Single-Sourced Double-Stage Multilevel Inverter for Grid-Connected Solar PV Systems

[1]Y. PRATHYUSHA, [2]K. ANITHA

M.Tech. Scholar, Asst prof
ELECTRICAL AND ELECTRONICS ENGINEERING
TADIPATRI ENGINEERING COLLEGE

Abstract:
The design demands of solar structures related to electricity conditioning consist of power best, performance, reliability, implementation fee, and more. This paper provides the topology of a multi-kingdom, out of control general efficiency, section doubling, dual segment, uncoupled supply DC inverter with a aggregate of suitable switches to conquer maximum of the constraints of a practical essential inverter software. A two-stage, greater touchy, multi-stage inverter is designed to make use of a double-price inverter, similarly to better comments efficiency. These illustrations reveal the electricity of reciprocity and the potential of innovation to triumph over incapacitating boundaries. Carefully simulate the transducer the usage of MATLAB/Simulink. Experimental outcomes from the laboratory prototype validate the proposed software principles.

Chapter-1
Introduction
The growing call for for energy and environmental emissions due to pollutants pressure studies and good sized funding in international energy sources. A photovoltaic (PV) inverter is one of the number one additives of a photovoltaic tool [1], [2], [3]. Current studies is focused on developing diverse topologies which includes inverters to reap incredible electricity, efficiency, stability and electricity management functionality for stimulating networks with the fewest variety of components [4]. This paper investigates photovoltaic inverters for big-scale sun photovoltaic projects (multi-megawatt (MW) scale). One such inverse constraint is that the sun PV array voltage should be between six hundred and 830 V, [6] to dispose of the PV module. If the voltage is limited to 300 volts for a gadget of numerous megawatts, the currents need to be within the kiloampere variety. The grid-related inverter have to function at a high sufficient switching frequency to keep a clean electricity supply with the precise apparent length. Power electronic converters have very high switching losses due to excessive current high frequency interference. It is not simplest related to overall performance, but also related to stability. Switching losses use up in the system and cause a large upward push in temperature, which reduces stability. Plants are a change of fields; However, for notable high-quality energy with modest filter out sizes, operation at high frequencies is required [8], [9]. Because of this more frequency, transformer losses may be excessive and this spike can appear in device temperature or warmness dissipation. So this regressive pressure not only creates, but additionally equalizes. Another alternative is to use a comparable level of express inverting. Single level inverter achieves better dv/dt, EMI and harmonic distortion compared to a couple of degree inverters. More than one inverse, as the variety of increments increases, the version in frequency decreases. This encourages studies into multi-level inverters, wherein the grid can be used at decrease voltages and the filter size may be decreased [11]. Because of their simplicity and low filter out loss, 3-section horse clip (NPC) inverters are optimized for solar applications [12], [13].

Chapter-2
Literature survey
[1] Y. Yang, P.NJT, F. Blabjorg and H. Wang, "Large-Scale PV Deployment: Investigation of Network Code Changes in Distribution Networks," IEEE Ind. Used Mag., Vol. 21, no. Five, p. 21-31, September 2015
Modern grid standards normally require less power (eg, some kilowatts). Single phase photovoltaic (PV) systems operate at a unit electricity aspect (pf) with most power factor trace (MPPT) and are disconnected from the grid in some unspecified time in the future during remoted fault detection. However, in view that photovoltaic structures have a significant pass-section devoted to the grid, a lack of grid closure also can make a contribution to at least 1) electricity surges, 2) electricity outages, and three) mechanical instability. This paper deals with social code adjustments for the implementation of massive photovoltaic systems in distribution networks. Furthermore, because of the fact that these days Italy and Japan have done the number one review of standards for high-voltage grid-related PV conversion systems, three second voltage drop technology (LVRT) and reactive strength substances for single-segment PV systems are considered a number of the critical screw ups. A simulation for a photovoltaic power system with LVRD functionality and supporting services is presented. An single section, a part of the bridge connected to the machine grid, changed into

tested experimentally to illustrate its potential blessings. Also, network capabilities for advanced photovoltaic structures are developed with exact functions.

