# Analysis of Voltage Frequency Control Method for Nine Phase Induction Motor Drive at very low frequency

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**Abstract- Three phase motor drive has limited torque density, hence Multiphase motor drives are better solutions for high torque density and heavy loads. Nine Phase Inverter is designed to drive Nine Phase Induction Motor. Nine phase inverter designed with nine legs and eighteen semiconductor switches to fed nine stator windings displaced by $40^0$ phase shift. Control signals of inverter are designed with PWM techniques to reduce Total Harmonic Distortion (THD). Open Loop scalar Voltage Frequency control method maintain the torque variation and air gap flux constant with synchronous speed of motor, in order to achieve higher run time efficiency. In this work, a Nine Phase Inverter is run with eighteen control signals simulated with Matlab/Simulink and also implemented by generating the control signals using microcontroller 8051. The analysis of experimental data carried out with V/F control method by varying voltage with respect to frequency with no load condition. The results are obtained and validated using power analyzer.**

**Keywords –Nine phase Induction Motor, Nine phase Inverter, PWM, V/F control, Matlab/Simulink, Microcontroller 8051, Power Analyzer.**

## I. INTRODUCTION

Three phase drives are generally used for heavy torque loads. If the phases are increased beyond three then it is more advantageous. The major advantages of using a multiphase drive machine instead of a three-phase machine are high torque density, reduced torque pulsations, greater fault tolerance, reduction in the required rating per inverter leg, better noise suppression, smoother torque and reduction of the torque ripple magnitude. Multiphase drives have major applications in high torque motor drives like' ship propulsion, electric aircraft, hybrid electric vehicles, electric traction and battery-powered electric vehicles etc.

An Induction Motor is energized by power supply and setup electromagnetic field around stator winding called synchronous speed (Ns) which, cuts stationary rotor and induces electromagnetic force in rotor winding and current flow. The conductors are placed in the stator's magnetic field, this exerts a mechanical force on them by Len's law, Thus, by Lenz‟ s law a torque is produced which tries to reduce the relative speed between the rotor and the magnetic field. Hence the rotor will rotate in the same direction as the flux which drives the motor. Hence the rotor speed Nr always remains less than the synchronous speed Ns. The equivalent circuit of induction motor is given in Fig.1. Speed, torque and current equations are given as shown in equations (1), (2) and (3).

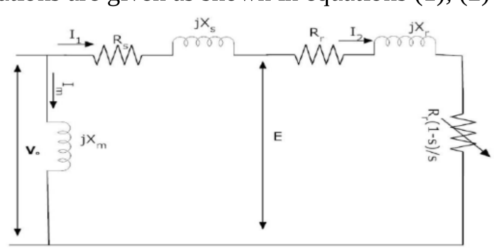



Figure.1. Equivalent circuit of Induction Motor

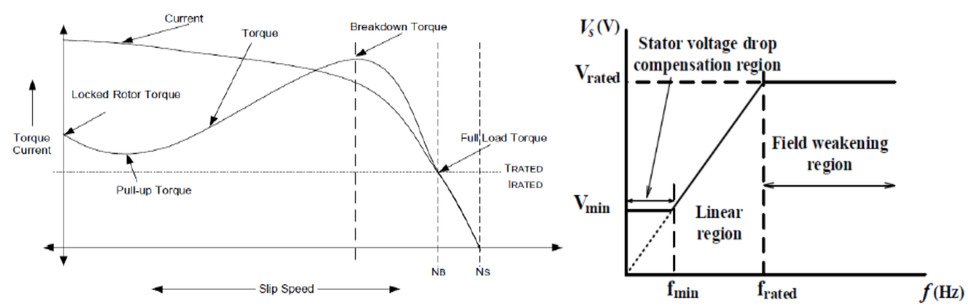
$$s = \frac{Ns-Nr}{Ns} \tag{1}$$

$$I2 = \frac{Vo}{\left(Rs+\frac{Rr}{s}\right)+j\,(Xs+Xr)} \tag{2}$$

$$T = \pm \frac{\left(\frac{3Vo^2 Rr}{s}\right)}{ws\left[\left(Rs+\frac{Rr}{s}\right)^2+(Xs+Xr)^2\right]} \quad (3)$$

Where,
s= slip
Ns= Synchronous speed
Nr= Rotor speed
Xm= Magnetizing Reactance
Xs= Stator Reactance
Xr= Rotor Reactance
Rs= Stator Resistance
Rr= Rotor Resistance

