TECH-CHRONICLE
AN INTERNATIONAL E-JOURNAL ON
EMERGING TRENDS IN SCIENCE, TECHNOLOGY AND MANAGEMENT

An Intelligent Grid- Tied PV System with Dual- Charge Pump Circuits for Single -Phase Transformer less Inverters

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***Abstract**: In this paper, we develop a grid-connected PV system using a single phase transformer-free solar inverter. We are creating a new topology that introduces the charge pump circuit concept in order to stop leakage current. In this paper, fuzzy logic controllers are used for controlling purposes. It has been explored how fuzzy logic controllers compare to other controllers. The PV panel's negative polarity is directly connected to the grid's neutral, resulting in a stable common mode voltage and no leakage current. The charge pump circuit creates the negative output voltage of the suggested inverter during the negative cycle. As a result, the injected current is controlled using the proportional resonant control approach. The proposed inverter has a number of benefits, including direct connection of the grid's neutral to the PV panel's negative terminal, which eliminates leakage current, compact size, low cost, use of a full-bridge inverter's equivalent dc voltage (as opposed to half-bridge, active NPC, and neutral point clamped inverters), flexible grounding configuration, reactive power flow capability, and high efficiency. We can validate the idea behind the suggested inverter and its practical use in grid-tied PV systems using the results of the simulation.*

***Keywords:** Grid-tied inverter, Charge Pump Circuit, Transformer Less Inverter, Leakage Current Elimination, Fuzzy Logic Control.*

I. INTRODUCTION

Photovoltaic (PV) power systems have been increasingly popular among renewable energy sources over the last two decades since they generate electricity but have no moving parts, operate quietly with no emissions, which means no pollution, and require maintenance. [1], [2]. Distributed grid-connected PVs are becoming an increasingly important component of the electrical system. PV systems, on the other hand, suffer from a high common mode (CM) current due to the huge stray capacitors between the PV panels and the ground, which affects system efficiency and may pose safety hazards such as electric shock. Transformers are often employed in PV systems to offer galvanic isolation in order to reduce leakage currents. Nonetheless, it has unfavourable characteristics such as enormous bulk, high cost, and weight with additional losses. As a result, eliminating the transformer is a significant benefit in terms of improving overall system efficiency, reducing size and weight.

This research introduces a new transformer-less inverter based on the charge pump circuit concept that minimises leakage current in grid-connected PV systems by employing a unipolar sinusoidal pulse width modulation (SPWM) approach. The neutral of the grid is directly connected to the negative terminal of the charge pump circuit in this method, thus the voltage across the parasitic capacitor is zero and the leakage current is eliminated. The charge pump circuit is used to produce negative output voltage. The proposed inverter's modulation approach has no limitations because the circuit architecture eliminates leakage current. The suggested topology uses only four power switches, lowering the cost of semiconductors while improving power quality. It is superior to three-level output voltage in order to eliminate output current ripple. The suggested inverter operates by passing current across two switches, resulting in a smaller conduction loss. The suggested inverter's dc voltage is similar to that of the FB inverter (unlike NPC, ANPC, half-bridge (HB) inverters) [3]. Many additional topologies, including H5, H6, the highly efficient and reliable inverter concept (HERIC), have been proposed to reduce leakage current when the grid is disconnected from the PV during freewheeling modes [4]. The suggested inverter can also offer reactive electricity to the grid.

Figure 1 depicts a single-phase grid-connected transformer-less inverter with CM current path, where P and N are the PV's positive and negative terminals, respectively. The leakage current (i Leakage) flows between the filters (L1 and L2), the inverter, the grid, and the ground impedance (Zg) via a parasitic capacitor (CP). This leakage current may pose safety issues, lower the quality of injection current to the grid, and diminish system efficiency[5].

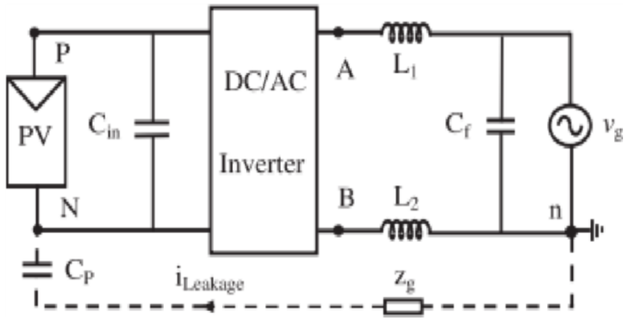

Fig. 1. Block diagram of a single-phase grid-connected transformer less inverter with a leakage current path.

