Pv Fed Boost Spwm Inverter Driven Single-Phase Induction Motor

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ABSTRACT

PV array is increasingly employed for water pumping system. In this paper, a boost converter to step up the input voltage of the inverter interposed between the PV array and single-phase induction motor is developed. The model was implemented using MATLAB/Simulink with SPWM controlled inverter model. The detailed modeling of the components of proposed scheme has been taken up. The developed boost converter steps up the voltage produced by the PV array to a value which is suitable to run a single-phase induction motor. The inverter converts DC to AC is controlled by using sinusoidal pulse width modulation (SPWM) technique. By using a LC-filter pure sine wave is obtained which can be directly used to drive a single-phase induction motor. Experimental investigation presented gives the utility of such a drive system.

1. INTRODUCTION

The need for energy is never ending. This is certainly true of electrical energy, which is a large part of total global energy consumption. The demand for electrical energy is increasing twice as fast as overall energy use and is likely to rise 76% by 2030. Another point of concern is that in many overpopulated countries, like India, there is a dearth of power generating resources and as a result many cities and towns are facing constant load shedding and black-outs. The existing centralized power generation units are not sufficient to meet the continuously rising power demand. The wide gap generation and distribution location lead to the inefficiency in supplying power to the rural areas. This can be eliminated by the use of advancement in power electronics by providing instantaneous supply to the people by providing flexibility in source by placing the inverters [2].

Sinusoidal Pulse width-modulated (SPWM) voltage-source inverters (VSI) are widely utilized in ac motor drive applications and at a smaller quantity in controlled rectifier applications as a means of dc to ac power conversion devices, about three quarters of a century of progress in the power electronics field, and about half a century of progress in the micro-electronics/macro-electronics and control fields are inherited in the state of the art SPWM-VSI converters. Mostly occurring at different time frames, The breakthroughs experienced in each field have strongly and positively influenced the evolution of today's various types of cost effective, efficient, compact, and reliable high performance SPWM-VSI converters. Since they involve various disciplines of engineering and there has always been a strong demand for them in the market, SPWM-VSI converters have continuously drawn the attention of many researchers all around the world. Therefore, in parallel with this progress, a substantial amount of literature relating to electric converters has been accumulated. In particular, the literature involving the SPWM methods boosting of input voltage.

Perhaps, the modern power electronics era began with the invention of the thyristor device in 1957. Overcoming the size, cost, efficiency, reliability, and performance deficiencies of the previous power converter switching devices, the solid state semiconductor made thyristor gained immediate acceptance. In particular, its application in power converter circuits with inherent natural commutation characteristics such as cycloconverter, phase controlled rectifiers, and reactive power compensators, etc. has been the most practical solution to the present date. However, lacking self-commutation capability, the thyristor would require involved commutation circuits in forced commutation applications, rendering the drive bulky, expensive, and complex. Therefore, its utilization in forced commutation power electronic converters, in particular in the VSI applications [2].

Safe-commutation strategy want be implemented is to solve switching transients. So, Insulated Gate Bipolar Transistor (IGBT) is use as switching devices. IGBT is preferable because it is easy to control and low losses. Thus the IGBT switches have become the most widely utilized devices and have revolutionized the SPWM-VSI converters.

The switching frequency of the early power electronic converters was typically low. For example a VSI would operate in the six-step mode, yielding a switching frequency equal to the output voltage fundamental frequency. The intelligence involved in generating the gate signals was not significant and the control could be implemented with analog circuits. However, the low switching frequency would result in large amount of low frequency harmonic voltages/currents.

2. PHOTOVOLTAIC

Photovoltaic are solid-state semiconductor devices that convert directly light energy into electricity. They are usually made of silicon with traces of other elements and are first cousins to transistors, LED's and other electronic devices.

