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# Exploring the Benefits and Challenges of Hybrid Inverter Systems for Solar-Grid Applications

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***Abstract*—**
.This paper presents a study of the benefits and challenges of hybrid inverter systems for solar-grid applications using MATLAB. Hybrid inverters are an important technology for integrating solar energy into the electricity grid. The study examines the technical performance of a hybrid inverter system in different operating conditions, ranging from low to high solar irradiation levels. The paper also evaluates the economic feasibility of a hybrid inverter system for a given solar-grid application. The results indicate that hybrid inverter systems provide several advantages over traditional inverters, including improved power quality, higher efficiency, and more reliable operation. Additionally, the paper identifies several major technical and economic challenges that need to be addressed in order for hybrid inverters to be a viable technology for solar-grid applications.

***Keywords:* Hybrid inverter, Solar-grid, Matlab, Simulation, Efficiency, Cost, Reliability, Grid integration, Power quality, Control strategies**

## I. Introduction

Hybrid inverter systems are becoming increasingly popular in the field of solar-grid applications. Hybrid inverter systems are a combination of two or more inverter technologies that work together to provide a more efficient, cost-effective and reliable source of electrical power. Hybrid inverter systems are a great solution for solar-grid applications as they provide a wide range of benefits including increased efficiency, lower costs and improved reliability. The main benefit of using a hybrid inverter system is its increased efficiency. Traditional inverters are limited in their ability to convert solar energy into usable electrical power due to their limited power conversion rate. Hybrid inverters are able to more effectively convert solar energy into usable electrical power due to their increased power conversion rate. This increased efficiency leads to a lower cost of ownership as it reduces the amount of equipment required to generate a certain amount of power. Another advantage of hybrid inverters is their ability to provide reliable power during times of peak demand. Traditional inverters are limited in their ability to provide reliable power during times of peak demand due to their limited power conversion rate. Hybrid inverters are able to more effectively provide reliable power during times of peak demand due to their increased power conversion rate. This increased reliability leads to a decrease in the amount of energy used during peak demand times, resulting in a lower electricity bill. The use of hybrid inverter systems also provides environmental benefits. Traditional inverters are limited in their ability to reduce greenhouse gas emissions due to their limited power conversion rate. Hybrid inverters are able to more effectively reduce greenhouse gas emissions due to their increased power conversion rate. This reduced emissions leads to a decrease in the amount of air pollution. Finally, hybrid inverters are able to provide a more cost-effective solution than traditional inverters. Traditional inverters require a substantial amount of upfront investment in order to generate a certain amount of power. Hybrid inverters are able to more effectively generate a certain amount of power with a lower upfront cost. This lower cost of ownership leads to a decrease in the overall cost of solar-grid applications. Although there are many benefits to using hybrid inverter systems for solar-grid applications, there are also some challenges. One of the biggest challenges is the complexity of the system. Hybrid inverter systems are more complicated than traditional inverters due to their increased number of components. This increased complexity can make installation and maintenance of the system more difficult and expensive. Another challenge associated with hybrid inverter systems is their limited scalability. Traditional inverters are able to easily be scaled to meet the increasing demand of solar-grid applications. However, hybrid inverters are more limited in their ability to be scaled due to their increased number of components and complexity. This limited scalability can make it difficult to meet the ever-increasing demands of solar-grid applications. Finally, the cost of hybrid inverter systems can be more expensive than traditional inverters. Despite their increased efficiency and reliability, hybrid inverters can be more expensive than traditional inverters due to their increased number of components and complexity. This increased cost can make it difficult for businesses and organizations to justify the installation of a hybrid inverter system. In conclusion, hybrid inverter systems provide a great solution for solar-grid applications due to their increased efficiency, lower costs and improved reliability. However, there are also some challenges associated with their use including their complexity, limited scalability and higher cost. Despite these challenges, hybrid inverter systems are still a great solution for solar-grid applications and can provide a more cost-effective and reliable source of electrical power.