[2] S.B. Kaiser, JC. Pedersen and F. Bliopjark, "A Review of Grid-Connected Inverters for Photovoltaic Modules," IEEE Trans. Ind Appl., Vol. 41, no. 5, p. 1292–1306, September/October. 2005

This score makes a speciality of inverter era that integrates photovoltaic (PV) modules with simple grids. Inverters are divided into four categories: 1) the wide variety of processing power ranges in watts; 2) the form of electrical disconnection between the photovoltaic module and the uncoupled community; three) whether or not they use transformers (linear or high frequency) or do no longer use them anymore; and 4) the character of the scene being adorned. Various inverter topologies are supplied, compared and evaluated primarily based totally at the necessities, life cycle, scores and element capabilities. Finally, a few topologies are indexed as best candidate configurations for one or extra PV modules.

[3] Q. Alluhaibi, i. Padres and H^. Hu, "Comprehensive Evaluation and Variation of Single-Phase Photovoltaic Network Microinverters," IEEE J. Prone. Sat. Caption Power Electron, Vol. Eight, no. 2, p

Power managing and electrical isolation between the PV module and the grid is an essential attention in a PV microinverter to fulfill common performance requirements and application operating specifications. Grid-connected PV microinverter gadgets can be divided into four training: 1) undivided block topology; 2) discrete section topology; three) non-separated phase topology; and four) separate the two topological stages. In preferred, microinverter performance can be improved by using non-far flung topologies due to the fact they are greater green, smaller, less complicated and fee greater than faraway topologies. The use of a converter within the microinvert topology ensures the very best electricity nice and galvanic isolation to take away safety troubles related to the requirements. Power processing (multiplying the DC voltage of the PV panel, extracting extra strength and converting it to AC power), which can be carried out in a single or more layers, has a massive effect at the microinverter. The principles and alternatives in this newsletter experimentally validate each microinverter topology in terms of efficiency, power density, reliability, and price. The most thrilling topologies in every category are produced and modeled earlier than the same old. Topologies are compared in terms of description format, enter voltage, modular format, software implementation, and battery integration.

[4] X. Zhang, T. Zhao, W. Mao, D. Tan, and L. Chang, "Multilevel Inverters for Grid-Connected Photovoltaic Arrays: A Survey of Recent Features," IEEE Power Electron. Mag., Vol. 5, no. Four, web page

As the cost of photovoltaic (PV) modules and inverters continues to lower, photovoltaic energy generation is gaining a larger percent of the power market. The marketplace and its customers are an increasing number of concerned about high efficiency inverters in terms of performance, power density, module energy degrees and ever better voltage and electricity. Due to its brilliant performance, multi-segment inverter has attracted the attention of all the researchers and technicians. This paper reviews the utility of multi-section inverter generation to grid-related photovoltaic arrays, five-segment inverters, single non-remoted inverters, and 3-section far flung H-bridge cascade inverters. The characteristics of photovoltaic panels are supplied with an in-intensity dialogue.

[5] S. Pinkel et al., Electrical Erosion with the aid of Solar Cells and Panels. 35th IEEE Photovoltaic Specification. Conference, 2010, p. 2817-2822.

As sun energy era spreads throughout the enterprise, photovoltaic structures and sun farms are getting large, and solar panels are linked in collection. As a end result, forums are frequently situation to an identifiable capability relative to floor, causing a excessive voltage drop (HVS). The impact of HVS on the lengthy-time period equilibrium of sun panels turned into first stated in 2005 the use of NREL as a assets of sun cells and recent lake currents in the floor. This capability degradation mechanism isn't governed with the aid of the precise PV guidelines codified in IEC 61215. This article introduces a unique P-kind silicon wafer PID generation that maximizes the lifestyles of solar panels after exposure to outside strength regulation. An experimental scheme is provided to simulate PID within the laboratory, and to illustrate that the impact of cellular populations on PID is vital for mobile PID. However, PIDs may be blocked or disabled at the board and gadget stage, as proven in the documentation.

Chapter-3
Existing system

• 	In sensible gadgets we use CHB (Inverse Cascade H-Bridge).

• 	Uneven electricity output at sure degrees due to leaf factors, specific room temperature, dust.

