

Optimal Design of EMI Filters for Switch Mode Power Supplies in Consumer Electronics

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Abstract—Every electronic device requires a stable and dependable power supply unit. This power supply unit serves as an AC-to-DC converter since it is necessary to transform the AC supply into an appropriate DC voltage level. The SMPS built for this project has a maximum current rating of 0.5a and would convert AC mains to 12v DC. The project aims to make a completely functional independent SMPS circuit that can be modified for 12V adapters, laptop and mobile chargers, or to power small devices. It also aims to create SMPS with a universal frequency range, with an expected output of about 6 watts; it also protects the device from input surges and accounts for the electromagnetic interference (EMI) brought on by such high-frequency operation. Circuit analysis is created and evaluated under various load scenarios and input voltages.

Index Terms— Flyback converter, Universal SMPS, Operating frequency, TNY274PN IC, EN91000-Class 3 standard.

I. INTRODUCTION

Most of our DC loads are powered by the typical AC mains supply. However, the voltage levels needed by different components, such as LEDs, microprocessors, etc., are typically not met by ordinary source voltages. Motor and other loads mainly occur when the supply voltage is not controlled. SMPS, abbreviated as Switch mode power supply, converts this AC to DC or lowers the high voltage level well. SMPS can be used in power electronics applications because of their smaller size and lighter weight. Current electronics research groups are working to create power supplies that are more compact, lightweight, dependable, and economical. Because the transformer is smaller at high frequencies, SMPS has historically addressed the size problem with linear power supplies.

There are four primary types of SMPS:

- DC-DC Converter: High-voltage DC is created by rectifying and filtering the AC mains power, which is then supplied to the transformer's primary winding. The output voltage is then collected at the secondary winding.
- Forward Converter: The inductor is always conducting as a critical element. The diode inside the transistor carries the current during the OFF cycle. During the ON cycle, the inductor stores the energy. It also transfers a part of it to the output load.
- Fly back Converter: Fly back Converter: When the switch is ON, the magnetic field of the inductor stores the energy. Similarly, when the switch is OFF, the energy is transferred to the output.

- Self-oscillating back Converter: The current primary grows linearly during conduction. The circuit becomes saturated as a result of this current spike. To remove the circuit from saturation, the switching motion starts. This paper focuses on the design of an AC-DC fly-back Converter customised for consumer electronic applications. The proposed converter operates at a frequency of 132 kHz. The single-phase module produces a regulated output of 12V when operated at 85–300V, 50Hz input. The converter's architecture and circuit setup are displayed. Lastly, simulation results show that it performs satisfactorily.

II. BLOCK DIAGRAM

The detailed Block diagram of the proposed Converter is shown in Fig.1

A. Stages of Proposed Fly Back Converter

The Converter has a Single isolated output (12V/0.5A), which is realised using a fly-back Converter topology. The project makes use of several components. Every single one serves a vital purpose. The overview is presented first, followed by a discussion of the individual parts.

- Input Specifications: The first requirement for the SMPS is the input supply voltage that will supply the load. The primary purpose of this design is to convert AC to DC, and the input AC voltage varies depending on the country in which the device is used: in India, the AC voltage value is 220V. The SMPS should operate with a universal input voltage range between 85V AC and 300V AC. The voltage range should be between 85-300V for stable output in any country. The frequency can vary between 50-60 Hz, which enables us to charge our electronic devices wherever we are.
- Output Specifications: An inductive or resistive load may be on the output side. The SMPS can vary according to the load. We have assumed that the load for this SMPS is resistive. There is nothing equivalent to an utterly resistive load, although it does have some inductance and capacitance, but we view this as insignificant; the load defines the output design. The SMPS may deliver 6W output for this project. It has 12V and 0.5A.
- Feedback and Power Management: The SMPS circuit needs power management. We must design it with 12V 0.5A, or 6W, input surge protection, universal input rating, instant voltage operations, over-voltage protection, over-current protection, and output short circuit protection. These are designed using a voltage-sensing circuit, an error amplifier, and a PWM generator.
- We choose a Power Integration IC to satisfy the abovementioned requirements and develop this into a hardware product. These ICs have been manufactured by the semiconductor company Power Integration; we can choose to use the TNY274PN from the Tiny Switch III Family.