Voltage/frequency (V/f) control is the most popular scalar control scheme that varies the terminal voltage in proportion to the supplied frequency to maintain the air-gap flux at approximately the rated V/f ratio as shown in Fig.2. (a) and (b) Synchronous speed can be controlled by varying the supply frequency. Voltage induced in the stator is □1 ∝ Φ □where Φ is the air-gap flux and f is the supply frequency, by neglecting the stator voltage drop the terminal voltage is □1 ∝ Φ □. Thus, reducing the frequency without changing the supply voltage will lead to an increase in the air-gap flux which is undesirable. Hence whenever frequency is varied in order to control speed, the terminal voltage is also varied to maintain the V/f ratio constant. Thus, by maintaining a constant V/f ratio, the maximum torque of the motor becomes constant for changing speed. [1].




(a) (b)

Figure.2. (a)Torque-Speed characteristics (b)V/f Controlled Induction Motor

A multiphase inverter is most commonly used for motor drive applications in industries. The function of the inverter is to convert DC voltage supply to AC voltage supply of desire magnitude and frequency. An inverter is the voltage or current source device. Most of the inverters use power MOSFETs or IGBTs as semiconductor switching devices. An inverter can be constructed with Half or full bridge semiconductor devices. The inverter topology uses two switches connected in series, each inverter leg performs the ON and OFF operation with upper and lower switch alternatively. The number of inverter leg depends on number of phases. The control signals to the inverter are generated by microcontroller and applied to the gate of semiconductor devices which controls the motor speed. The variation in synchronous speed of an induction motor affects the torque density, air gap flux and efficiency of the motor.

In PWM inverters, gate of semiconductor device is controlled by PWM control singles. The Pulse Width Modulation (PWM) technique is characterized by the generation of constant amplitude pulse by modulating the pulse width or duty cycle. In this technique the control signals to the inverter switches are pulse width modulated (PWM) signals. The amplitude of the generated pulse decides the modulation index. The presence of harmonics depends on selection of modulation index. Harmonics can be reduced by making modulation index to unity. The Fig.3(a) shows PWM control signal generated by microcontroller, thee output is changed by varying the width of the pulses, also frequency of the two signals is nearly made equal [1-7].

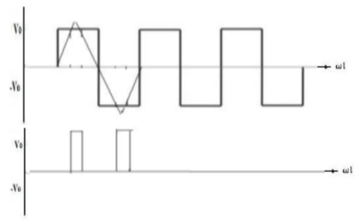


Figure.3. PWM signal generation

The presented work focused on the analysis of V/F control of Nine Phase Inverter to drive to run Nine Phase Induction Motor. PWM Control signals are simulated with Matlab/Simulink and generated through the microcontroller 8051. Analysis of experimental data carried out with V/F control method by varying voltage with respect to frequency.

## II.DESIGNOF NINE PHASE INDUCTION MOTOR DRIVE

The N phase Induction Motor drive has "n" number of stator windings displaced by "360/n" phase. Hence nine phase induction motor has nine stator windings displaced by $40^0$ phase shift and squirrel cage rotor windings are used in the motor. The nine phase induction motor is fed by nine phase inverter is as shown in Fig.4. [8-11].

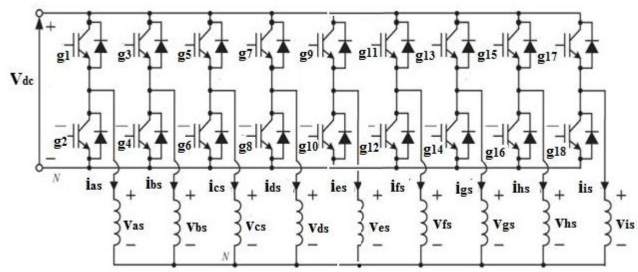



Figure.4. Nine Phase Induction Motor drive by Nine Phase Inverter

Nine Phase Induction Motor designed with specifications shown in table 1:

Table 1. Specifications of Nine Phase Induction Motor

| Motor | Induction Motor |
|---|---|
| Rotor Type | Squirrel cage |
| Supply | 9 phase |
| Rated Voltage | 230V |
| Rated Frequency | 50Hz |
| Hp | 2hp |
| pole | 2 pole |
| speed | 3000rpm |
| class | F |
| connection | star |
| Output power | 1.5kw |

## III. DESIGN OF NINE PHASE INVERTERS

Fig.5. shows the Nine phase inverter, a Nine phase inverter is energized by a fixed DC voltage and constructed with nine legs and eighteen switches to control the output of the Nine Phase Induction Motor, the MOSFET's are used as a semiconductor switching devices. There are nine push pull drives, each drive is triggered by PWM signal as shown in Fig.6, there are eighteen PWM trigger signals which are 40° out of phase with each other and all the switches conduct for the period of 1800 [12-15].