• 	If the union of PV modules is split into numerous rows, several

• 	Symmetrical CHB photovoltaic programs are not suitable for use in large sub-circuits (working in high frequency switching) and require a couple of conductors to be spanned across space for first elegance lightning protection.

Dis Advantages
•   Asymmetric potentials increase the ratio of dozens of lightning rods.
•   Thus, the viable output voltage tiers are elevated with a minimum variety of electricity switching devices and additives.
•   The main downside of a strong state MLI bridge is that its cascades can't provide fantastic and terrible 1/2-cycles of the AC load.

Proposed system
•   The idea of LDN has been proposed in the literature to achieve higher stage of expertise in two inverted CHBs.
•   This concept is relevant to each symmetric topology and asymmetric converter topology. LDN helps to do away with isolated auxiliary assets.
•   By including a half of-bridge to an current H-bridge, the voltage degree may be almost doubled.

Advantages
•   The benefit of multilevel inversion is that dv/dt voltages are reduced with the help of switching devices due to small step increments.
•   Reduces electromagnetic compatibility (EMC) when running at high voltage, lowers semiconductor tool ratings and offers higher average performance in low voltage improvement.

Modeling of Solar PV
Solar cells are used to generate electricity via converting sun strength into electricity on the identical time. Every solar cellular is basically a p-n diode. When the sun reaches the cellular sun mild, the mild is immediately transformed into electric power without any mechanical effort. The voltage that comes from photovoltaic cells and present day sizes are small, so photovoltaic cells are called modules and attire, which can be related in collection and in parallel to acquire the favored voltage and level. Solar PV systems designed to keep the typical output traits of PV panels can be without difficulty related to electric present converters within the gadget. The sun photovoltaic array is a non-linear device which can be thought of as a voltage distribution parallel to that of diodes.

Photovoltaic (PV) cells are products of semiconductor substances that convert radiation throughout the sun spectrum into electric modern. Photovoltaic cells are generally made of silicon and are available in two types: crystalline and thin movie. When a photon is absorbed by a semiconductor fabric, it increases the energy of an electron inside the conduction band, pushing it into the conduction band. This takes place when the strength of the incident photon exceeds the band gap. The conductive electron band then flows thru the semiconductor tool to generate contemporary.

Mobile solar can't be a unmarried preferred strength supply. Therefore, it's miles crucial to mix two photovoltaic solar cells to enhance the power output of the photovoltaic device field. A solar module commonly consists of some solar cells linked in collection to meet a extensive range of voltage and electricity requirements. The strength of sun modules can range from 3W to 300W. Solar modules or commercially available photovoltaic modules are the simple constructing blocks of sun strength generation structures.

Indeed, a solar photovoltaic cellular produces as little as 0.1 to 2 watts of energy. However, it isn't constantly beneficial to use a unmarried critical unit with low engine electricity. Hence a business sun set up is formed by way of connecting the preferred wide variety of such cells collectively, that's known as a sun module or photovoltaic module.

In a solar module, the sun cells are related further to the battery % in a battery gadget. The higher voltage of the cell terminal related to the terminal of the solar module is the sum of the voltages of the man or woman cells connected to the sun module.
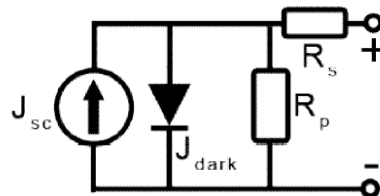

Fig. 2. Equivalent circuit of PV model.

The photovoltaic output voltage is a function of the mild modern-day, which is determined by way of the amount of sun radiation in operation (1) the usage of the modern load.

$$V_c = \frac{Ak\,T_c}{e} \ln\left(\frac{I_{ph} + I_o - I_c}{I_o} \right) - R_s I_c \quad \text{----- (1)}$$

Where the marks are defined as follows;
E: Electronic rate (1.602 10-19 C).
K: Boltzmann consistent (1.38 x 10-23 J/°K).
IC: cell output modern, A. IF: photocurrent characteristic, line radiation and junction temperature (5a).

I0: Diode contemporary (0.0002 A).
Rs: collection resistance of cells (0.001 mol).
Tc: reference cellular operating temperature (20 °C).
Vc: cellular output voltage, V
K and Tc each have the equal temperature unit: Kelvin or Celsius.