B. Detailed Specifications for Sections

- AC-DC conversion- We use a full bridge rectifier (DB107). We can use four diodes (1N4148/1N4007). Correcting the alternating current (AC) from the mains supply into a steady direct current (DC) voltage that can be effectively transformed into lower DC voltages is the aim of AC-DC conversion. DC input voltage is necessary for most power electronics circuits to function effectively, including buck/boost converters, fly-back converters, and switching power supplies (SMPS).
- PI filter- This design adheres to the EN61000-Class 3 standard. The configuration of the PI filter is optimized to enhance common-mode EMI rejection. It is a passive low-pass filter that power electronics employ to smooth out DC output and lessen ripple. Its π -like topology, here two capacitors (10 μ F, 450v) and one inductor (1mh), organized in the shape of the Greek letter π -gives it its name.

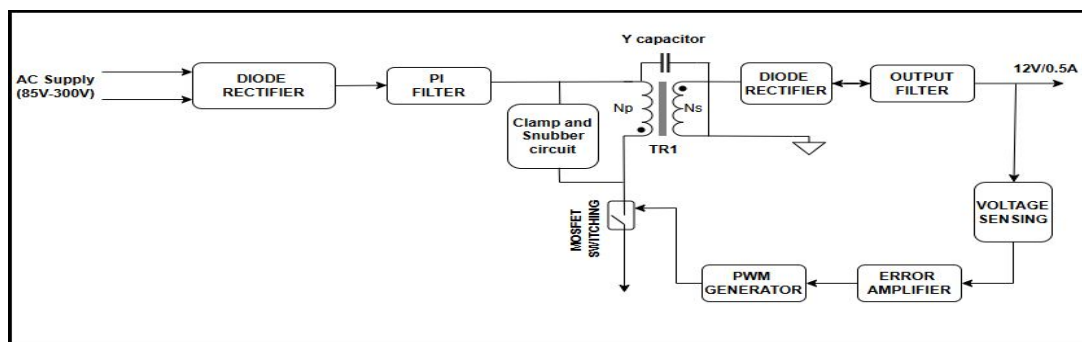


Figure 1. Block Diagram of Proposed Fly Back Converter

- Switching circuit- The transformer's primary winding's energy transmission is controlled by the MOSFET (M1), which is switched by an amplified control signal of U3 and related components. To facilitate effective energy transfer, the switching circuit, which comprises M1 (BSZ16DN25NS3 MOSFET) and associated parts, functions in high-frequency switching mode, usually between 125 kHz and 140 kHz. By giving feedback to the controller, the feedback voltage sensing circuit, which consists of resistors R1, R2, C3, and U2, maintains voltage stability and adjusts for changes in input voltage or load circumstances.
- Clamp circuit- The DRAIN pin's peak voltage upon turn-off is limited by a clamp. An RCD clamp or ZENER (~200V) and diode clamp over the primary winding can be used to accomplish this. In every situation, an effort should be made to reduce the circuit route from the clamp components to the transformer and MOSFET to reduce EMI.
- EMI filtering- The Y- y-capacitor should be positioned directly between the standard/return terminal of the transformer secondary and the positive terminal of the primary input filter capacitor. Reduces the switching transformer's high-frequency switching noise.
- Snubber circuit and Secondary Rectifier transform and rectify the transformer output using a Schottky rectifier diode. During switching operations, the Snubber circuit suppresses the transient voltage.
- Filter Section- Filter capacitor along with LC filter made using capacitor and inductor for better ripple rejection.

III. WORKING

The SMPS can be constructed with varying voltage and current specifications depending on the output needs. The SMPS design used in this paper is 12V, 0.5A, and 6W SMPS.

The input's AC signal is transformed into a controlled DC output. The bridge rectifier receives the AC input and converts it into a DC output that is not controlled. The switching circuit receives this output. The switching circuit generates a DC pulsating wave at high frequencies, such as 120 kHz to 140 kHz. Shown in the Fig. 2.