In order to remove the leakage current, CM voltage (CMV) (v_{cm}) must be kept constant during all operation modes according to [6] the VCM with two filter inductors (L_1, L_2) is calculated as follows:

$$V_{cm} = \frac{V_{An} + V_{Bn}}{2} + \frac{(V_{An} - V_{Bn})(L_1 - L_2)}{2(L_1 + L_2)} \quad (1)$$

Where,

V_{An} and V_{Bn} are the voltage differences between the midpoints A and B of the inverter to the dc bus minus terminal N, respectively. If $L_1 = L_2$ (asymmetrical inductor), v_{cm} is calculated according to (1) and the leakage current appears due to a varying CMV. If $L_1 = L_2$ (symmetrical inductor), v_{cm} is simplified to

$$V_{cm} = \frac{V_{An} + V_{Bn}}{2} = Constant \quad (2)$$

In this state, the CMV is constant and the leakage current is eliminated. In some structures such as the virtual dc-bus inverter [7] and NPC inverter, one of the filter inductors is zero and only one filter inductor is used. In this state, after simplification of vcm, it will have a constant value according to (3) and the leakage current will be eliminated

$$V_{cm} = \frac{(V_{An} - V_{Bn})}{2} + \frac{V_{An} + V_{Bn}}{2} = Constant\ (L_1 = 0)$$

Then,

$$V_{cm} = \frac{V_{An} + V_{Bn}}{2} - \frac{(V_{An} - V_{Bn})}{2} = Constant\ (L_1 = 0) \quad (3)$$

As shown in Fig. 2, there are various transformer less grid connected inverters based on the FB inverter in the literature to overcome these problems. The H5 inverter that is a FB-based inverter topology, compared to the conventional FB inverter, needs one additional switch (S5) on the dc side to decouple the dc side from the grid as shown in Fig. 2(a).

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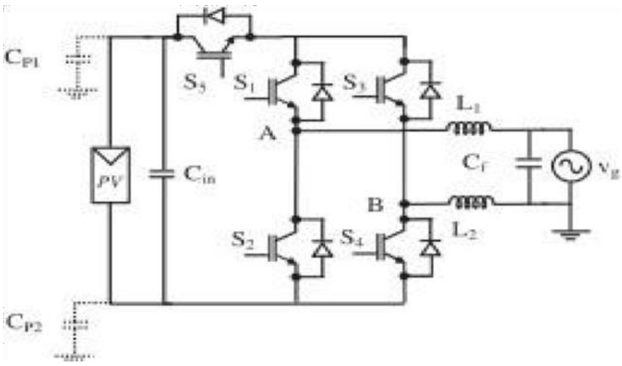
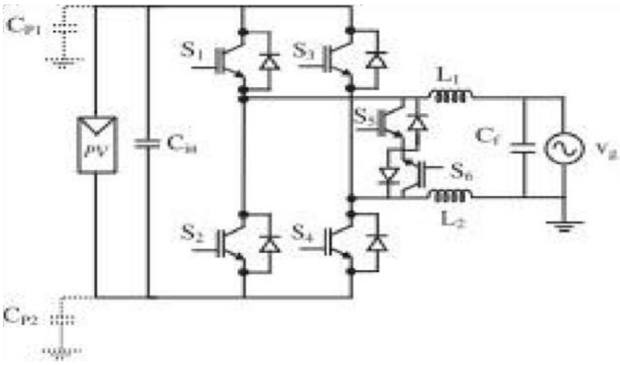


(a)

As shown in Fig. 2(b), the HERIC topology needs two extra switches on the ac side to decouple the ac side from the PV module in the zero stage. HERIC combines the merits of unipolar and bipolar modulation**.**



(b)

Another solution to eliminate leakage current in the system is to connect the negative PV terminal directly to the neutral point of the grid, as shown in Fig. 2(c). The virtual dc-bus inverter is made up of five insulated-gate bipolar transistors (IGBTs), two capacitors, and one filter inductor Lf.