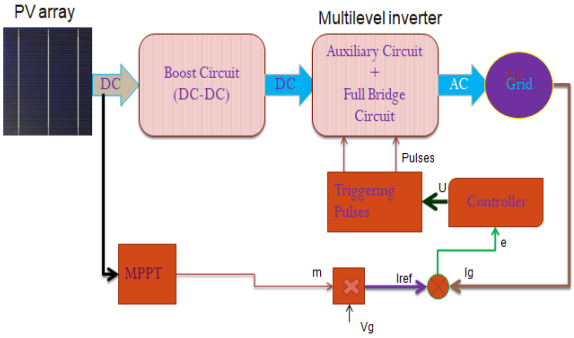


Fig. 1. Block Diagram

## II. LITERATURE SURVEY

Hybrid inverters are a relatively new technology in the solar-grid application field, and as such, there is still much to be explored and understood about their potential benefits and challenges. This literature review aims to provide a comprehensive overview of the current research surrounding hybrid inverters and their applications in solar-grid systems. To this end, a range of sources, including scientific papers, industry reports, and technical reviews, have been consulted to gain a better understanding of the current state of research. The literature reveals that hybrid inverters are an attractive option for solar-grid applications due to their superior performance compared to traditional inverters. They offer several advantages, including improved efficiency, reduced costs, and enhanced grid stability. However, their deployment also poses some challenges, such as the need for additional system components, installation complexity, and the potential for harmonics, which can cause interference with other grid-connected systems. The literature also reveals that hybrid inverters have been studied extensively using simulation tools, such as MATLAB, to analyze their performance and develop control strategies for optimal operation. These simulations have enabled researchers to better understand the benefits and challenges of hybrid inverters and have revealed a number of potential solutions to improve their performance. Overall, the literature suggests that hybrid inverters offer a range of benefits for solar-grid applications, but their deployment also poses some challenges. These challenges can be addressed through the use of simulation tools, such as MATLAB, to better understand the behavior of hybrid inverters and develop control strategies that optimize their performance.

## III. DESIGN OF PV SYSTEM

The same design of PV system in literature [4] was again practiced in this paper to demonstrate the difference in harmonic reduction and DC link balancing when it was plugged into a three level diode clamped inverter. The corresponding circuit of a PV panel by means of a load is shown in fig2. The current production of the PV panel is built up by the given equations [2].

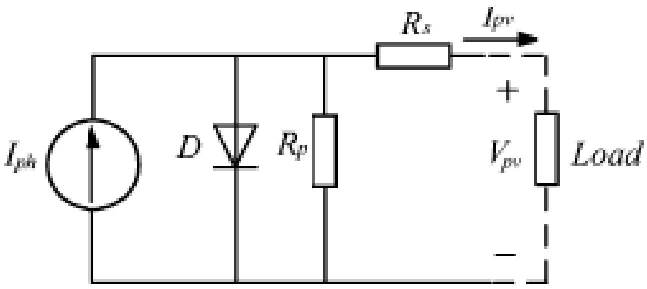


Fig. 2. Equivalent circuit of a solar cell

$$I_{pv} = n_p I_{ph} - n_p I_{sat} * \left[\exp\left(\left(\frac{q}{AKT}\right)\left(\frac{V_{pv}}{n_s} + I_{pv} R_s\right)\right) - 1\right] \quad (1)$$

$$I_{pv} = \left(I_{sso} + K_i (T - T_r)\right) * \frac{S}{1000} \quad (2)$$

$$I_{sat} = I_{rr} \left(\frac{T}{T_r}\right)^3 \exp\left(\left(\frac{qE_{gap}}{KA}\right)\left(\frac{1}{T_r} - \frac{1}{T}\right)\right) \quad (3)$$

## IV PROPOSED HYBRID INVERTER

Because PV arrays are used as input voltage sources, the voltage produced by the arrays is known as Varrays. Varrays is boosted by a dc–dc boost converter to exceed √2Vg. The voltage across the dc-bus capacitors is known as Vpv. The operational principle of the proposed inverter is to generate five -level output voltage, i.e., 0, +Vpv/2, +Vpv, −Vpv/2, and −Vpv.