Photovoltaic (PV) generation is becoming increasingly important as a renewable source, since it offers many advantages such as incurring no fuel costs, not being polluting, requiring little maintenance, and emitting no noise, among others. The amazing thing about solar power is that all the electricity is generated from the material of the solar panels and the energy from the sun. The solar panels are mainly made out of semiconductor material, silicon being the most abundantly used semiconductor. The benefit of using semiconductor material is largely due to the ability of being able to control its conductivity whereas insulators and conductors cannot be altered. The electrons of the semiconductor material can be located in one of two different bands, the conduction band or the valence band. The valence band is initially full with all the electrons that the material contains. When the energy from sunlight, known as photons, strikes the electrons in the semiconductor, some of these electrons will acquire enough energy to leave the valence band and enter the conduction band. When this occurs, the electrons in the conduction band begin to move creating electricity. As soon as the electron leaves the valence band, a positively charged hole will remain in the location the electron departed. When this occurs, the valence band is no longer full and can also play a role in the current flow. This process basically describes how Photovoltaic (PV) systems function. However, PV systems further enhance the rate at which the electrons are sent into the conduction band through the process of doping [1], [3].

3. BOOST CONVERTER

For high efficiency, the SMPS switch must turn on and off quickly and have low losses. The advent of a commercial semiconductor switch in the 1950's represented a major milestone that made SMPSs such as the boost converter possible. Semiconductor switches turned on and off more quickly and lasted longer than other switches such as vacuum tubes and electromechanical relays. The major dc to dc converters were developed in the early-1960s when semiconductor switches had become available. The aerospace industry's need for small, lightweight, and efficient power converters led the converter's rapid development [5].

Switched systems such as SMPS are a challenge to design since its model depends on whether a switch is opened or closed. R.D. Middle brook from Caltech in 1977 published the models for dc to dc converters now used today. Middle book averaged the circuit configurations for each switch state in a technique called state-space averaging. This simplification reduced two systems into one. The new model led to insightful design equations which helped SMPS growth.

APPLICATIONS

Battery powered systems often stack batteries in series to achieve higher voltage. However, stacking batteries is not possible in many high voltage applications due to lack of space. Boost converters can increase the voltage and reduce the number of cells. Two battery-powered applications that use boost converters are hybrid electric vehicles (HEV) and lighting systems.

Boost converters also power devices at smaller scale applications, such as portable lighting systems. A white LED typically requires 4V to emit light, and a boost converter can step up the voltage from a single 1.5 V alkaline cell to power the lamp. Boost converters can also produce higher voltages to operate cold cathode fluorescent tubes (CCFL) in devices such as LCD backlights and some flashlights [5].

4. INVERTER

From the late nineteenth century through the middle of the twentieth century, DC-to-AC power conversion was accomplished using rotary converters or motor-generator sets (M-G sets). In the early twentieth century, vacuum tubes and gas filled tubes began to be used as switches in inverter circuits.

D. Prince was the person who invention of the earliest inverter device in 1925. He suggests the name\inverter was given to this device for its operating characteristics are the reverse of the rectifiers; instead of AC to DC voltage transformation, DC to AC. The first practical application of single phase inverters is claimed to be in textiles. However, inverters did not find widespread applications until the development of the modern power electronic switches.

TYPES OF INVERTERS

Power inverters produce one of three different types of wave output:

- Square Wave
- Modified Square Wave (Modified Sine Wave)
- Pure Sine Wave (True Sine Wave)

The three different wave signals represent three different qualities of power output.

One might wonder why there are so many types of inverters. The primary reason is cost. Some types of devices won't work on the cheaper modified square wave of cheaper inverters and generators. Audio/ video equipment, some computers and some microwave ovens require a nearly pure (low distortion) sine wave input. In audio/video equipment, the higher frequency harmonics present in distorted sine waves can come through as buzzing in the speakers [1].

Square Wave

Square wave inverters result in uneven power delivery that is not efficient for running most devices. Square wave inverters were the first types of inverters made and are obsolete.
Square wave inverters works well for a resistive load like an incandescent light. But things get a bit more complicated with inductive loads

Modified Square Wave

Modified square wave (modified sine wave) inverters deliver power that is consistent and efficient enough to run most devices fine. Some sensitive equipment requires a sine wave, like certain medical equipment and variable speed or rechargeable tools.
Modified sine wave or quasi-sine wave inverters were the second generation of power inverter. They are a considerable improvement over square wave inverters. These popular inverters represent a compromise between the low harmonics (a measure of waveform quality) of a true sine wave inverter and the higher cost and lower efficiency of a true sine wave inverter.