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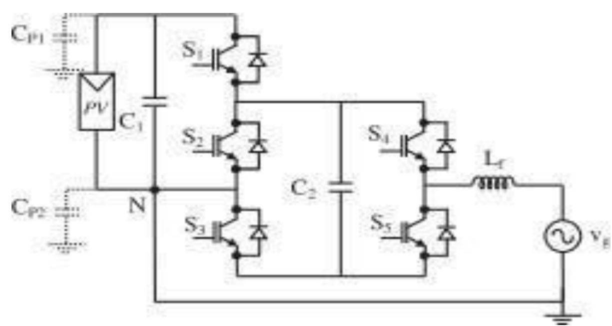

(c)

The negative output voltage is generated via the virtual dc-bus. The fundamental problem of this architecture is that no channel exists to charge the capacitor C2 during the negative cycle, resulting in a significant output total harmonic distortion (THD). The presented topology, depicted in Fig. 2(d), shares a common ground with the grid.

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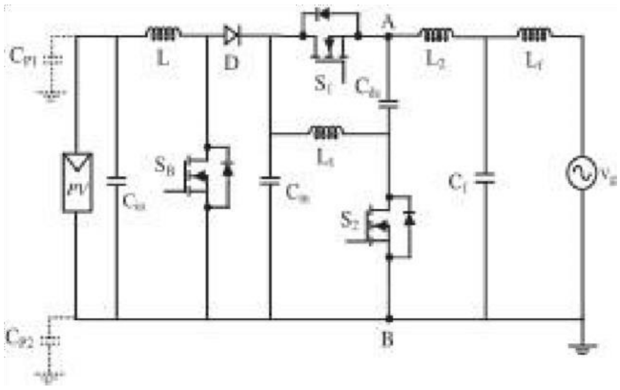

(d)

Fig. 2. Single-phase grid-tied transformer less PV inverter topologies: (a) H5 inverter, (b) HERIC inverter, (c) virtual dc-bus inverter and (d) CM inverter proposed

This architecture employs a small number of semiconductors. However, the output voltage of this inverter is only two levels, positive and negative, without producing zero voltage, which necessitates the use of a big output inductor L2 and a filter. The inductor medium-type inverter, often known as the "Karschny" topology, is another topology evolved from the buck-boost topology.

This study offers a new transformerless inverter based on the charge pump circuit concept. Using a unipolar sinusoidal pulse width modulation (SPWM) approach, this transformerless inverter minimises the leakage current of grid-connected PV systems. The proposed topology uses only four power switches, lowering the cost of semiconductors while improving power quality with a three-level output voltage in order to reduce the output current ripple.

II. TOPOLOGY AND MODULATION STRATEGY PROPOSAL

Charge Pump Circuit Design

Figure 3 depicts the notion of a basic charge pump circuit that will be employed in the proposed topology to generate the inverter's negative output voltage. The circuit is made up of two diodes (D1 and D2) and two capacitors (C1 and C2). The capacitor C1 connects the voltage point A to the node D. To pump the output voltage, two Schottky diodes, also known as hot-carrier diodes, D1 and D2, are used.

The output voltage of the negative charge pump circuit (vCn) can be calculated in steady state by

$$V_{cm} = -V_{dc} + V_{cut-in-D_1} + V_{cut-in-D_2} \quad (4)$$

Where,

V_{dc} is the input voltage, $V_{cut-in-D1}$ and $V_{cut-in-D2}$ are the cut-in voltages of the diodes D_1 and D_2, respectively. For high power applications, these values can be negligible.

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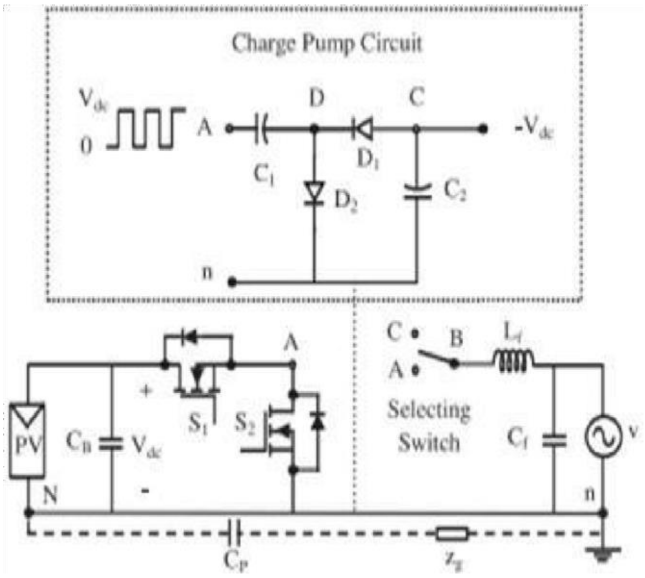