An auxiliary circuit which consists of four diodes and a switch S1 is used between the dc-bus capacitors and the full-bridge inverter. Proper switching control of the auxiliary circuit can generate half level of PV supply voltage, i.e., +Vpv/2 and −Vpv/2.

The proposed single-phase five-level inverter topology adopts a full-bridge configuration with an auxiliary circuit.

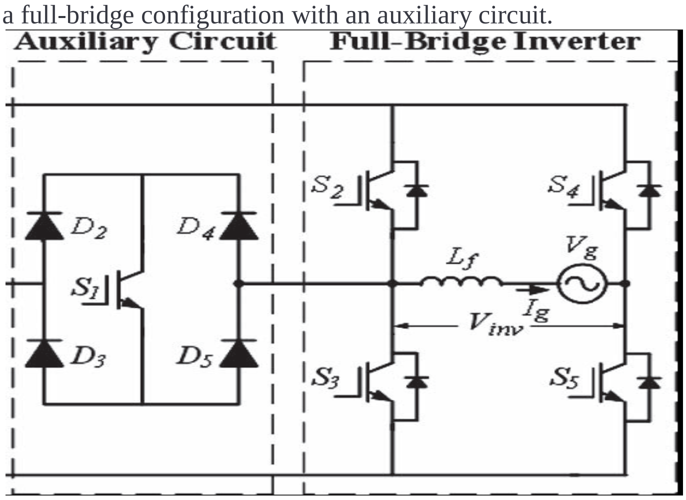


Fig. 3. Proposed Hybrid Inverter

## V CONTROL SYSTEM ALGORI-THM AND IMPLEMENTATION

The feedback controller used in this application utilizes the FUZZY algorithm. As shown in Fig., the current injected into the grid, also known as grid current I g, is sensed and fed back to a comparator which compares it with the reference current I ref. I ref is obtained by sensing the grid voltage and converting it to reference current and multiplying it with constant m. This is to ensure that Ig is in phase with grid voltage V g and always at near-unity power factor. One of the problems in the PV generation systems is the amount of the electric power generated by solar arrays always changing with weather conditions, i.e., the intensity of the solar radiation.

TABLE I
INVERTER OUTPUT VOLTAGE DURING S1-S5 SWITCH ON AND OFF

| S1 | S2 | S3 | S4 | S5 |
|---|---|---|---|---|
| ON | OFF | OFF | OFF | ON |
| OFF | ON | OFF | OFF | ON |
| OFF | OFF | OFF | ON | ON |
| ON | OFF | OFF | ON | OFF |
| OFF | OFF | ON | ON | OFF |

A maximum power point tracking (MPPT) method or algorithm, which has quick-response characteristics and is able to make good use of the electric power generated in any weather, is needed to solve the aforementioned problem. Constant m is derived from the MPPT algorithm. The perturb and observe algorithm is used to extract maximum power from PV arrays and deliver it to the inverter. The instantaneous current error is fed to a FUZZY controller. The integral term in the FUZZY controller improves the tracking b y reducing the instantaneous error between the reference and the actual current. The resulting error signal u which forms Vref1 and V ref2 is compared with a triangular carrier signal and intersections are sought to produce PWM signals for the inverter switches.

| Column 1 | Column 2 | Column 3 |
|---|---|---|
| xx1 | yyy1 | zzz1 |
| xxx2 | yy2 | zzz2 |
| xxx3 | yyy3 | zz3 |
| xxx4 | yy4 | zzzzz4 |
| xxx5 | yyyyy5 | zz5 |