A step-down transformer receives this output, lowers the voltage, and then sends the stepped-down DC pulsing wave to the filter circuit. The feedback circuit is in place to transfer the output to the switching circuitry, providing us with the regulated output DC signal. This allows adjusting the switching cycles to keep the SMPS's output voltage steady. An SMPS is utilised in its place since a linear power supply becomes cumbersome as the current rating increases.

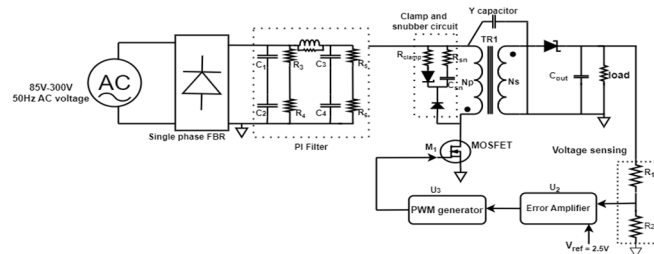


Figure 2. Circuit Diagram of the Proposed Flyback Converter

A. Design and Construction of SMPS

The specifications are used to choose the components and topology type. The DC input to the fly-back converter varies between $V_{DCmin120}$ V to $V_{DCmax400}$ V, corresponding to the bridge rectifier DC voltage for the converter's AC input voltage, which fluctuates between $V_{inmin85V}$ and $V_{inmax300V}$. Shown in the Fig. 3.

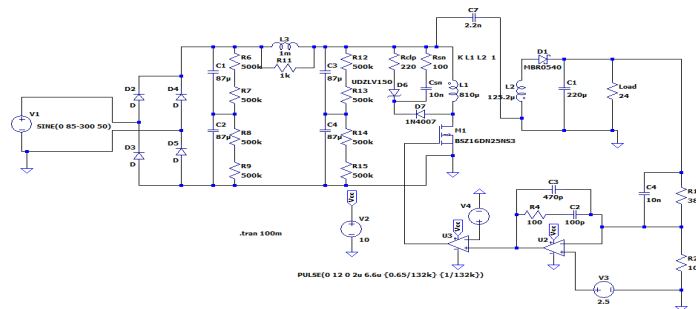


Figure 3. LT-Spice Schematic of the Proposed Flyback Converter

The nominal switching frequency is 132 kHz, and the switching frequency of the converter topology is expressed by an equation that varies between 120 and 140 kHz based on changes in load and input voltage and represented by “(1)”.

$$F_{sw} = \frac{1}{I_{primary_pk} * L_{primary} * \left(\frac{1}{V_{in}} + \frac{1}{V_R} \right) * \pi * \sqrt{L_{primary}} (C_d)} \quad (1)$$

W

F_{SW} : Switching Frequency

V_{in} : AC input voltage

V_R : Reflection voltage

$L_{primary}$: Primary inductance of the transformer

C_d : Capacitance of drain

$I_{primary_pk}$: primary peak current of the transformer

Equation (2) illustrates how the duty cycle varies about the switching frequency.

$$D = \frac{T_{on}}{T_{on} + T_{off}} \quad (2)$$

Where

D: Duty cycle

T_{on} : Period. The switch is ON T_{off} : Period, the switch is OFF Total output Power

$$P_{out} = V_{out} * I_{out} = 12 * 0.5 = 6W \quad (3)$$

B. System Specifications and Requirements

The proposed fly-back converter's specifications are shown in Table I.

TABLE I: SPECIFICATIONS

Parameter	Value	Name
V_{ac} Maximum	300V	Maximum AC input voltage
V_{ac} Minimum	85V	Minimum AC input voltage
D_{max}	65%	Maximum Duty cycle
F_{SW}	132kHz	Switching Frequency
η	85%	Efficiency (η)
P_{out}	6W	Output power (maximum)
V_{out}	12V	Output Voltage
f_{line}	50	Line frequency