Fig. 3. Schematic diagram of the proposed inverter including the charge pump circuit.

By adding more switching devices, the aforementioned idea is incorporated into the suggested inverter. For grid-tied applications, the charge pump circuit in the transformer-less inverter has the following features.
1. The leakage current is minimised by this circuit's common line, which connects to both the neutral point of the grid and the negative terminal of the input dc voltage.
2. The charge pump circuit is less expensive for grid-tied applications since it lacks an active device.

Proposed Methodology

The proposed topology, which is based on the charge pump circuit described in Section 2.1, consists of four power switches (S1 through S4), two diodes (D1, D2), and two capacitors (C1, C2).

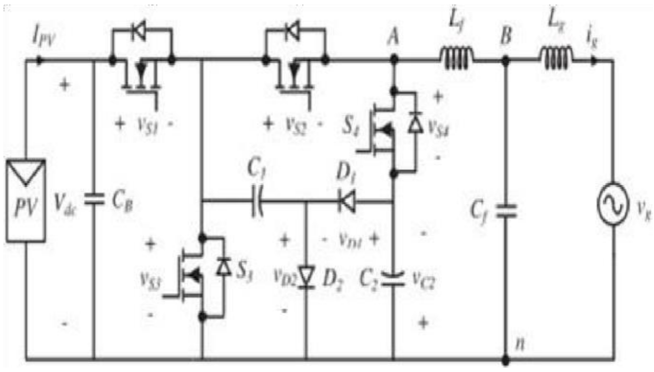

Fig. 4. Proposed single-phase transformer less grid-connected inverter

The operation of the suggested inverter is divided into four zones as depicted in Fig. 6 depending on the direction of the inverter output voltage and output current.

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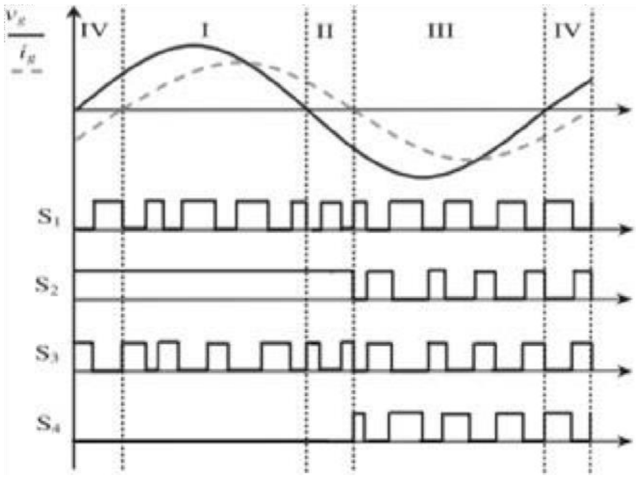
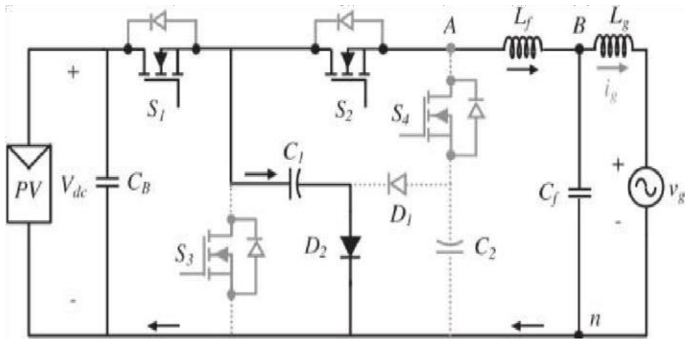
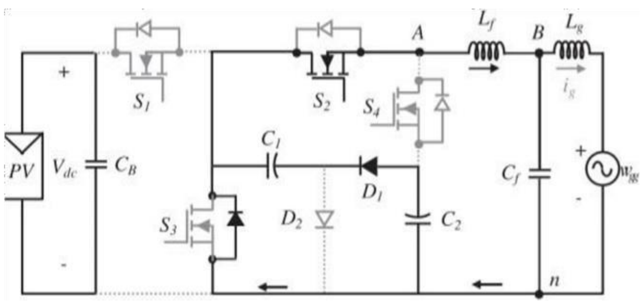


