Grenze International Journal of Engineering and Technology, June Issue

Performance Analysis of V/F and Variable Frequency Control Schemes for an Induction Motor

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***Abstract*—This paper presents the different strategies used for controlling the speed of induction motor. Induction motors are widely used in various industrial and domestic applications. The aim of this work is to efficiently use the solar power from a PV system to run an AC Induction Motor and control the speed of the motor using various techniques. In this work PV cells are used to obtain the power which is given to a buck converter to obtain a constant DC output. This DC output is used as input to the inverter where the DC power is converted to AC power. The output of inverter is AC power and is supplied to the Induction motor. Speed of the Induction motor is continuously monitored. Whenever there is change of speed in the motor due to variation in the torque the speed of the motor decreases and this will be controlled by using the analyzed techniques that will adjust the duty cycle of the switches used in the H bridge Inverter accordingly. In this work Variable frequency method and V/f method are used to control the speed of the motor. This will change the input to the motor and speed will be corrected and maintained at a constant value.**

***Index Terms*— PV system, Variable frequency, MPPT, PWM pulses, Torque.**

I. INTRODUCTION

In recent times, the invention is increased by expanding the usage of renewable energy in the industry which is more cost effective and it ensures the future supply of clean energy. This shows that the developing energy sector is steadily replacing the fossil fuel in the energy sector by reducing the level of pollution like emissions of carbon, nitrogen etc. the energy that is originating from the nature or through any natural form are always developing. This energy is commonly represented as new technology, that harness the power of nature. Due to more technological advancements and the usage of reduced expensive methods to retain solar energy. It has become a most important source of energy.

To generate the sunlight into electrical energy. The cells are made of silicon called as photovoltaic cells even known as solar cells. PV system is composed of two types namely grid-connected and stand-alone [1]. Photons, or the energy packets strikes on a solar cell, which produces electricity through the photovoltaic effect. The solar panels produce direct current (DC). Computer systems, mobile phones, and other electronic gadgets are built to operate on the grid's alternating current (AC). According to the National Renewable Energy Laboratory, the availability of solar radiation received on Earth in an hour is larger than the amount consumed by every person in the universe in a year. For thousands of years, people have been harnessing the solar energy.

As a result, an inverter is used which converts solar energy from DC power to AC power so that it can be used to charge digital gadgets or transferred to the grid for usage [2]. The functioning of the PV structure is dependent

Grenze ID: 01.GIJET.8.2.536

on the operating conditions. The major factors that affect the maximum power generated from a PV source are the load characteristic, temperature, and irradiance. The maximum power point (MPP) of a solar array's I-V characteristics is the point at which the product of current and voltage is the highest, providing the highest current and voltage. A maximum power point tracker (MPPT) is often used to ensure the correct functioning of the PV system and to collect the maximum current at MPP [3]. The productivity of the Pv panel changes based on the MPPT algorithm's performance, The efficiency of the PV module varies depending on the MPPT algorithm's efficiency, the PV array's reliability, and the performance of the inverter in use[4].

The converted AC Power is supplied as input to the Induction motor and the speed is controlled using Variable frequency method by keeping the voltage constant and by varying the duty cycle of the inverter using PWM technique[5]. Speed of the Induction motor is continuously monitored. Whenever there is change of speed in the motor due to torque load the speed of the motor decreases. With the help of microcontroller the PWM pulses are varied and the speed is controlled accordingly [6]. The Buck converter, H Bridge Inverter, Maximum power point tracker are efficiently used.

II. SYSTEM STRUCTURE

This is the block diagram of the project. The power for the entire system is taken from the solar panel as the solar energy is the cleanest form of energy and our aim of the project to encourage generation of clean green energy. The power generated by the panels are maximized by the use of MPPT.

MPPT is used to track the voltage and current which will result in tracking the maximum power. The voltage which is regulated by the MPPT is given to a controlled buck converter. This buck converter will have feedback to increase the efficiency of the converter and to decrease time taken by the converter to provide designed output. The output from the buck converter is given as input to the H bridge inverter which converts dc power to ac power.