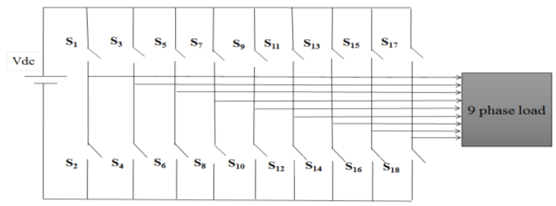



Figure.5. Topology of Nine Phase Inverter

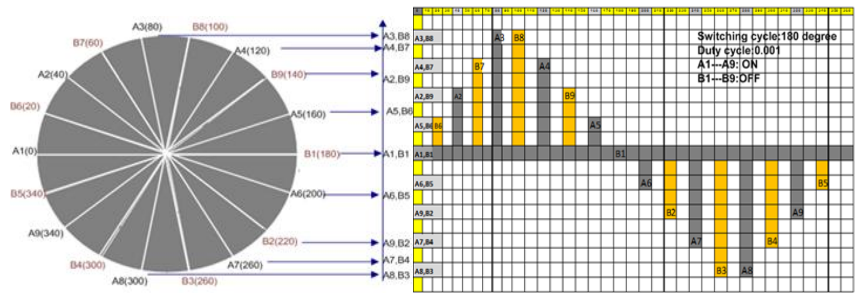



Figure.6. Switching Cycle of Inverter legs with 1800. Conduction mode

*3.1 Simulation of Nine Phase Inverter*

A sinulink model of nine phase inverters constructed with eighteen switching devices with DC supply is shown in Fig.7. The inverter is controlled by PWM control singles. The design of control signals include nine legs and eighteen PWM trigger signals which are 40° out of phase with each other. The control signals are arranged in such a way that alternate switching of positive and negative signal are provided to each switch at a regular interval of time. The switching pulses of all the legs of the switching devices are monitored using a scope.