Fig. 5. Switching pattern of the proposed topology with reactive power flow.

Region I: The inverter output voltage and the output current are positive energy is transferred from dc side to grid side as shown in Fig. 6(a).

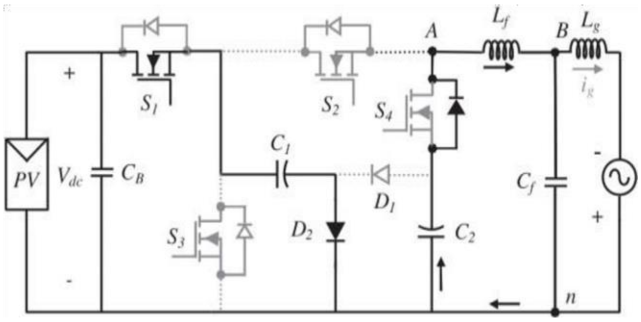


(a)

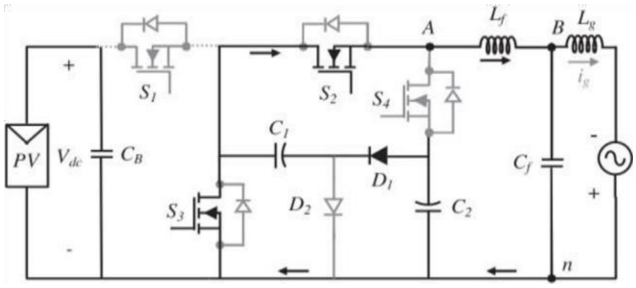


(b)

Region II: The inverter output voltage is negative and the output current is positive energy is transferred from grid side to dc link as shown in Fig. 6(c).



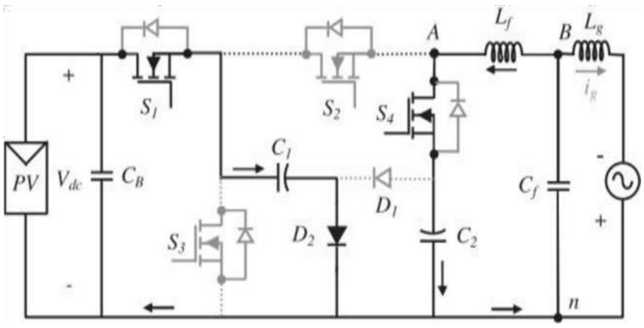
(c)



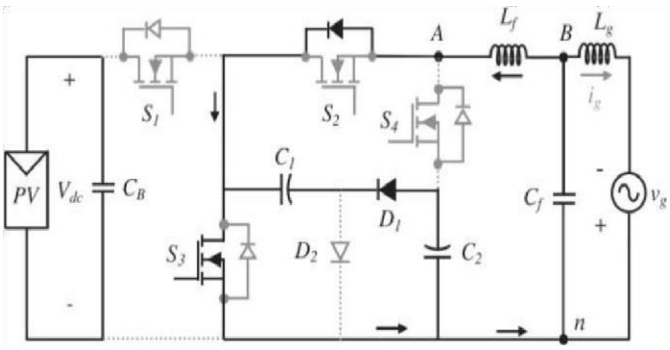
(d)

Region III: the inverter output voltage and the output current are negative energy is transferred from dc link to grid side as shown in Fig. 6(e).