The output of the buck converter is given as input to the inverter. This inverter converts dc to ac power. The converted ac power is given to an induction motor. By applying the torque load the speed is decreased. This speed is monitored continuously, which by controlling the pulses given to the inverter, tries to maintain the speed of the motor even if there is change in the load applied. Thus, this project is combination of Power generation and utilization.

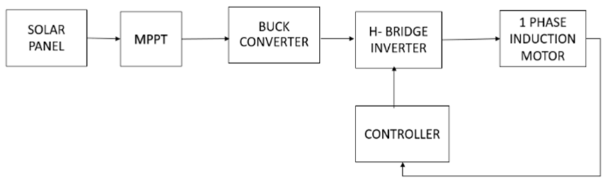


Fig. 1: Block Diagram of a system

A. Maximum Power Point Tracking (Perturb and Observe Algorithm)

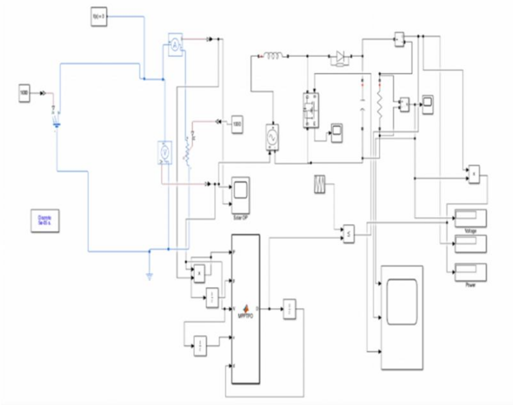
P&O procedures is one of the appreciated and reasonable strategy to reap the most possible power out of a PV framework. The calculation depends on current, voltage detecting and power estimation. It is depicted bothering of the PV framework and discovery of the result force of a PV board. This is carried out by shifting the obligation proportion of the converter to acquire MPPT naturally. On the off chance that the new power is not exactly the old power put away in a memory, the MPPT procedure diminishes the reference voltage. Yet, on the off chance that the new power P(n) is more prominent than the old power P(n-1), the reference voltage is expanded until the ideal greatest result power is accomplished.

The figure 2 shows the simulation design of Maximum power point tracking using Perturb and Observe Algorithm. Figure 3 shows the output waveform the MPPT simulation, which shows the maximum power tracked from the MPPT. At 0.1 sec the MPPT is tracking the maximum power. The purple waveform represents the maximum power obtained from the panel and the red waveform represents the maximum voltage obtained from the panel.

B. Buck Converter

Buck converter is a Power Electronic device which is called as Step down converter which means that the output voltage is less than the input voltage. The operation is divided into two different modes.

In Mode 1 – The pulses are given to the switch, the switch can be IGBT, BJT or MOSFET.