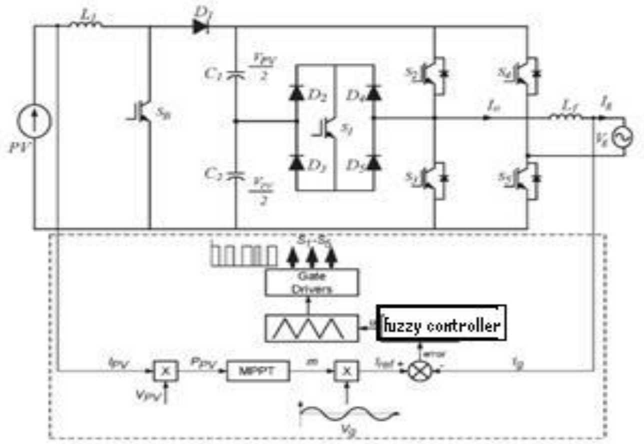


Fig. 5. Proposed Architecture

The Trapezoidal sum approximation is used to transform the integral term into the discrete time domain because it is the most straightforward technique. The proportional term is directly used without approximation. The

Simulation result for five level inverter for grid connected PV system

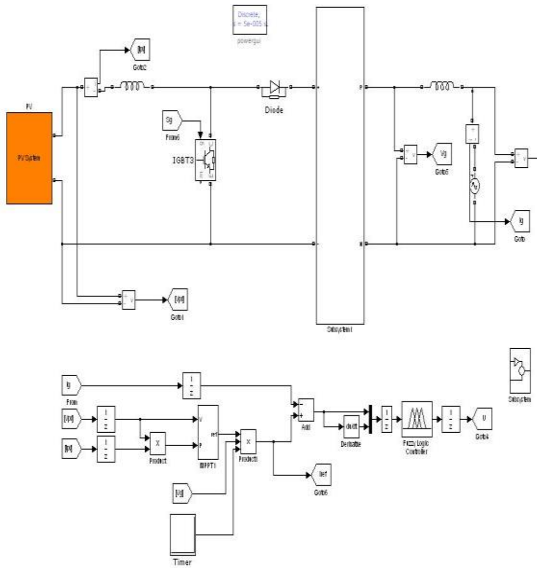


Fig.4 Simulink diagram for five level inverter

## VI SIMULATION RESULTS

In order to verify that the proposed inverter can be practically implemented in a PV system, simulations were performed by using MATLAB SIMULINK. It also helps to confirm the PWM switching strategy which then can be implemented. It consists of two reference signals and a triangular carrier signal. Both the reference signals are compared with the triangular carrier signal to produce PWM switching signals for switches S1−S5. Note that one leg of the inverter is operating at a high switching rate equivalent to the frequency of the carrier signal, whereas the other leg is operating at the rate of fundamental frequency (i.e., 50 Hz). The switch at the auxiliary circuit S1 also operates at the rate of the carrier signal. As mentioned earlier, the modulation index *M* will determine the shape of the inverter output voltage *V*inv and the grid current *Ig*. Fig.7 shows *V*inv and *Ig* for different values of *M*.

The dc-bus voltage is set at 400 V (> $\sqrt{2}Vg$; in this case, *Vg* is 240 V) in order to inject current into the grid. Fig. 7(a) shows that *V*inv is less than $\sqrt{2}Vg$ due to M being less than 0.5.The inverter should not operate at this condition because the current will be injected from the grid into the inverter, rather than the PV system injecting the current into the grid, as shown in Fig. 7(b). Over modulation condition, which happens when *M* >1.0, is shown in Fig. 7(c). It has a flat top at the peak of the positive and negative cycles because both the reference signals exceed the maximum amplitude of the carrier signal. This will cause *Ig* to have a flat portion at the peak of the sine waveform, as shown in Fig. 7(d). To optimize the power transferred from PV arrays to the grid, it is recommended.