Modified sine wave inverters approximate a sine wave and have low enough harmonics that they do not cause problems with household equipment. They runs TV's, stereos, induction motors (including capacitor start), universal motors, computers, microwave, and more quite well. The main disadvantage of a modified sine wave inverter is that the peak voltage varies with the battery voltage. Inexpensive electronic devices with no regulation of their power supply may behave erratically when the battery voltage fluctuates.

True Sine Wave

True sine wave inverters represent the latest inverter technology. The waveform produced by these inverters is the same as or better than the power delivered by the utility. Harmonics are virtually eliminated and all appliances operate properly with this type of inverter. They are, however, significantly more expensive than their modified sine wave cousins.

For many other loads, a less than perfect sine wave is adequate. The issue then becomes a trade-off between cost and waveform purity. An approximation of a sine wave may be created by outputting one or more stepped square wave with the amplitudes chosen to approximate the sine. The more steps, the more like a sine wave the output is. The more steps, the higher the cost.

Most inverters convert DC power in two stages. The first stage is a DC-to-DC converter that raises the low voltage DC at the inverter input to 230 volts DC. The second stage is the actual inverter stage. It converts the high voltage DC into 230 volt, 50 Hz internationally The DC-to-DC converter stage uses modern high frequency power conversion techniques that eliminate the bulky transformers found in inverters based on older technology. The inverter stage uses IGBT switches in a full bridge configuration. This gives you excellent overload capability and the ability to operate tough reactive loads like lamp ballast's and small induction motors [2], [1].

APPLICATIONS

Inverters are used in wide range applications such as

- DC Power source utilization
- Uninterruptible power supplies
- Induction heating
- HVDC power transmission
- Variable-frequency drives
- Electric vehicle drives
- The general case

5. Sinusoidal Pulse Width Modulation

Since voltage source inverters employ switching devices with finite turn-on time and turn-of time characteristics, inverter switching losses are inevitable. Because the switching losses strongly affect the energy efficiency, size and reliability of an inverter, a modulation method with high performance is desirable. Therefore, the modulation method choice is significantly important. Of the variety of modulation methods, the carrier based SPWM methods are used [7].

Now a day's most of the inverters available in the market utilizes the SPWM (Sinusoidal Pulse Width Modulation) technology .The inverters based on SPWM technology are superior in many factors compared to other inverters designed using conventional technologies. The SPWM based inverters generally use IGBTs in the output switching stage. In such cases the inverters are generally termed as SPWM IGBT inverters. The inverters based on SPWM technology has a lot of protection and control circuits compared to the traditional inverters.

5.2 WHAT IS SPWM TECHNOLOGY? &WHY SPWM IS USED?

SPWM or Sinusoidal Pulse width Modulation is used to keep the output voltage of the inverter at the rated voltage (110V AC / 220V AC) (depending on the country) irrespective of the output load. In a conventional inverter the output voltage changes according to the changes in the load. To nullify effect caused by the changing loads, the SPWM inverter correct the output voltage according to the value of the load connected at the output .This is accomplished by changing the width of the switching frequency generated by the oscillator section. The AC voltages at the output depend on the width of the switching pulse. The process is achieved by feed backing a part of the inverter output to the SPWM controller section (SPWM controller IC). Based on this feedback voltage the SPWM controller will make necessary corrections in the pulse width of the switching pulse generated at oscillator section. This change in the pulse width of the switching pulse will cancel the changes in the output voltage and the inverter output will stay constant irrespective of the load variations.

Output voltage from an inverter can also be adjusted by exercising a control within the inverter itself. The most efficient method of doing this is by sinusoidal pulse-width modulation control used within an inverter.