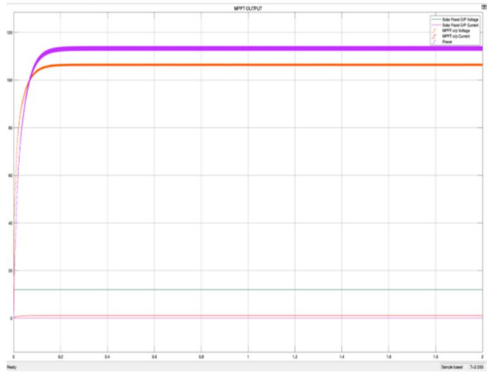


Fig. 2: Simulation of MPPT Fig. 3: Simulation Output of MPPT

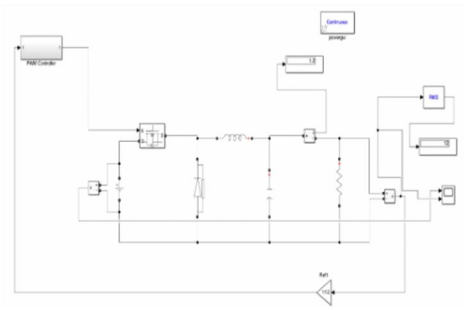
In this project MOSFET is considered. The switch is turned on, the current flows from inductor, load. In this time period the capacitor also gets charged. The inductor current and the inductor voltage also gets increased.
In Mode 2- The switch pulses will be zero and the switch is turned off. The freewheeling diode starts conducting because of the stored energy. The current flows from Inductor, Capacitor, load and then back to free-wheeling diode. In this period of time the inductor current decreases.
The output of the buck converter using gain is sent to a feedback loop consisting of PI controller which generates modulated signal. The Ramp signal is used as carrier signal which is compared. The gate signals to the MOSFET switch are varied accordingly to maintain the output of the converter at fixed voltage.
Calculations of Inductor and Capacitor for Buck Converter

INDUCTOR CALCULATION

V_{out} = 12 V
V_{in} = 15V
I_{out} = 4.2A
Switching Frequency=50KHz
Duty cycle = 80% or 0.8
(V_{out}/V_{in}) = 12/15 = 0.8
L= $(V_{in}=V_{out})$ * D * (1/f) *(1/di)
di= 35% of 4.2 =1.47
(15-12) = 0.8 * (1/50K) * (1/1.47)
= 32.65µ ≈ 33 µH

CAPACITOR CALCULATION

Capacitance = di/ (8* f* dv)
Assume dv = 20mV=0.02V
C_{out} = 1.47/ (5*50000*0.02)
=183.75 µF
=220µF(Standard Value)



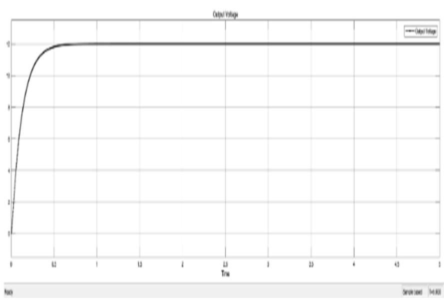


Fig. 4: Buck Converter Simulation Design Fig. 5: Simulation Output of Buck Converter

The Figure 4 shows the Buck converter simulation design using controller and the figure 5 shows the output waveform of the Buck converter. The Output voltage from the mosfet gradually increases from 0 to 12 Volts in 0.2 sec, As the switch starts conducting and voltage becomes constant.

C. H-Bridge Inverter

H Bridge is a type of power electronics circuit that has 4 switches which helps in controlling the flow of current. According to the simulation diagram, when the switch 1 and 2 are closed and switch 3 and 4 are open, the positive voltage is applied to the load similarly when the switch 1 and 2 are open and the switches 3 and 4 are closed the voltage is reversed. This is how the H bridge inverter works.

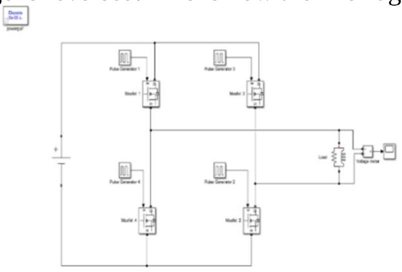


Fig. 5: H-Bridge Inverter Simulation Design

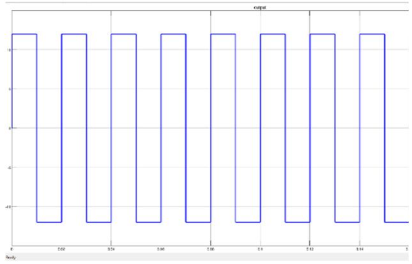


Fig. 6: Simulation Output of H-Bridge Inverter

The simulated output waveform of the H bridge inverter is shown in fig 6. It is a 12 Volts square wave output with a time period of 0.2 sec.

D. Speed Control of Induction Motor by Variable Frequency Method

The output from the inverter is fed to the input of the Induction motor which will run at some speed decided by the user. The Input for the gate pulses of the inverter will be given by the closed loop system from where the gating pulses of the MOSFET's are generated. The reference voltage and inverter load voltage are compared and fed into PI controller. The PI controller will control the voltage loop. The output from the controller is compared with the load current and the output from the controller is split between 4 MOSFET's and fed to Inverter. The PWM loop smoothens any fluctuations that is generated by inverter output which is trying to control the speed of Induction Motor. In this way the speed of the Induction motor is controlled and achieved.