Region IV: the inverter output voltage is positive and the output current is negative energy is transferred from grid side to dc side as shown in Fig. 6(g)

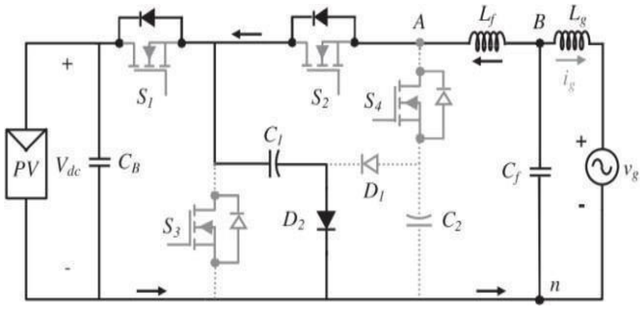


(e)

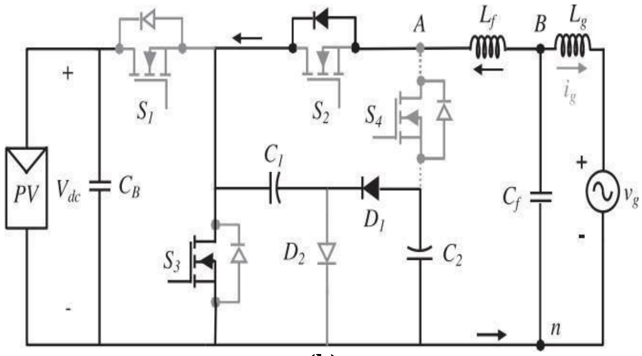


(f)

The output voltage of the inverter (vAn) will be +Vdc (positive state) when switches S1 and S2 are ON, as shown in Fig. 6(a) and (g). Diode D1 is reverse biassed during this period, D2 is turned on. Capacitor C1 is subsequently charged through diode D2, the voltage across capacitor C2 remains constant. In this state, vAn will be 0 (zero state) when the switches S2 and S3 are ON, as shown in Fig. 6(b) and (h).



(g)



(h)

Fig :6 Operational stages of the proposed inverter during (a), (b) region I, (c), (d) region II, (e), (f) Region III and (g), (h) region IV

(a) $vAn= +Vdc,\ ig>0$. (b) $vAn=0,\ ig>0$. (c) $vAn=-Vdc,\ ig>0$.
(d) $vAn=0,\ ig>0$. (e) $vAn=-Vdc,\ ig<0$. (f) $vAn=0,\ ig<0$. (g) $vAn= +Vdc,\ ig<0$. (h) $vAn=0,\ ig<0$.

The negative and zero voltage levels are generated in regions II and III. The comparable circuit that S4 and S1 are ON is depicted in Fig. 6(c) and (e). When switch S4 is turned ON and the voltage across capacitor C2 reaches the inverter output voltage (vAn = Vdc) (negative state), the negative voltage is produced.

The modulation technique can maintain a constant voltage across the capacitor C1 in this state. The grid's zero state during this period operates similarly to the grid's zero state during the positive half-period, as shown in Fig. 6(b) and (h). In this situation, the capacitor C2's charging time constant (C2) can be represented as follows:

$$\tau_{C2} = R_{e1} C_{e1} \quad (5)$$

The current through capacitors ($i_{capacitors}$) is calculated by

$$i_{Capacitors} = C_{e1} \frac{V_{C1} - V_{C2}}{\tau_{C2}} \quad (6)$$

According to (5), the charging time constant of C_2 is larger than its natural discharging time constant and $V_{C1} - V_{C2}$ has a very small value in steady state.

3. Fuzzy Logic Controller

A set of linguistic regulations in FLC specify the fundamental control action. The system chooses these guidelines. In FC, mathematical modelling of the system is not necessary because the numerical variables are transformed into linguistic variables.

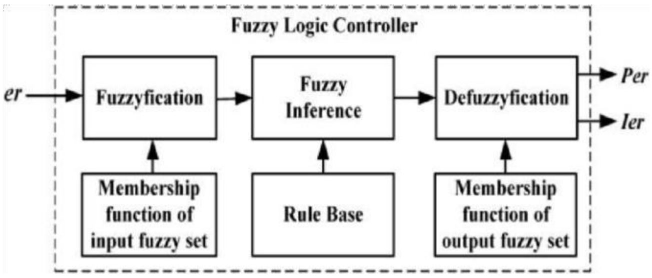


Fig.7. Fuzzy logic controller

The FLC comprises of three parts: Fuzzification, interference engine and Defuzzification. The FC is characterized as

i. For each input and output, seven fuzzy sets.
ii. For ease of use, triangular membership is used.
iii. Fuzzification using the ongoing conversation universe.
iv. Application of the "min" operator by Mamdani.
v. Employing the height approach for defuzzification.