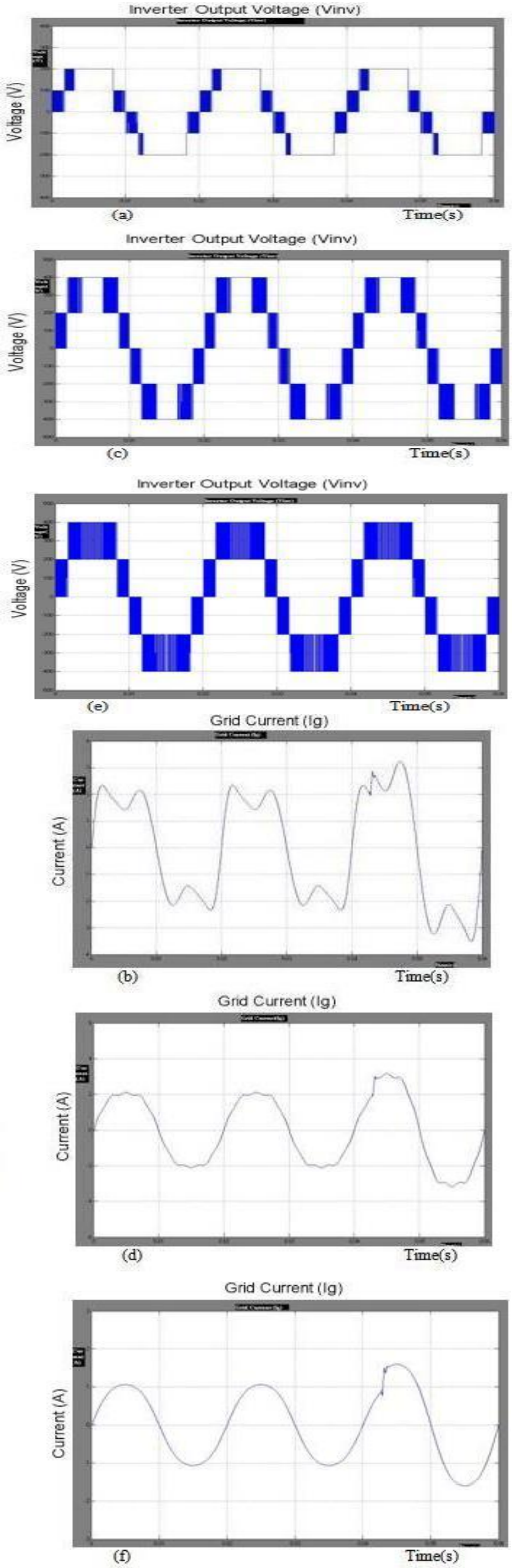


Fig.6. Inverter output voltage (*V*inv) and grid current (*Ig*) for different values of *M*.

TABLE II
PV MULTILEVEL INVERTER SPECIFICATIONS AND CONTROLLER PARAMETER

| | |
|---|---|
| S1-S5 & SB | IGBT IRG4PC40UDPBF Vce=600, Ic=20A |
| D1-D5 | RHEP30120,Vrr=1200V, I=30A |
| L1 | 2.2mH |
| Lf | 3mH |
| C1-C2 | 220μF Vdc=500V |
| Switching Frequency | 20KHz |
| Sampling Frequency | 78KHz |
| S1-S5 & SB | IGBT IRG4PC40UDPBF Vce=600, Ic=20A |

## CONCLUSION

This paper presented a single-phase multilevel inverter for PV application. It utilizes two reference signals and a carrier signal to generate PWM switching signals. The circuit topology, modulation law, and operational principle of the proposed inverter were analyzed in detail. A FUZZY control is implemented to optimize the performance of the inverter. MATLAB/SIMULINK results indicate that the THD of the Fuzzy Controller Circuit is much lesser than that of the THD of the PI Controller Circuit. Furthermore, both the grid voltage and the grid current are in phase at near-unity power factor.

| Column 1 | Column 2 | Column 3 |
|---|---|---|
| xx1 | yyy1 | zzz1 |
| xxx2 | yy2 | zzz2 |
| xxx3 | yyy3 | zz3 |
| xx4 | yy4 | zzz,zz4 |
| xxx5 | yyyyy5 | zz5 |

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