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SOLAR INVERTERS BASED ON STM32 MICROCONTROLLER

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ABSTRACT

In this paper, the focus is given on the implementation of a solar inverter with the use of STM32 and closed-loop communication. A power electronic switch is used to convert the voltage either into the grid or store it into a battery. In this topology, the STM Microcontroller has to control each and every function as per requirement, and advanced control algorithms are required to achieve control over each and every stage. For this closed-loop communication to control the switches, STM32 can interface with a CAN controller to easily communicate with the pulse width modulation (PWM) generation circuit. High-end PWM techniques control the analog voltage and convert it into binary digital form, which can be used to control the digital controller. High-end PWM increases the dynamic response to the control voltage change, improve efficiency, and have inner feedback loops and easy signal processing. By using sine wave pulse width modulation, we can generate the same sine voltage wave to control the inverters. Finally, power electronic switches can control each level of the sine wave into our desired output waveform and greatly reduce power loss.

Keywords: STM32 Microcontroller, Solar Inverters, Pulse Width Modulation (PWM).

I. INTRODUCTION

Solar energy has been hence implemented with the role of the critical renewable source in the field of environmentally friendly energy, whilst responding to the growing power demands of the global economy. In solar energy technology, it is the solar inverter that is first and foremost in converting the DC that solar panels produce, into AC that can be used to power electrical systems in residential, commercial, and industrial applications. In the last few years, microcontroller technology has taken a huge leap and has changed the both game and performance of solar inverters compared to its past those STM32 microcontroller series takes a very strong position in the eyes of developers and engineers. [1][2]

The introduction of solar inverters based on STM32 microcontrollers signifies a convergence of two innovative fields: converting solar energy during daytime and utilizing microcontroller technology. multiped STM32 microcontrollers by STMicroelectronics are well-known for their multi-purpose, high performance, and energy efficiency characteristics, they are suitable for use in different applications such as solar inverters. These microcontrollers come with abundant processing power, a multitude of peripherals (I/O's), and diverse development tools and support, allowing designers to independently design and realize punctilious and faultless solar inverter systems. [3][4][5]

The relevance of this research paper to this exploration lies in the look into the process of using STM32 microcontrollers as a component of the solar inverter system. Through the presentation of technical specifications, design considerations, and implementation challenges, along with performance evaluations of STM32 microcontrollers in photovoltaics, the purpose of this work is to gain a deeper knowledge about the feasibility and effectiveness of applying STM32 microcontrollers in solar energy applications. In addition to merely highlighting the interplay behind such a technology, it aims to offer insights about the advantages, present barriers, and the way forward in the field of renewable energy integration and microcontroller-led systems will be an objective of the study. [6][7][8][9][10]

II. METHODOLOGY

The first step in the design process was to carry out research on the various types of inverters available in the market and the inverters that are being designed by other students. This involved researching the theory and the methods of implementation of these inverters and understanding why certain design choices were made.

This research was fundamental in identifying the direction of STM32 microcontroller simulations and code implementation. Solar inverters are essentially designed to convert direct current (DC) power generated from photovoltaic solar panels into alternating current (AC) power for use within the home or commercial building infrastructure. Finally, a thorough understanding of the STM32F1 series microcontroller was required for this project. This included learning the different functionality for analogue and digital peripherals, a clear understanding of timer functions, knowledge of code implementation into the microcontroller, and learning the use of peripheral interface. [23][24]

III. MODELING AND ANALYSIS

Components and subsystems involved

In most parts of the world, the power grid requires the inverter to have a power factor of greater than 0.95 and total harmonic distortion of current less than 5%. This is to replicate the same quality of power being delivered by conventional power stations. Compliance with power quality requirements is essential in order to prevent curtailment of solar energy and maintain high levels of grid acceptance for PV systems [12] [13]. The STM32 microcontroller series has a range of inbuilt peripherals useful for inverter control including operational amplifiers for signal conditioning, high-speed and high-resolution A/D converters, PWM timers with complementary outputs for DC motor control, and sigma-delta modulators for power electronics control. Implementing power factor correction and various modulation and control techniques required for power quality will depend on the type of inverter. [15][16][17]