Table I: Fuzzy Rules

e / ė	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

- **Fuzzification:** Membership function values are assigned to the linguistic variables, using seven fuzzy subsets: NB (Negative Big), NM (Negative Medium), NS (Negative Small), ZE (Zero), PS (Positive Small), PM (Positive Medium), and PB (Positive Big). The input error for the FLC is given as

$$E(k) = \frac{P_{ph}(k) - P_{ph}(k-1)}{V_{ph}(k) - V_{ph}(k-1)} \quad (7)$$

$$CE(k) = E(k) - E(k-1) \quad (8)$$

• Inference Method: The literature has proposed a number of composition approaches, including Max-Min and Max-Dot. This study use the Min technique. Each rule's output membership function is determined by the minimum and maximum operators. The FLC's rule set is displayed in Table 1.

• Defuzzification: Because a plant often needs a non-fuzzy control value, this stage is necessary.

The "height" approach is used to calculate the FLC's output, and the FLC output affects the control output. Additionally, the switch in the inverter is controlled by the FLC's output.

To do this, FC's membership duties include: Error and modification of error and Results

The set of FC regulations is based on

$$u = -[\ \alpha E = (1-\alpha) * C\ ] \quad (9)$$

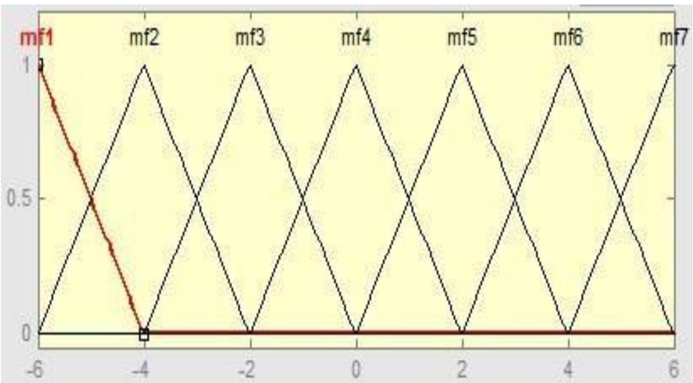


Fig. 8. input error as membership functions

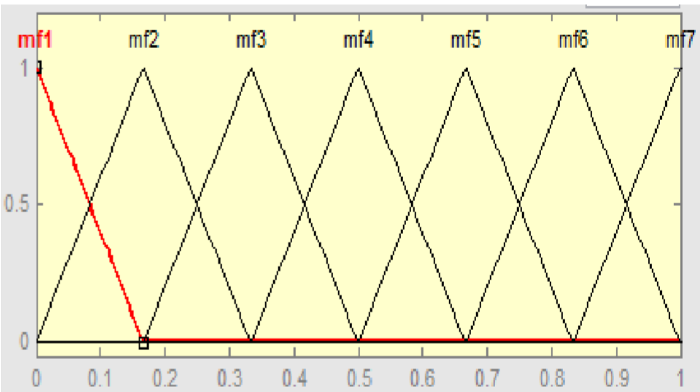


Fig. 9. Change as error membership functions

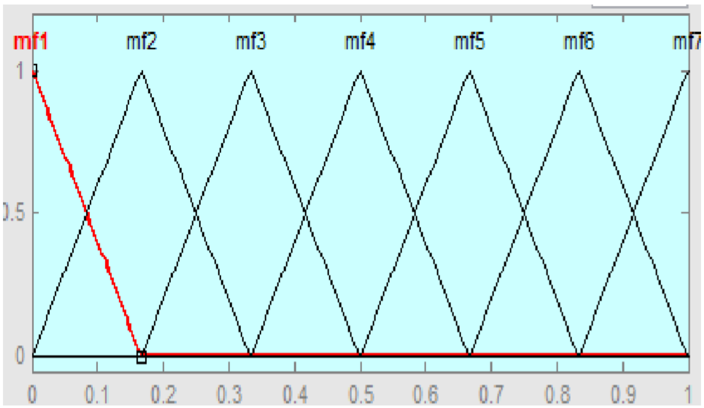


Fig. 10. Output variable membership functions

Where α is self-adjustable factor which can regulate the whole operation. E is the error of the system, C is control variable.