CHAPTER 4
PULSE WIDTH MODULATION TECHNIQUES
4.1 INTRODUCTION
The pulse width modulation technique makes use of a tough and rapid DC inverter voltage, and with the aid of adjusting the levels of the inverter additives, a suitable AC output voltage is obtained. This popular method to controlling the output voltage is referred to as pulse width modulation (PWM control).

4.2 TYPES OF PWM TECHNIQUE
Below we present PWM manipulate methods.
• Single Pulse Width Modulation (Single PWM)
• Multiple Pulse Width Modulation (MPWM)
• Sinusoidal pulse with modulation (PWM)
• Modified Sinusoidal Pulse with Modulation (MSPWM)

4.2.1 Single Pulse Width Modulation (Single PWM)
Pulse width modulation is a simple manner to deal with pulses, one pulse according to half cycle. The single pulse width can be adjusted to deal with the inverted output voltage. 75 By evaluating the reference amplitude square wave (AR) and triangular wave (AC), a gate sign may be generated as shown in Figure 5.1. This gate-generated signal is used to pressure an uncoupled full-bridge inverter. The frequency of the specified output voltage is decided through the frequency of the reference signal. For this the importance of the modulation index (M) may be defined and given by the immediately voltage of the inverter.

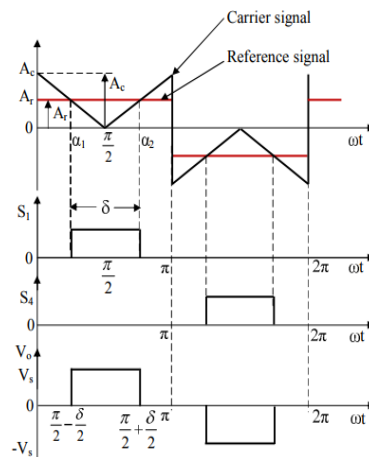$$M = \frac{A_c}{A_r},$$

$$V_O = V_s\left(S_1 - S_4\right)$$

Fig 4.1 Generation of Single Pulse width modulation

4.2.2 Multiple Pulse Width Modulation (MPWM)
The fundamental drawback of the single PWM technique is immoderate harmonics. To lessen harmonics, a two PWM method is used, wherein a large variety of pulses complete a voltage correction of 1/2 cycle every. As shown in Figure five.2, the epoch provider sign is applied by evaluating the amplitude signal (AR) with the triangular service signal (AC).
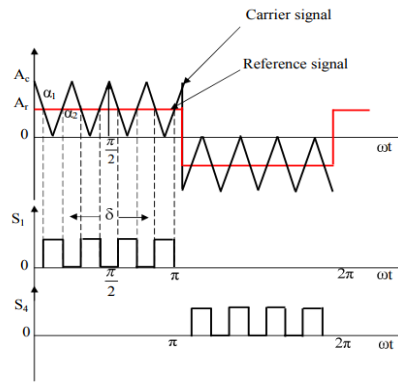
Fig 4.2 Generation of Multiple pulse width modulation

The variety of pulses per half cycle (P) is calculated on the provider frequency (FC). The variety of pulses corresponding to half of cycle is decided the usage of the formula

$$p = \frac{f_c}{2f_o}$$

$$= = \frac{m_f}{2}$$

Where

$m_f = \frac{f_c}{f_o}$, called as frequency modulation ratio.

The instantaneous output voltage of the inverter can be given as

$$V_O = V_s(S_1 - S_4)$$

The output frequency (FO) is decided by way of the frequency of the reference signal. Output voltage optimization with the aid of modulation index.

4.2.3 Sinusoidal Pulse Width Modulation (SPWM)

Figure four shows a 3-segment PWM sinusoidal sign, that is extensively utilized in enterprise. A gate sign can be generated by means of reference without the evoked waveform with a triangular waveform, which varies the width of each pulse as a percentage of the peak amplitude of the equivalent projected pulse at the center. Inverting the output frequency can be decided using a acknowledged reference frequency (fr). The control RMS voltage output (Vo) is managed the use of the modulation index M and the height amplitude modulation index. We can start with

$$V_O = V_s(S_1 - S_4).$$

The wide variety of pulses consistent with half cycle relies upon at the service frequency.