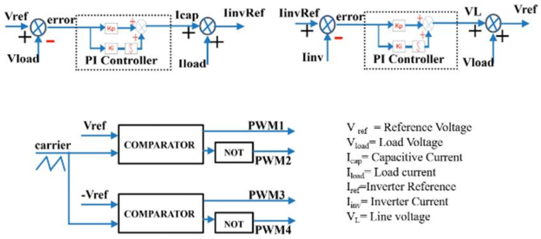


Fig. 7: PI Controller for speed controlling of Motor

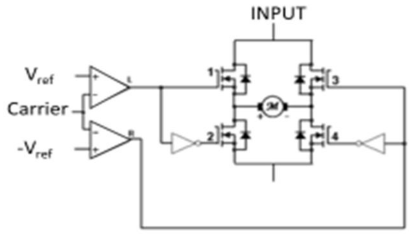


Fig. 8: PWM generation with inverter

The values of Kp and Ki for PI Controller are taken based on standard calculations.
The above figure represents the transfer functions of PI controller used for speed controlling of Induction Motor. Firstly, the V_{ref} (Reference voltage) is compared with the V_{load} (Load voltage) which gives V_{error} (Error Voltage) signal and that gives I_{cap} (Capacitive current) using PI controller, which is compared with I $_{load}$ gives I_{inv} ref (Inverter current ref), This current is again compared with I_{inv} (Inverter current) and the obtained error is fed to PI controller which gives the V_L (Line voltage). This line voltage is added to V_{load} which gives Vref. The Vref is compared with the carrier signal and the PWM pulses are generated for the H bridge inverter. It is shown in Fig 9.

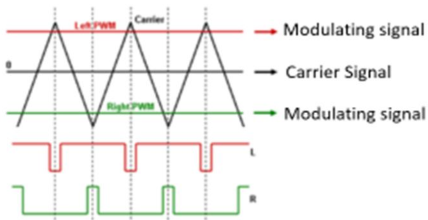
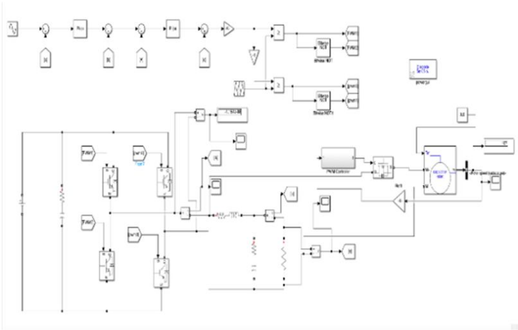


Fig. 9: Timing diagram of PWM

Calculation of synchronous speed I shown in below Equation (7).
Synchronous Speed = 120 x f/ P ---------------(7)
F= frequency in Hz, P= number of pole of the motor
The frequency of the power supply is fixed at 50Hz



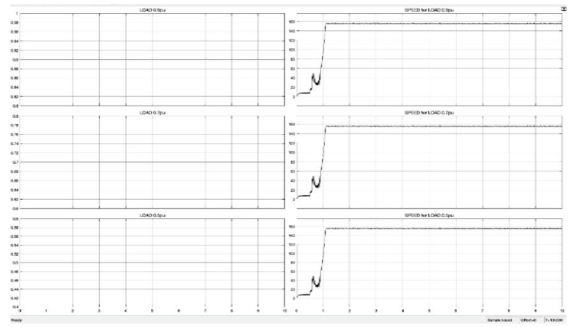


Fig. 10: Simulation of speed control by variable frequency method torque load

Fig. 11: Simulated speed control waveform with different

Figure 11 shows the speed control of the Induction motor using the controller. Variable torque is applied to the motor and motor speed is controlled.

In figure 12 the waveform shows the constant speed for different loads. In first waveform the torque load is applied at 0.9pu and the corresponding is the speed vs time waveform in which at the time period of 1 sec the speed is maintained constant after some time as it requires more rise time high by using the controller and the same is done for other two load torque. In this way the speed of the Induction Motor is controlled.

