

Resonant frequency of the circuit with LCL-filter scheme can be obtained by equation (5).

$$fo = \frac{1}{2\pi}\sqrt{\frac{L1+L2}{L1L2C}} \quad . \qquad (5)$$

Where, f_o is the frequency of resonance, 'L' is an 'Inductor' and 'C' is a 'capacitor', resonance frequency has been taken as 150Hz to eliminate 3[rd] harmonic (3x50Hz). The values of inductor and capacitor have been taken accordingly.

VI. SIMULATION RESULTS

The results has been obtained using buck boost regulator and nine phase inverter drive with and without filter are as shown in Fig.10. and Fig.11. Waveforms are generated for line voltage and line current. Simulation work has been done for nine phase PWM Inverter Drive with and without LCL filter. Speed Drives studied and simulated for rated frequency 50Hz. The results obtained are analyzed for harmonics and (THD).

FFT analysis has been done to obtain voltage waveforms using simulink and the results are compared, with and without LCL filter of nine phase PWM inverter drive.

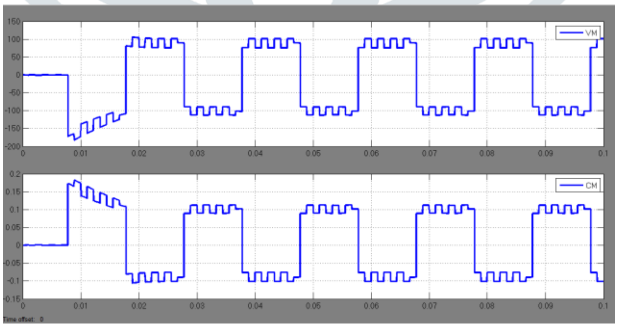

Figure.10. Line Voltage and Line Current waveforms without filter

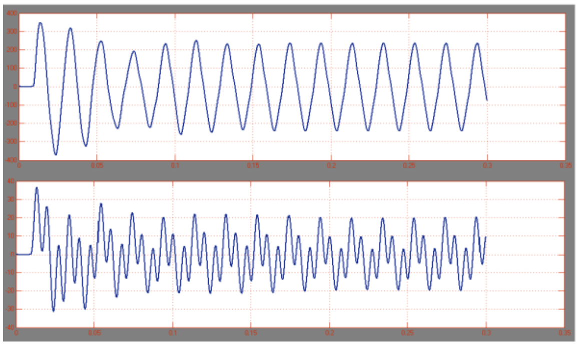

Figure.11. Line Voltage and Line Current waveforms with LCL filter

Fig.12 and Fig.13 shows the FFT analysis of nine phase Inverter drive without filter for 50Hz and with LCL filter using buck boost regulator respectively. The comparison of percentage of reduction in THD with normal drive and with LCL filter is as shown in Table.1. Tremendous change in presence of odd harmonics content with and without LCL filter for f= 50Hz is as shown in Table.2.

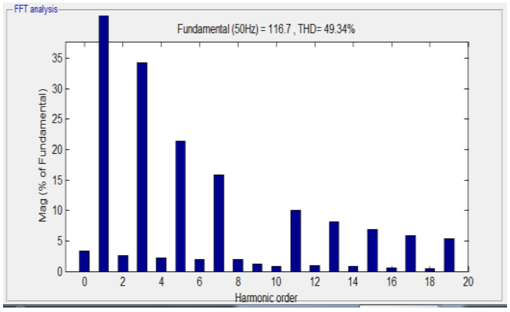

Figure.12. FFT analysis without filter for 50 Hz using buck boost regulator

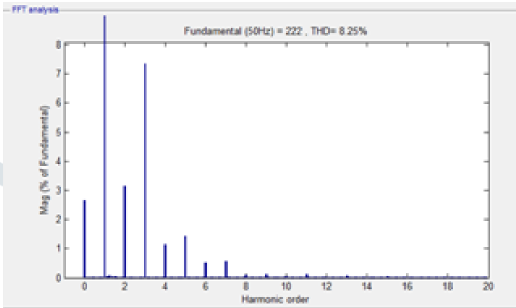

Figure.13. FFT analysis with LCL filter for 50 Hz using buck boost regulator

At fundamental frequency f= 50 Hz, $V_{in(dc)}$= 150 to 250v, $V_{o(ac)}$= 180v, THD % is as shown in Table.1.

Table.1. Overall THD comparison without and with LCL filter for frequency 50 Hz

Modes	THD %
Without LCL Filter	49.93%
With LCL Filter	8.25%

At fundamental frequency f= 50 Hz, $V_{in(dc)}$= 150 to 250v, $V_{o(ac)}$= 180v, THD % comparison for nth harmonics is as shown in table.2.
Table.2. Overall THD comparison of nth harmonics without and with CLC filter for frequency 50 Hz using buck boost regulator.

Harmonics	Without Filter THD %	With Filter THD %
3rd	34.70%	7.96%
7th	16.92%	0.00%
9th	0.00%	0.00%
11th	11.85%	0.00%
13th	10.34%	0.00%
17th	8.05%	0.00%
19th	0.00%	0.00%

VII. CONCLUSION

A buck boost regulator and nine phase Inerter drive has been constructed using Simulink/Matlab to study the constant output voltage of 180v, harmonics and THD of the nine-phase inverter and compared the results using Nine Phase Inverter and LCL filter. It is observed that the output voltage is maintaining a constant 180v with respect to variable input voltage from 150v to 250v. Harmonics and percentage in Total Harmonics Distortion (THD) at the nine-phase inverter output is found to be less using LCL filter. In future this work can be used to drive nine phase induction motor.

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