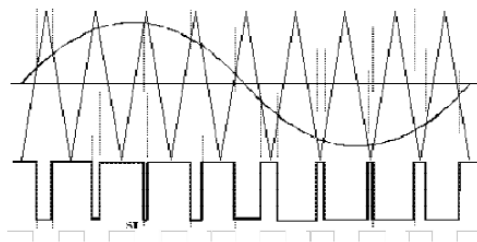The gate sign can be obtained the usage of a unidirectional triangular provider wave

Fig 4.3 Generation of Sinusoidal pulse width modulation

4.2.4 Modified Sinusoidal Pulse Width Modulation

When you think of a sinusoidal PWM waveform, the exchange-off inside the modulation index not involves a alternate-off inside the width of the pulses. The design is associated with sinusoidal traits. Therefore, this sinusoidal PWM method is modified so that the provider sign is used for the primary and final intervals similar to the DC half cycle, as shown in Figure four.Four. The vital part is superior and amplified with harmonic notes. The major advantages of this era are the growth in fundamental harmonic traits, the discount of various adjustments in electric device, and the reduction of switching losses.
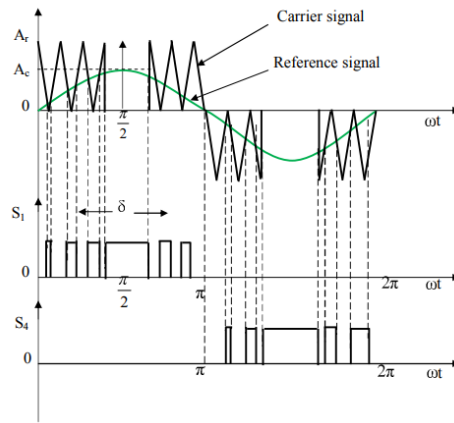
Fig 4.4 Generation of modified sinusoidal pulse width modulation

4.2.5 Advantages of PWM

•   Output voltage manipulation may be completed without any extra system

•   With this method, suppressed series harmonics within the transverse voltage impedance can be eliminated or reduced.

Will return you filter model

PIC 16F877A MICROCONTROLLER

6.5 INTRODUCTION :

We use a PIC 16F877A to convert the heartbeat into several inverters. Use vectors that do not create a common sample of hysteria in contrasting designs. This method excludes the commonplace voltage and is used to unique capacitive voltage imbalances. The microcontroller boosts the trigger voltage to 9V all through the activation circuit. We offer an optocoupler isolator to supply 230V power in the equivalent riding power circuit so as no longer to damage the microcontroller.

6.6 FEATURES OF PIC MICRO CONTROLLER :

The microcontroller has the subsequent features:

1. High Performance RISC Processor:

• A general of 35 one-word commands. That's why sorrow is a pal. Use neat.

• All unmarried instructions may be -stringed, except for branches used.

• Operating pace: DC - input clock 20 MHz DC - guidance cycle two hundred ns

• Up to 8K x 14 Flash Program Phrases, 368 x 8 Bytes Data Memory (RAM), EEPROM Statistics Memory up to 256 x eight Bytes. It's miles identical

2. External Features:

• Timer0: eight-bit timer/counter with 8-bit prescaler. It's miles set to sync

• Timer 1: Sixteen bit timer/counter timer, may be prolonged through sleep.

• Timer2: Eight-bit timer/counter with eight-bit duration sign in, prescaler and postscaler.

• Multiple PWM modules with two heads, Probe and After

• Intervene sixteen times. The result is 12.5 ns

At least sixteen • Compare max. So that makes it ns hundred

• Maximum PWM output is 10 spikes

• Synchronous Display Port (SSP) with SPI (master mode) and I2C (grasp/slave)

• Universal synchronous asynchronous receiver-transmitter with 9-bit addressing

• Parallel Slave Port (PSP) eight port huge with RD, WR and CS. With overseas governments

3. Need for analogies:

It has the identical parameters for contrast:

(I) Analog Comparator

(2) Input from built-in programmable voltage (VREF) module input and inner programmable voltage reference tool, so 3 elements

four. CMOS amplifier;

Its features are;