III. IMPLEMENTED WORK

As per proposed topology, single prototype for the inverter has been modelled in MATLAB/Simulink 2016 as follows,

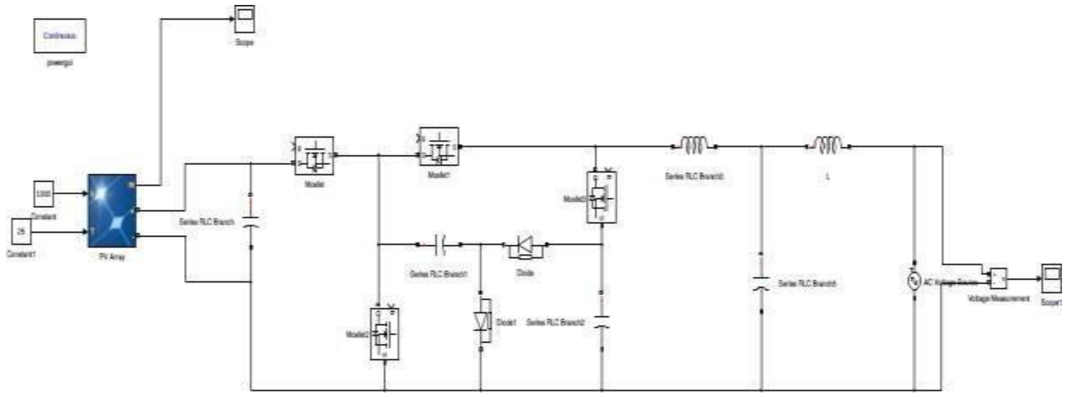


Fig. 11. Simple Prototype of Inverter Circuit

In order to create larger voltages, currents, and power levels, photovoltaic cells are electrically coupled in series and/or parallel circuits in a PV array, as depicted in fig. 11. The main components of PV systems, photovoltaic modules are composed of PV cell circuits sealed in an environmentally friendly laminate. One or more PV modules are put together as a pre-wired, field-installable unit in a photovoltaic panel. A photovoltaic array, which can have any number of PV modules and panels, is the entire power-generating system.

A current source IL (light-generated current), a diode (I0 and nI parameters), a series resistance Rs, and a shunt resistance Rsh are used in the PV Array block's five parameter model to reflect the modules' irradiance- and temperature-dependent I-V characteristics.

Parameters: - For PV array:

- Irradiance range: 250 – 1000
- Temperature Range: 20 – 35^0 C
- Series connected modules: 14

For Each Module -

- maximum Power: 250W
- open circuit voltage: 37.6V
- V_{mp} (Max. Power Voltage) = 31V
- Cells per module: 60
- Short circuit current = 8.55 A
- I_{mp} (Max. Power current) = 8A

IV. CONCLUSION

In this study, we use a charge pump circuit concept and fuzzy controller to develop a new single-phase transformer-less inverter for a grid-tied PV system. The primary goal of the suggested system is to produce the negative output voltages created by the suggested inverter. Because the fuzzy controller is best suited for the human decision-making mechanism and provides the operation of an electronic system with expert decisions, we are employing it here to get superior performance.

Since the neutral line in the grid is similar to the suggested topology, the leakage current will be reduced and the transformer will no longer be necessary. Additionally, the suggested topologies are able to supply the grid with the necessary reactive power. As a result, the suggested topology is used to realise that a higher power density may be reached at a lower design cost while using the fewest possible components. We can validate the suggested system using the simulation results.

V. ACKNOWLEDGMENTS

It gives me a great deal of joy to thank the person who inspired me to create a novel single-phase transformer-less inverter for a grid-connected PV system that uses the fuzzy controller and a charge pump circuit concept. I want to start by expressing my gratitude to Prof. Radharaman Saha, Head of Department, EE, TGPCET, Nagpur, for his invaluable advice and assistance. In addition, I appreciate the support I received from my teachers' staff as well. I also thank my parents and friends, without whose help I would not have been able to carry out this plan.

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