Due to varying sunlight levels and weather conditions, the input power and voltage to the inverter will constantly change. In order to achieve the maximum available output power from the PV array, the inverter must use maximum power point tracking techniques to fix the operating point of the PV array. This is typically implemented using a perturb and observe or incremental conductance algorithm. These methods require a high-speed A/D converter and computation core to efficiently track the maximum power point. The changing nature of the PV array characteristic means that the inverter may be required to operate in a range of input voltages marginally higher or lower than the nominal voltage; ±18 V for a 24 V PV array. Step changes in the input voltage due to the array operating at a different power point, or changes in the grid voltage can cause the inverter to lose synchronization with the grid and disconnect. For instance, a high dV/dt seen on the array voltage can cause the grid-tied inverter to disconnect. A subsystem may be employed to help regulate the input voltage into the inverter to keep the array at an optimum power point, preventing abrupt frequency and power changes. An isolated DC-DC converter between the array and the inverter is one method to regulate the input voltage. The DC voltage delivered to the inverter will still need to be buffered by a large capacitor to store energy for high-frequency power changes. Simulation tools for energy system designs are becoming more prevalent and can be used to model PV array dynamics including environmental factors and the use of different array configurations. Given the complexity of the solar inverter task, using a digital control platform for power design has become very desirable. [18][19][20][21][22]

Figure 1: A typical solar inverter system. [36]

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During the design of solar inverters, many factors need to be taken into account to ensure optimum performance including efficiency, insulation coordination, thermal control, power quality, and reliability. Many ways exist to implement the design; however, it is beyond the scope of this paper to cover them. Thus, we discuss what we believe are key modern design considerations.

Circuit Diagrams and Block Diagrams

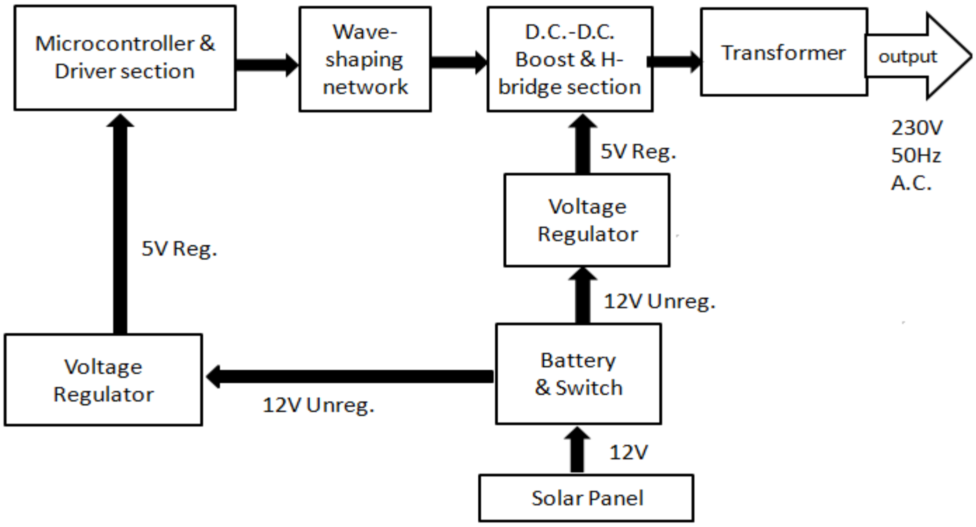

Figure 2: Block Diagram of Microcontroller based solar powered inverter [37]