(1) High dealing with, excessive velocity FLASH/EEPROM generation

(2) Simple design

(3) Wide running voltage of the battery (2.Zero to 5.5V)

(4) commercial temperature and industrial septa

(5) Maximum strength consumption

4. CMOS technology;

It has the subsequent functions:

(1) High manipulate, excessive pace FLASH / EEPROM era

(2) Simple static design

(3) Wide operating voltage range (2.Zero to 5.5V)

(4) industrial temperature and industrial septa

(5) Low strength consumption

ADVANTAGES OF MICROCONTROLLER

•   If the pc is designed with a microprocessor, the designer should use outside memory consisting of RAM, ROM or EPROM as peripherals, so that the PCB size may be big sufficient to address all necessary peripherals. But the microcontroller has all the peripherals on the wedding chip, so the mi is sort of a gadget with a microcontroller.

•   The foremost distinction between microcontroller and microprocessor is the mileage of the controller. As in actual systems, it often returns bits in preference to bytes, for instance, switching contacts can be on or off, lights can be on or off, automobiles may be on or off, and so on.

•   The microcontroller has two incorporated sixteen bit timer/IS counters, that is suitable for this software, as it is vital to generate correct time delays.

•   This microcontroller has an internal octal analog to digital converter with 10-BL outputs, which lets in you to carry out work after the usage of an external ADC and reduces the complexity of the circuit and hardware.

•   This additional controller cycles ten thousand objectives and 1 AP tank at a time. Another gain of this controller is that it's miles a RISC pc gadget.

•   This log incorporates the today's information of the device.
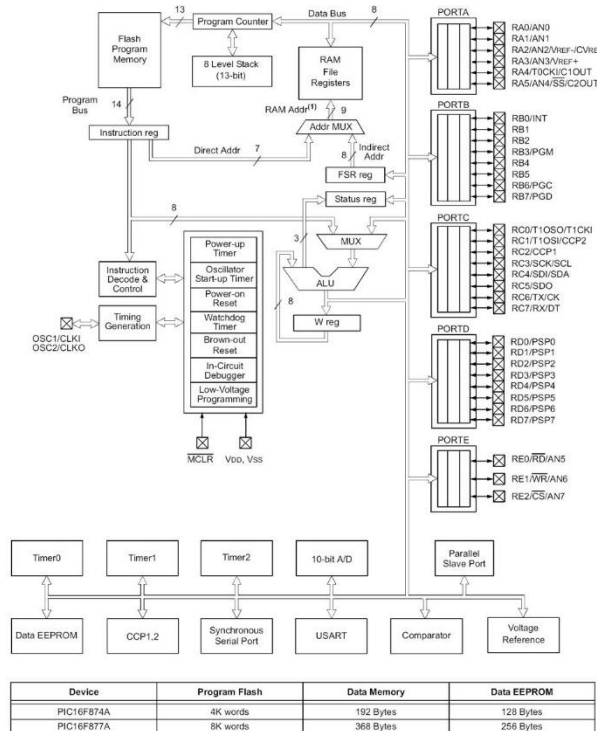
Block diagram of PIC 16F877A:

Device	Program Flash	Data Memory	Data EEPROM
PIC16F874A	4K words	192 Bytes	128 Bytes
PIC16F877A	8K words	368 Bytes	256 Bytes

Figure 6.3: Block diagram of PIC 16F877A

6.7: Block diagram of PIC 16F877A
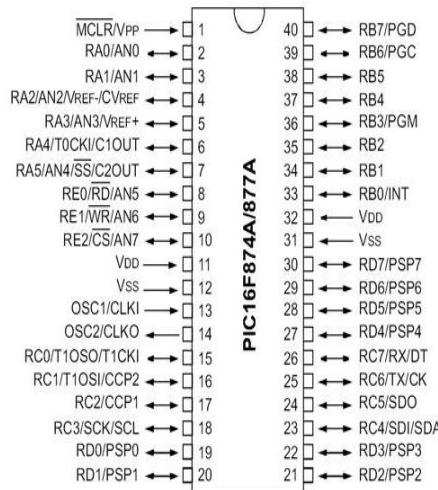**PIN DIAGRAM OF PIC 16F877A**