In this method, a fixed dc input voltage is given to the inverter and a controlled ac output voltage is obtained by adjusting the on and off periods of the inverter components. This is the most popular method of controlling the output voltage and this method is termed as Pulse-Width Modulation (PWM) Control. If the reference signal used in generation of pulses, then it is called sinusoidal pulse width modulation [8], [9].

Advantages

SPWM technique has several advantages. They are as listed below [8].

- The output voltage control can be obtained without any additional components
- Lower order harmonics can be eliminated.
- The filtering requirements are reduced to higher order filters only.
- High power handling capability.
- Efficiency up to 90%.
- Low power consumption.
- SPWM generates less harmonic distortion in the output voltage or currents in comparison with PWM.

6. FILTER

Need For Filter

Filters play a key role in the inverter driven loads. It is mainly used for two reasons. They are as listed below.

1. To convert the inverter output (i.e., square wave) into pure sinusoidal wave
2. To eliminate the higher order harmonics.

Conversion of Square Wave In to Sine Wave

The output of an inverter is in square wave. This output is suitable for lighting loads. But is not suitable for motor and other sensitive loads like electronic loads. Since this project is a motor drive (i.e., single-phase induction motor), it is necessary to convert the square wave output into pure sinusoidal wave. Thus we need filter [8], [9].

Elimination of Higher Order Harmonics

Harmonics are classified into two types. They are higher order harmonics and lower order harmonics. To eliminate higher order harmonics, we use filter. Where the lower order harmonics are eliminated using SPWM technique.

Types of Filters

There are different types of filters. They are as shown below [4].

- L-filter
- LC-filter
- LCL-filter

LC-Filter

In this project, we use LC-filter. LC-filter is a second order filter and it has better filtering ability than L-filter. This simple configuration is easy to design and it works mostly without problems. The basic block diagram of a LC-filter is as shown below.

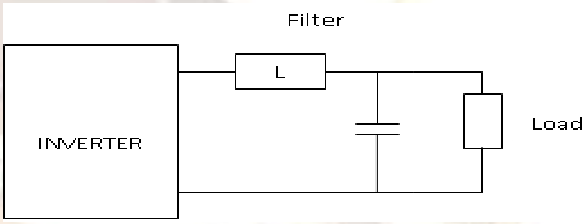

Fig 6.1: Basic block diagram of LC-filter

MODELING OF LC-FILTER

In filter designing, the first step is finding the best filter. The second step is calculating the designed impedance from the lowest voltage (Vmin) divided by the highest current (Imax) where is Rd. the third step is equating the inductor (L) and the capacitor (C) values from the second step using the following equation [4].

The design impedance form can be calculated by using the below equation.

$$Rd = \frac{Vmin}{Imax}$$

The inductance (L) and the capacitance (C) values of the filter can be calculated by

$$L = \frac{Rd}{2\pi f}$$

$$C = \frac{1}{2\pi f Rd}$$

Calculations of L & C

The values of the inductor and capacitor that are used in a LC-filter are calculated as shown below.

The design impedance form can be calculated as below.

$$Rd = \frac{Vmin}{Imax} = \frac{170}{5.15} = 33$$

The values of inductance and capacitance in the LC-filter are given by

$$L = \frac{Rd}{2\pi f} = \frac{33}{2 * 3.14 * 50} = 105 \text{ mH}$$

$$C = \frac{1}{2\pi f Rd} = \frac{1}{2 * 3.14 * 50 * 33} = 96 \ \mu F$$

7. SINGLE-PHASE INDUCTION MOTOR

The characteristics of single phase induction motors are identical to 3-phase induction motors except that single phase induction motor has no inherent starting torque and some special arrangements have to be made for making itself starting. It follows that during starting period the single phase induction motor must be converted to a type which is not a single phase induction motor in the sense in which the term is ordinarily used and it becomes a true single phase induction motor when it is running and after the speed and torque have been raised to a point beyond which the additional device may be dispensed with. For these reasons, it is necessary to distinguish clearly between the starting period when the motor is not a single phase induction motor and the normal running condition when it is a single phase induction motor. The starting device adds to the cost of the motor and also requires more space. For the same output a 1-phase motor is about 30% larger than a corresponding 3-phase motor.