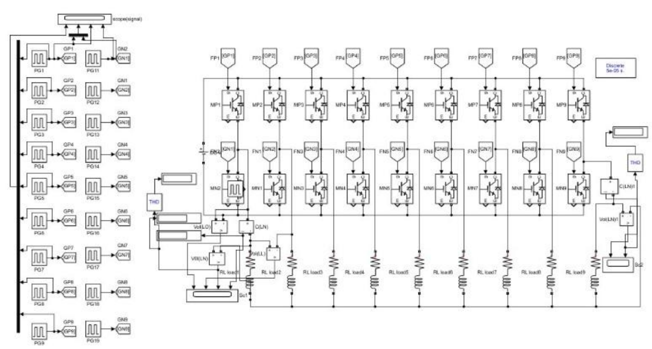


Figure.7. Simulink model of Nine Phase Inverter with PWM Technique

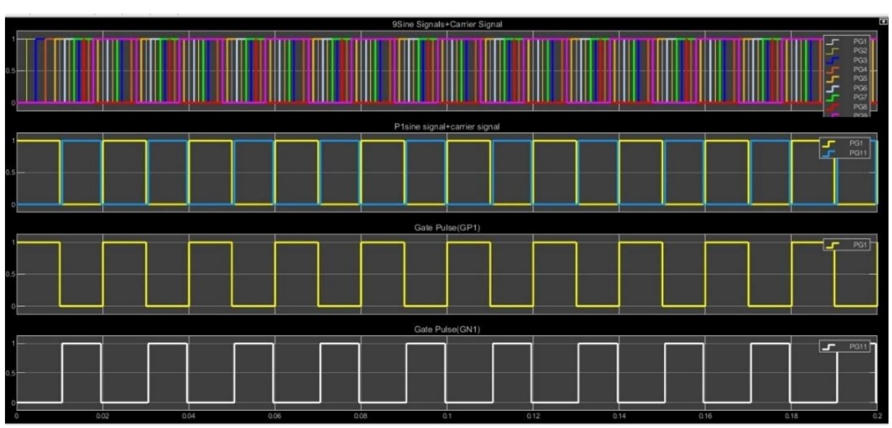


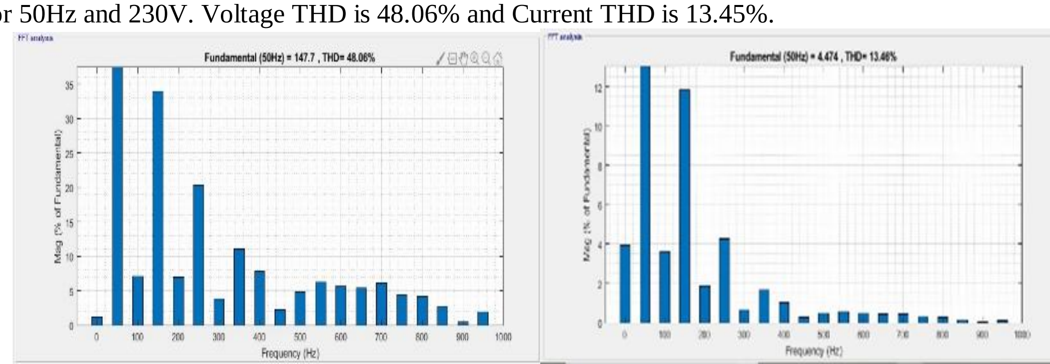

Figure.8. Simulink model of Nine phase PWM signal generation with square waveform

*3.2 Simulation Results with PWM Inverter*

The results obtained using nine phase inverter drive with PWM technique are as shown in Fig.9. Waveforms are generated for line voltage and line current. Simulation work has been done for nine phase PWM inverter Drive. Each control signal is studied and simulated with RL load for rated frequency of 50Hz and dc voltage (Vdc) of 230v. The results obtained are analyzed for harmonics (THD) distortion.

Figure.9. (a)Line-Output voltage (b)Line-Line voltage (c)Line-neutral Voltage and (d)Line-neutral Current waveforms of PWM Inverter

FFT analysis has been done to obtain voltage and current THD using Simulink/Matlab and the results are compared with PWM inverter drive. Fig.10. (a) and (b) shows FFT analysis of nine phase Inverter drive with PWM Inverter Drive for 50Hz and 230V. Voltage THD is 48.06% and Current THD is 13.45%.




(a) (b)

Figure.10. (a) Voltage THD (b) Current THD with PWM Inverter for 50 Hz

*4.3 Generation of PWM Control Signals for Nine Phase Inverter*

Results obtained using rated frequency(50Hz) and voltage(230V) are taken as a reference and control signals for very low variable frequency and voltage are generated using Simulink. FFT analysis has done to obtain voltage and current THD. The nine phase inverter drive output voltage is obtained and run to monitor V/F control of the Nine Phase Induction Motor.

## IV. EXPERIMENTAL SETUP OF NINE PHASE INDUCTION MOTOR DRIVE

The methodology for the illustration of Nine Phase Induction Motor is shown in block diagram of Fig.11. Control signals are generated by Microcontroller kit and feed to MOSFET's of nine phase inverters through driver circuit. The generated control signals used to run nine phase induction motor with variable V/F control method at no load condition. Results are monitor with power Analyzer to study various parameters of Nine phase Induction Motor. The complete experimental setup shown in Fig.12.