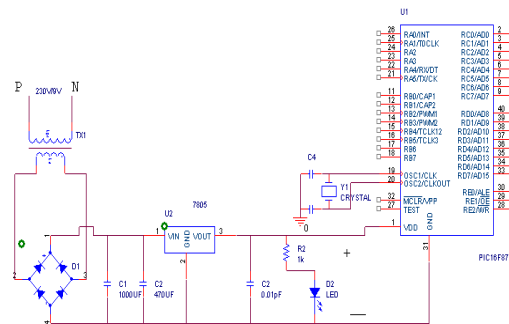Figure6.7: Pin diagram of PIC 16F877A

TRIGEERING CIRCUIT:

Figure 6.8: Triggering circuit.

5.MATLAB:
5.1 SOFTWARE DESCRIPTION:

MATLAB® is a high-stage computer language and surroundings for technical programming, interactive statistical visualization, statistical inference, and numerical computation. Using MATLAB, you may resolve technical computational problems quicker than with traditional programming languages which includes C, C++, and Fortran.

Matlab is an assessment and visualization tool developed with sturdy support for matrices and matrix operations. In addition, Matlab has excellent photographic abilties and its unique programming language is useful. One motive why MATLAB has emerged as such an crucial device is using the MATLAB Design Tools to resource in the design selection technique. These files are called media equipment and we have unique gear to apply for image processing. Rather than describe all of Matlab's functions, I'll cover best the ones associated with picture processing. Essential operations, methods and strategies might be brought. A function is an actual key-word that takes a number of parameters and produces a few type of output: as an instance, an array, a string, an array. Examples of such abilties are Sin, Ankit, Intimate. Perf has many capabilities, and as we will see, it is very smooth (and every so often vital) to put in writing your own.

The equal old matrix kind is a valid statement, assumed to be a matrix of type 1 or otherwise. The images are path matrices whose factors are the grey values (or perhaps RGB values) in their person pics. Sort and serialize each price as a string of characters; Wires of Time In this breakdown we can cover the general concepts of amendment and discuss pictures inside the following chapters.

When you start Matlab, there's an empty window, called the control window, into that you input commands. Since they are able to handle a terrific quantity of Matlab strains and a wide form of options, the command line interface is some distance more green than a complex array of pull-down menus.

You can use MATLAB in a extensive variety of programs which includes picture reputation and processing, communique, layout, manipulation, verification and measurement, economic modeling and evaluation. The MATLAB environment includes extra gear (MATLAB special function units) for fixing particular styles of problems in application regions.

MATLAB presents many centers for sharing your files and invites. You can distribute MATLAB algorithms and applications via porting your MATLAB code to unique languages and programs.

When working with pictures in Matlab, there are many things to remember, along with loading the photographs, the usage of the ideal layout, storing unique forms of data, how the picture is displayed, and switching between different image codes.

The Image Processing Toolbox gives a entire set of fashionable and graphical algorithms for image processing, assessment, visualization, and algorithm development. You can perform picture enhancement, photo blurring, motion detection, noise reduction, image segmentation, transposition, and photo registration. Many equipment are multi-threaded, permitting you to apply a multi-core and multi-system pc.

Conclusions

This paper proposes a redundant-stop-signal inversion topology based totally on a single DC deliver. Filter requirements are substantially decreased by the extreme removal of inverted output voltage. This reactive strength deliver is greatly extended by means of the usage of an inverter due to the low voltage drop throughout the coupling inductor. In addition, the high-sensing output voltage ensures higher grid energy demand. Additionally, DC inverters have higher blocking capability than conventional -phase inverters. With high floating operation, this DC converter avoids the faster circuit predicament than a traditional-segment converter. The application topology of the given converter has been stepped forward, with 2 stages of operation of this converter optimized for grid-linked solar photovoltaic structures. The two-degree configuration additionally gives more energy capture, permitting using two electric turbines. The topology is inherently greater reliable due to the fact losses are disbursed with lower voltages to handle better frequency exchanges. It is likewise a effective tool. Such capabilities make the proposed inverse topology competitive in comparison to the presently crucial topologies. A unique simulation visualization displaying the homes of the proposed transducer configuration, at the side of laboratory prototypes to aid the experimental effects.