E. Speed Vs Torque Relation

The speed of the induction is inversely proportional to the torque load. When the torque load increases the speed of the motor decreases. And when the speed increases the output torque decreases. Since the output power of the motor is fixed value.

The Speed Vs torque characteristics is shown below figure 10.

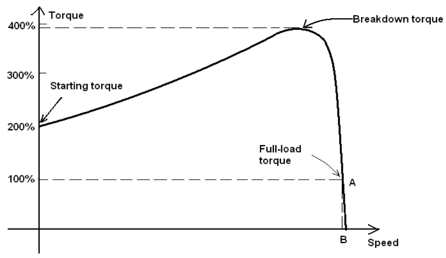


Fig.12: Speed Vs Torque characteristics of Induction Motor

F. Speed Control of Induction Motor by V/F Method

V/f method is the most common method to control the speed of electric motors as these motors are widely used in industrial applications. The applied voltage and frequency determines the flux produced in the stator. Therefore, by controlling the voltage and frequency the flux produced can be controlled to the same ratio there by controlling the speed. The torque is kept constant throughout the speed controlling. The below graph represents the characteristics of V/f Control method.

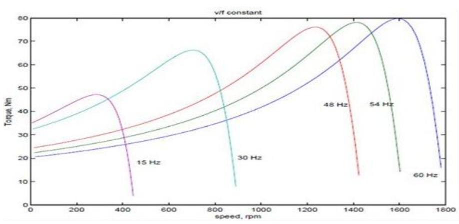


Fig. 13: Speed Vs Torque characteristics of Induction motor with V/f Ratio

The above figure shows the simulation design of the speed control by V/f method. In this design the ratio of the voltage and frequency is kept constant so that the flux also remains constant. When the voltage and frequency is varied but the torque is kept constant the while the speed is varied and it is controlled using frequency controller

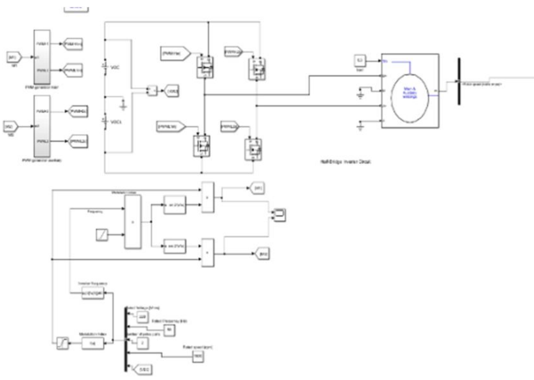


Fig.14: Simulation of speed control by V/f Method

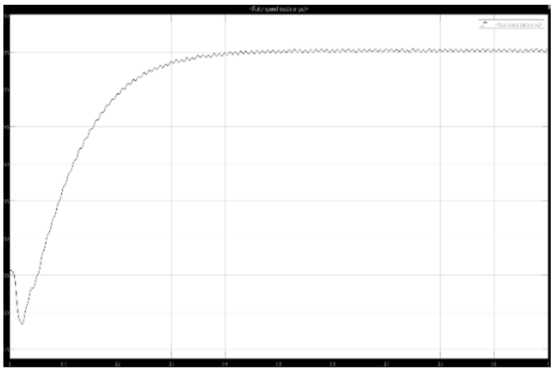


Fig. 15: Simulated speed control waveform with torque 0.5 pu

and using PWM technique pulses are given to the H Bridge inverter which changes the duty cycle and speed is controlled.

The fig 15 represents the simulated speed control waveform with 0.5pu torque. The waveform is the speed vs time in which at the time period of 1 sec the speed is maintained constant by using the controller. The motor is speed is at 153rad/sec.