The single phase induction motor in its simplest form is structurally the same as a poly-phase induction motor having a squirrel cage rotor, the only difference is that the single phase induction motor has single winding on the stator which produces mmf stationary in space but alternating in time, a polyphase stator winding carrying balanced currents produces mmf rotating in space around the air gap and constant in time with respect to an observer moving with the mmf. The stator winding of the single phase motor is disposed in slots around the inner periphery of a laminated ring similar to the 3-phase motor [7].

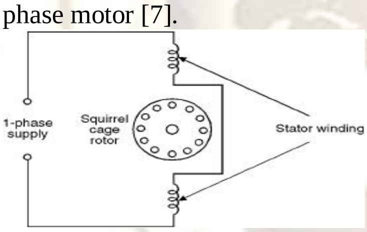

Fig 7.1: Elementary single phase induction motor

8. Functional block of PV fed boost SPWM inverter driven single- phase induction motor

The below shown figure 8.1 is the implementation of PV fed boost SPWM inverter driven single-phase induction motor in MATLAB/SIMULINK.

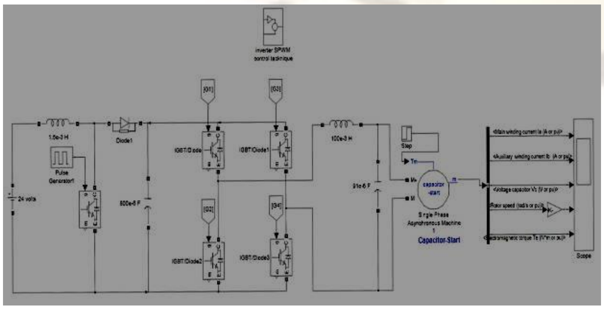

Fig 8.1: Functional block of PV fed boost SPWM inverter driven single phase induction motor

9. MATLAB RESULTS

In the analysis of the PV fed boost SPWM inverter driven single-phase induction motor, the resultant waveforms are used for the verification of the results for the desired response.

The results include

- Boost converter output voltage,
- SPWM wave forms for positive sequence and negative sequence operation of inverter,
- Voltage and current wave forms of inverter model,
- Voltage and current wave forms of inverter model with filter,
- Torque-Speed characteristics of single-phase induction motor &
- Output characteristics of single-phase induction motor.

Voltage Wave Form Of Boost Converter

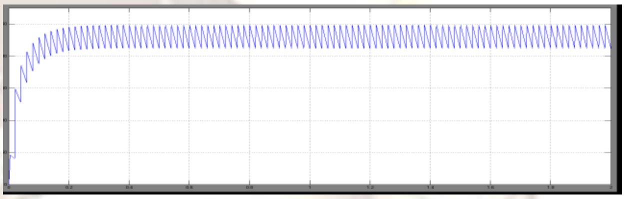

Fig 9.1: Simulation output voltage of boost converter

The above shown figure is the simulation output voltage. The output voltage of boost converter is 250 volts.

SPWM Wave Forms for Positive & Negative Sequence Switches

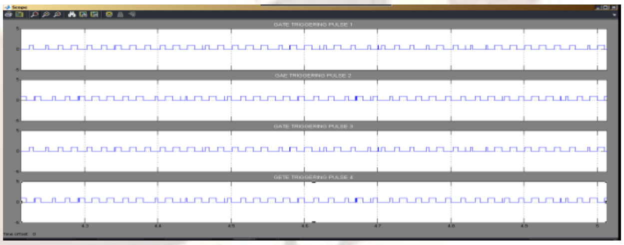

Fig 9.2: SPWM waveforms for positive and negative sequences Positive sequence G1 & G3, Negative sequence G2 & G4