REFERENCES:

[1] Y. Yang, P. Enjeti, F. Blaabjerg, and H. Wang, "Wide-scale adoption of photovoltaic energy: Grid code modifications are explored in the distribution grid," IEEE Ind. Appl. Mag., vol. 21, no. 5, pp. 21–31, Sep./Oct. 2015.

[2] S. B. Kjaer, J. K. Pedersen, and F. Blaabjerg, "A review of single-phase grid-connected inverters for photovoltaic modules," IEEE Trans. Ind. Appl., vol. 41, no. 5, pp. 1292–1306, Sep./Oct. 2005.

[3] K. Alluhaybi, I. Batarseh, and H. Hu, "Comprehensive review and comparison of single-phase grid-tied photovoltaic micro inverters," IEEE J. Emerg. Sel. Topics Power Electron., vol. 8, no. 2, pp. 1310–1329, Jun. 2020.

[4] X. Zhang, T. Zhao, W. Mao, D. Tan, and L. Chang, "Multilevel inverters for grid-connected photovoltaic applications: Examining emerging trends," IEEE Power Electron. Mag., vol. 5, no. 4, pp. 32–41, Dec. 2018.

[5] S. Pingel et al., "Potential induced degradation of solar cells and panels," in Proc. 35th IEEE Photovoltaic Spec. Conf., 2010, pp. 2817–2822.

[6] S. Koch, D. Nieschalk, J. Berghold, S. Wendlandt, S. Krauter, and P. Grunow, "Potential induced degradation effects on crystalline silicon cells with various antireflective coatings," in Proc. 27th Eur. Photovoltaic Congr. Exhib., Sep. 2012, pp. 1985–1990.

[7] J. Kim, J. Kwon, and B. Kwon, "High-efficiency two-stage threelevel grid-connected photovoltaic inverter," IEEE Trans. Ind. Electron., vol. 65, no. 3, pp. 2368–2377, Mar. 2018.

[8] R. Mali, N. Adam, A. Satpaise, and A. P. Vaidya, "Performance comparison of two level inverter with classical multilevel inverter topologies," in Proc. IEEE Int. Conf. Elect., Comput. Commun. Technol., 2019, pp. 1–7.

[9] A. Aghazadeh, M. Davari, H. Nafisi, and F. Blaabjerg, "Grid integration of a dual two-level voltage-source inverter considering grid impedance and phase-locked loop," IEEE J. Emerg. Sel. Topics Power Electron., vol. 9, no. 1, pp. 401–422, Feb. 2021.

[10] W. Wu, Y. He, T. Tang, and F. Blaabjerg, "A new design method for the passive damped LCL and LLCL filter-based single-phase grid-tied inverter," IEEE Trans. Ind. Electron., vol. 60, no. 10, pp. 4339–4350, Oct. 2013.

[11] L. Franquelo, J. Rodriguez, J. Leon, S. Kouro, R. Portillo, and M. Prats, "The age of multilevel converters arrives," IEEE Ind. Electron. Mag., vol. 2, no. 2, pp. 28–39, Jun. 2008.

[12] Y. Wang and F. Wang, "Novel three-phase three-level-stacked neutral point clamped grid-tied solar inverter with a split phase controller," IEEE Trans. Power Electron., vol. 28, no. 6, pp. 2856–2866, Jun. 2013.

[13] N. Beniwal, H. D. Tafti, G. G. Farivar, S. Ceballos, J. Pou, and F. Blaabjerg, "A control strategy for dual-input neutral-point-clamped inverter-based grid-connected photovoltaic system," IEEE Trans. Power Electron., vol. 36, no. 9, pp. 9743–9757, Sep. 2021.

[14] L. Zhang, K. Sun, L. Feng, H. Wu, and Y. Xing, "A family of neutral point clamped full-bridge topologies for transformerless photovoltaic grid-tied inverters," IEEE Trans. Power Electron., vol. 28, no. 2, pp. 730–739, Feb. 2013.

[15] H. Wang, L. Kou, Y. Liu, and P. C. Sen, "A new six-switch five-level active neutral point clamped inverter for PV applications," IEEE Trans. Power Electron., vol. 32, no. 9, pp. 6700–6715, Sep. 2017.