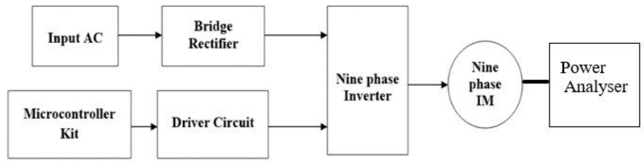



Figure.11. Methodology setup of Nine Phase Induction Motor Drive


Figure.12. Experimental setup of Nine Phase Induction Motor Drive

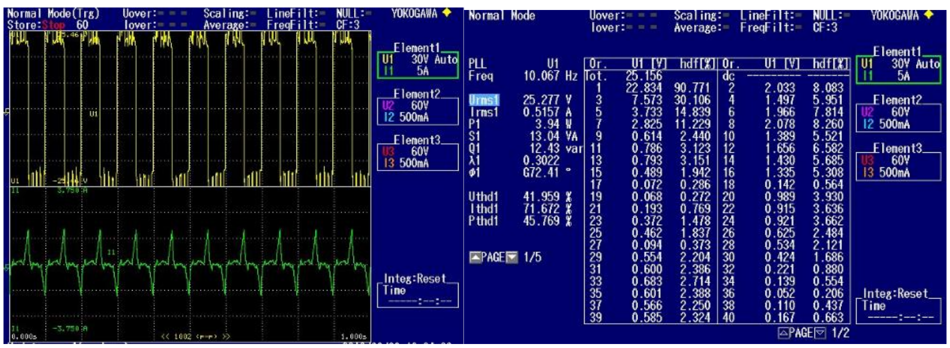
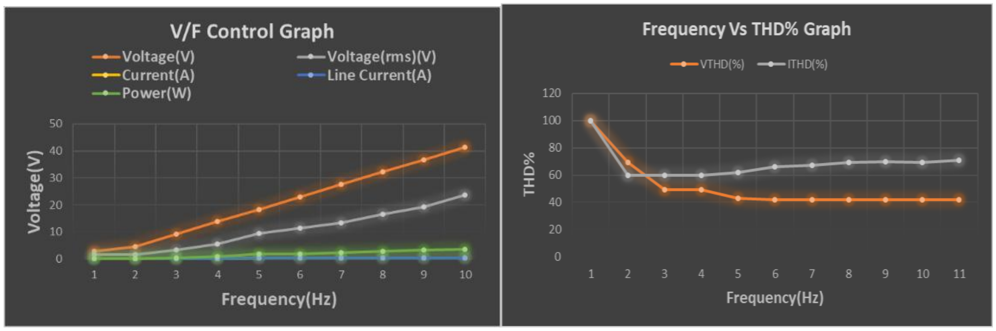



Figure.13. Power Analyzer results of Nine Phase Induction Motor Drive for 10 Hz

The analysis of V/F control method has been done to obtain different parameters of Nine phase Induction Motor for very low frequency using Power Analyzer. Experimental results are monitored, studied and compared with theoretical data. Table.2. shows V/F control parameters of Nine Phase Induction Motor drive for 0.6Hz-10Hz and 2.76V-46V respectively. Fig.13. (a) and (b) shows the graphical representation of theoretical and experimental data analysis between V/F control and speed verses torque control.

Table.2. V/F control parameters of Nine Phase Induction Motor drive

| V/F control (Theo) | Speed (rpm) (Theo/Exp) | Voltage (rmsV) | Current (rmsA) | Power (W) | Line Current (A) | VTHD (%) | ITHD (%) |
|---|---|---|---|---|---|---|---|
| 2.76v/0.6Hz | 36/10rpm | 1.5v | 0.06A | 0.09W | 0.02A | 100% | 100% |
| 4.6v/1Hz | 60/51rpm | 1.6v | 0.11A | 0.16W | 0.02A | 69% | 60% |
| 9.2v/2Hz | 120/111rpm | 3.2v | 0.17A | 0.43W | 0.14A | 49% | 46% |
| 13.8v/3Hz | 180/176rpm | 5.4v | 0.24A | 0.84W | 0.20A | 49% | 60% |
| 18.4v/4Hz | 240/235rpm | 9.5v | 0.37A | 1.9W | 0.31A | 43% | 62% |
| 23v/5Hz | 300/295rpm | 10v | 0.36A | 1.88W | 0.32A | 42% | 66% |
| 27.6v/6Hz | 360/348rpm | 13.4v | 0.4A | 2.34w | 0.33A | 42% | 67% |
| 32.2v/7Hz | 420/414rpm | 16.5v | 0.4A | 2.8W | 0.34A | 42% | 69% |
| 36.8v/8Hz | 480/477rpm | 19.3v | 0.47A | 3.2W | 0.35A | 42% | 70% |
| 41.46v/9Hz | 520/535rpm | 23.6v | 0.49A | 3.6W | 0.36A | 42% | 69% |
| 46v/10Hz | 600/595rpm | 25.2v | 0.51A | 3.9W | 0.37A | 42% | 71% |




(a) (b)

Figure.13. Experimental Data Analysis (a) VF control graph(b) THD% graph

## V. CONCLUSION

Theoretical and Experimental data analysis of V/F control method and percentage of THD for Nine Phase Induction Motor has been studied for very low frequency of 0.6Hz to 10Hz with no load conditions. The Experimental data analysis of V/F control method and percentage of THD has been successfully obtained and analyzed, there is an improvement of linearity at very low V/F is observed, hence V/F is constant at very low frequency. therefore, it is concluded that the power consumption at very low V/F is found this improvement work has been validated with the results.

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