Voltage and Current Wave Forms of Inverter

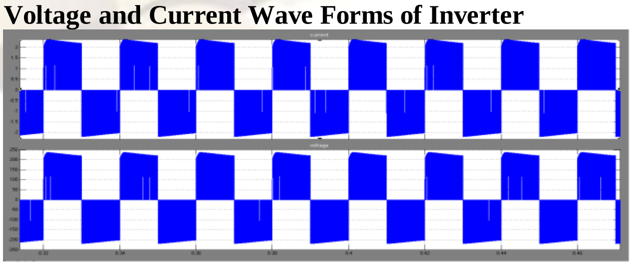

Figure 9.3: Simulation output current and voltage without filter

The above shown figure is the simulation output voltage. The output voltage and current of single phase boost SPWM inverter is 230 volts and 2.3 amps.

Voltage and Current Wave Forms of Inverter with Filter

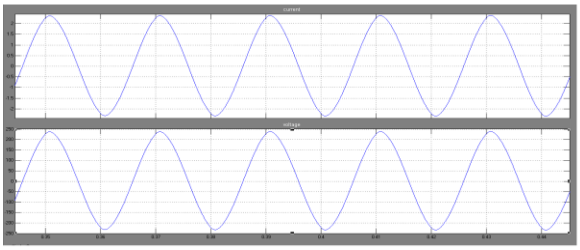

Figure 9.4: Simulation output current and voltage with filter

The above shown figure is the simulation output current. The output voltage and current of single phase boost SPWM inverter is 230 volts 2.3 amps.

Speed-Torque Waveforms of Single Phase Induction Motor.

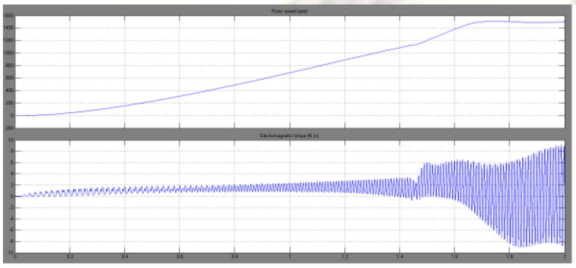

Figure 9.5: Simulation speed-torque of single phase induction motor

The above shown figure is the simulation output speed and torque. The output speed and torque of single phase induction motor is 1500 rpm 8 N-m.

Output Characteristics of Single-Phase Induction Motor

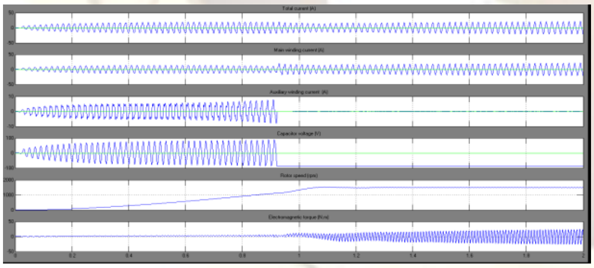

Fig 9.6: Output characteristics of single-phase induction motor

a) Total current, b) Main winding current,

c) Auxiliary winding current, d) Capacitor voltage, e) Rotor speed & f) Electromagnetic torque.

Conclusion

The system descried here is a PV system for water pumping, employing a single-phase boost SPWM inverter and single-phase induction motor. The boost converter is used to step up the low input voltage produced by PV array. The proposed scheme is thus successfully used to drive a single-phase induction motor. SPWM technique is used to control the IGBT inverter and for the effective elimination of lower order harmonics, where higher order harmonics are eliminated by using proposed LC filter. The experimental results on MATLAB/Simulink are presented to validate our drive scheme. The drive scheme is easy to implement economically.

Future Scope

In this project, "PV fed boost SPWM inverter driven single-phase induction motor" is implemented using open loop control. In open loop control system there is no scope for automatic voltage regulation and peak power tracking. In future, "PV fed boost SPWM inverter driven single-phase induction motor" can be implemented with a closed loop control system to eliminate the above stated problem. The closed loop control can be implemented using any controller like P, PI & PID. The controller can be selected according to the designer requirement.

10. References

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