Figure 3: STM32 F100 Microcontroller circuit diagram

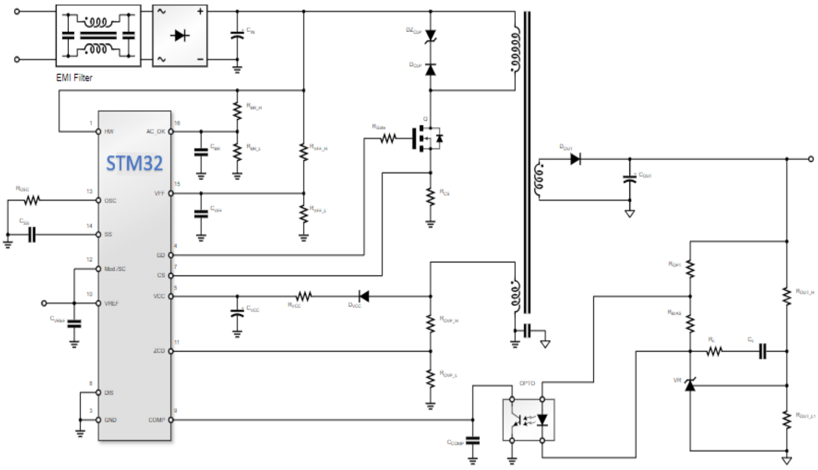

Figure 4: Solar inverter with the STM32 Microcontroller circuit diagram drawn in the eDesignSuite.

Efficiency and Performance Optimization Techniques

Adaptive techniques can be implemented to inverter logic to enable operation at the best possible efficiency at any given time. If the inverter is not confined to a single application, it can be possible to increase efficiency by using maximum power point tracking to vary the input voltage. Many renewable energy sources have variable output characteristics, and a typical solar panel can increase its efficiency by up to 20% when its voltage is increased. This is due to the panel's I-V curve having an output current that can change significantly with a small change in voltage. The maximum power (and voltage) that the panel can produce is dependent on the illumination and temperature of the ambient environment, so a real-time system that enables measurement of the panel power and subsequent dynamic change of the inverter input voltage could deliver the most efficient operation. This power measurement can be done through the use of a shunt resistor in series with the panel and an ADC to convert the voltage across the shunt to a digital value.

One sure way to increase efficiency is by reducing the number of conversion steps and by increasing the pulse width modulation (PWM) resolution so that less energy is lost in the switching of the transistors. This can be achieved by using multilevel inverters. A basic two-level inverter has a high energy loss in the switching of the transistors. This is due to high dV/dt value for the output voltage where each pulse of voltage is followed by a large step where the voltage must quickly change. This generates a higher level of harmonics and a high frequency of switching. Multilevel inverters divide the DC voltage to produce a stepped AC output. The most common being the three-level inverter that can give an output voltage of +V, 0, and –V. This will lead to fewer harmonics and a lower switching frequency as there are more possible output voltage levels. This will reduce the switching energy loss of the transistors and provide a lower dV/dt value. High PWM resolution can be achieved by using analogue methods; however, a microcontroller-based implementation would be more flexible. Pulse width modulation has an effect on more than just the inverter. Enabling a method to dynamically change the modulation to give a more energy-efficient output is an optimization problem that could be carried out.

The efficiency of the inverter is a primary concern when an inverter is designed. Inverters use up a lot of energy in the form of losses. There is always a trade-off between the cost of adding technology for improvement in efficiency and the value that will be gained from doing so.