G. Simulation of the Entire System

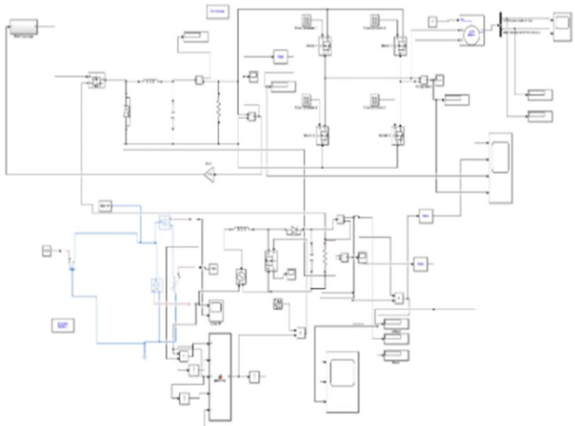


Fig. 16: Simulation of complete system

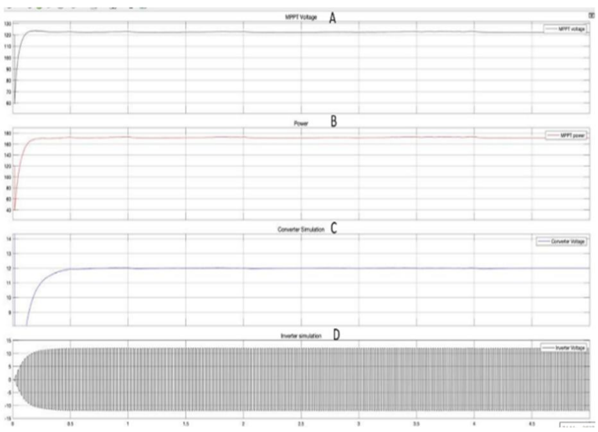


Fig. 17: Simulated waveforms of the complete system

The above figure 13 represents the simulation of the entire system which includes Maximum power point tracking using perturb and observe algorithm, Buck converter, H bridge Inverter, and the speed controlling of the Induction Motor.

The figure 14 represents the simulated output waveforms of the system. The waveform (A) represents the Maximum voltage Vs time obtained from solar tracked by MPPT using Perturb and observe algorithm, at 0.2 sec the maximum voltage is tracked, In the waveform (B) represents the maximum Power is extracted from solar tracked by the MPPT. The waveform (C) represents the Buck converter output voltage 12 Volts DC obtained from converter The output Voltage from the converter gradually starts increasing as the switch starts conducting at 0.2sec the 12Volts is obtained. And the waveform (D) represents the H bridge Inverter output voltage 12 Volts AC obtained from the inverter.

H. Comparison Analysis of the Methods of Speed Controlling

In this work the comparison analysis between control strategies for speed control is represented. The controllers used in this work are PI controller for Variable frequency method and V/f control. The simulation is carried out in MATLAB to understand the performance and working of the different controllers. It is observed that the PI controller is incompatible for high performance in variable frequency drive. But V/f can overcome the drawback by keeping the voltage and frequency ratio constant. The efficiency and power factors are high in V/f control, even at the maximum torque the operation is carried out and it also gives good, effective performance.

The below table shows the remarks of the controller used for controlling the speed of Induction motor.

TABLE I. REMARKS OF THE METHODS USED FOR CONTROLLING THE SPEED OF INDUCTION MOT

Sl. no	Type of controller	
	Variable frequency control Method (VFD)	V/f Control Method
1	Requires longer response time	Smooth start and stop, and less harmonics
2	Needs more rise time (fig 11)	Required current at starting is reduced
3	High starting overshoot (fig 11)	Motor runs in stable region (fig 13)
4	High voltage spikes observed	High efficiency and increase power factor

III. CONCLUSION

The solar power is harnessed using solar panels and is used to run AC Induction motor with the help of this system. By implementing the Pulse width modulation (PWM) Technique the users can control the speed according to the requirement. Two methods variable frequency method and V/f method of speed controlling are simulated and the results are analysed to compare the performance of the two methods. Both the methods have various benefits under different conditions but there are lots of benefits from V/f control method as the starting current required. It also helps the motor for smooth starting and also increases the power factor and helps in controlling the speed of the motor more effectively as shown in figure 15.
Future scope of this work will focus on implementing these speed control using different techniques and testing the working of the motor under various conditions which will be used for different applications.

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