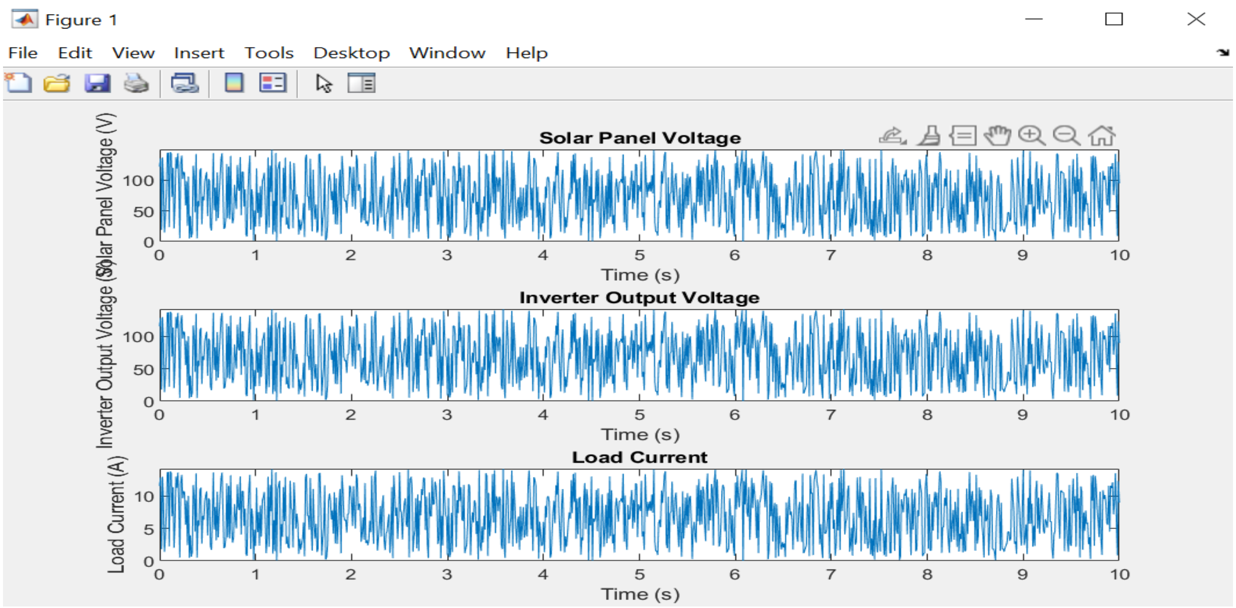

Figure 5: Matlab Simulink stability simulation of a typical solar panel array, inverter system with STM32 microcontroller, load simulator, and grid simulator.

Integration and Testing

The first step taken in trying to run the program into the microcontroller was to ensure that the program could be compiled without any error. As for the inverter, the Keil µVision4 IDE was used together with the MDK ARM version 5.12. In order to do the compilation, all the components were created in a single project. Then, the

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device for the project was chosen to ensure that the device selected was similar to the microcontroller that was going to be used. In this case, the STM32F100C4 was used, hence the device for the project was chosen. After everything has been set up, the compilation process was done by clicking "Build target" and the result of the compilation was displayed in the "Build Output" window. If there is no error, the program can proceed to the next stage. Otherwise, the error in the program has to be solved first. Usually, the error in the program is due to the difference in syntax between the standard C language and the processor of the compiler.

In this inverter, the STM32 microcontroller was chosen due to its large flash memory and RAM to store program codes and data, and also its high processing capability. Besides that, the availability of development tools such as the compiler, emulator, and debug tools are also one of the criteria to choose the microcontroller. Since STM32 is getting popular and it is currently actively developed by STMicroelectronics, there are various development tools that are available in the market and the price is quite cheap. This was a very beneficial stage for the development process. [13][30]

Performance Evaluation

The method to calculate angle of incidence losses using solar panel voltage measurements promises accurate calculation. Results from this method were compared with results from radiation sensor tests on a similar system, showing a promising conclusion.

Energy potential calculation from solar altitude is already believed to be a successful method. This compares at any given time, solar azimuth, declination, and noon hour angle with reference to conventional measurement at the latitude of the test site. A graphical representation is produced to confirm.

Prediction of solar energy availability at different time slots is a difficult task. The data given by NASA is in the form of average values corresponding to a certain period and area. A calculator program was written in Microsoft Excel using equations explained to compute energy potential at any different time, day, or month of the year [31]. The code below was used in the calculations.

```
=B2 * C2 * 1.0 / 100 * 1.0 / 3600
```

Comparison is done between the actual PV power output taken and the expected value using data from parameters to evaluate the effectiveness of the prediction algorithm.

IV. RESULTS AND DISCUSSION

The newly developed standalone solar PV system based on STM32 microcontroller has been successfully designed and implemented. This project evaluates the performance of the solar inverter in terms of hardware and software. The hardware part uses STM32 microcontroller, power transistor, single-phase inverter, and ferrite transformer. Meanwhile, the software part uses force PWM with a sinusoidal reference signal to produce a 50Hz SPWM signal. The H-bridge inverter then produces a 50Hz AC signal. The solar panels supply 270V DC power to the inverter through a boost converter. The inverter is able to convert the fixed 270V DC voltage into AC voltage. Next, the AC voltage will go through the ferrite transformer to step down the voltage to 52V AC. This 52V AC voltage will go through a full-wave rectifier to change the AC voltage into DC voltage and then charge the battery. This project is functioning and capable of driving a 60W fluorescent lamp. The waveform produced is in good sinusoidal form. This project is very cost-effective and best suited for rural areas that don't need electricity power supply around the clock. This is due to the low-cost maintenance and being free from the electricity bill. [32][26]

V. CONCLUSION

STM32 microcontroller provides interesting features which can be used to design a solar inverter. The proposed model of the solar inverter is simple, less expensive, and reliable because the power delivered by the solar panel is low. It is widely used for street lights, domestic purposes, and on farms, etc. In conclusion of the research, the single-phase inverter using STM32 microcontroller and other related devices has already been proven as a good method in generating sine wave pulse width modulation that is being used in the production of AC voltage from a DC source. By using the development kit, Silicon Labs C8051F development kit, we managed to successfully generate sinusoidal pulse width modulation (SPWM) signals so that it can control a class D inverter to produce AC voltage from a DC source. Although a sinusoidal waveform has been successfully generated, it does not guarantee that the generated signal can produce a 100% similar waveform compared to the sinusoidal waveform from the AC main. This new design of a single-phase inverter is hoped to be a reference in building a simple solar inverter for academic purposes.

As for future work, the MPPT algorithm can be applied to the STM32 microcontroller to extract the maximum power from the solar panel so that it can be used to design a solar inverter. And then the microcontroller programming will be continued with running the H bridge inverter using a new development kit to prove that a class D inverter using a sine wave signal has already been successfully built. After that, an experiment can be done by using a transformer so that it can be used to increase the voltage from the inverter, and the last step is to compare the result of the AC voltage from the solar inverter with the real AC main voltage waveform.

VI. FUTURE RESEARCH DIRECTIONS

This chapter has arranged new methodologies and calculations, which are an assurance to supply maximum future solar inverter system. Several new topologies and tidied PWM calculating algorithms have been designed and simulated results have shown motivation of success. These methodologies can more be improved and implemented with better control techniques in future. Fuzzy logic control and adaptive neural network control are the upcoming advanced methods and have capability to improve the performance of inverter, during load variations and new algorithm for SVM will be well eligible for this.

Induction of new devices like SiC power devices, super junction MOSFET and GaN based devices, will also lead to decrease the passive elements in inverter, as they provide very high frequency operation and high efficiency. These devices have also high current capacity and can easily operate with Si devices, as its gate threshold voltage of turned-on Si IGBT and Si MOSFET are more. High voltage gain DC-DC boost converter with SiC power devices and GaN based devices are capable for achieving very high frequency and result of its implementation will be viable to further simulate PWM algorithms for frequency and also for reducing EMI. Last but not the least, control for this converter with solar MPPT, will be higher beneficial to increase the efficiency of new solar inverter system. Future also has a demand for space efficient and high frequency power transformer, as it will make significant reduction in size and weight of inverter. Step up transformer is currently eminent for inverters with H bridge topology. [33][34][35]

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