C. Calculation Of Maximum Primary Inductance And Primary Peak Current

Finding the maximum primary inductor value is the goal of the initial design calculation. Although there are other design approaches, the converter in this example always runs in Discontinuous conduction mode. Use the following equation to determine the primary inductor value (LP):

$$L_p = \frac{\eta * D_{max} * D_{max} * V_{dc_max} * V_{dc_max}}{2 * F_{SW} * P_{out}} \quad (4)$$

The worst-case situation is when the converter operates at maximum duty cycle and minimum input voltage while operating at full power. The limit for the maximum inductance is 13.25mH by applying the design inputs in “(4)”.

$$P_{in_max} = \frac{P_{out}}{\eta} = 7.5W \quad (5)$$

Peak primary current is calculated by using “(6)”.

$$I_{primary_pk} = \frac{2 * P_{in_max}}{V_{dc_min} * D_{max}} = 0.192A \quad (6)$$

D. Transformer Design

One of the main parts of the Flyback converter, the transformer, provides isolation between the power supply module's input supply and load. Typically, a high-frequency transformer is chosen to minimise the size. The suggested converter operates at 132 kHz. Input PI filters prevent EMI and electromagnetic compatibility (EMC) problems.

Where,

Maximum Duty cycle (D_{max}) = 0.65 Output power (P_{out}) = 6 Watts

Efficiency = 80%

Window Factor (K_w) = 0.29 Current Density (J) = 5 Amp/mm²

Magnetic Flux Density (B_{MAX}) = 0.13 Tesla

The core size, wire gauge, and number of turns needed for the intended output are chosen for transformer design using the area product (A_p) approach. By using the "(7)", we can determine the transformer core's (A_p).

$$A_p = \frac{L_p \cdot I_{primarypk} \cdot I_{primaryRMS}}{B_{MAX} \cdot 0.0085} \cdot 1000 \quad (7)$$

An appropriate core with an area product that is more excellent than the calculated A_p will be selected. Selected EE Core: E25/9/6, which will have Cross-sectional Area, (A_c) = 40 mm², Window Area, (A_w)=78 mm², (AL)=4040 mH/1000 Turns and bobbin with a minimum 0.27mm length have been selected.

The transformer ratio (T ratio) of primary and secondary is given from the "(8)".

$$T \text{ ratio} = \frac{V_{out} + (V_D \cdot D_{max})}{D_{max} \cdot V_{dcmin}} = 0.23 \quad (8)$$

The following formula determines the transformer's primary turns (N_p) and secondary turns (N_s).

$$N_p = \frac{V_{out} + (V_D \cdot D_{max})}{D_{max} \cdot V_{dcmin}} = 30 \quad (9)$$

$$N_s = T \text{ ratio} \cdot N_p = 7 \quad (10)$$

$$\text{skin depth} = \frac{6.62}{\sqrt{f_{sw}}} = 0.0182 \text{ cm} \quad (11)$$

$$\text{Wire diameter} = 2 \cdot (\text{skin depth}) = 39 \text{ AWG}$$

E. Selection Of Input Capacitor

$$C_{in} = \frac{2 \cdot E_{in}}{(V_{peak})^2 - (V_{dcmin})^2} \quad (12)$$

We can select 47μF,400V ,105°C or 68μF,400V ,105°C for less ripples.

F. Selection Of MOSFET

The Drain-Source voltage (V_{DS}), Drain current (I_D), Drain-Source ON resistance (R_{dson}), Gate charge (Q_g), and Output Capacitance (C_{out}) all influence the MOSFET selection. The MOSFET's size and package are determined by the losses that occur within it. The following formula is used to determine the MOSFET's maximum voltage stress. ($V_{peakMOSFET}$)

$$V_{DS_max} = V_{dc_max} + \frac{D_{max} \cdot V_{dcmin}}{(1 - D_{max})} = 567.85 \text{ V} \quad (13)$$

A 20% security buffer has been added to V_{DS_max} to ensure the converter operates safely. Selected MOSEFT: BSZ16DN25NS3 [V_{ds} = 700V, R_{ds_on} = 0.165 ohm, I_d = 80A @100deg].

G. Output Filter

To obtain the required output parameters, the secondary output voltage of transformers is appropriately rectified and filtered. The suggested converter uses an LC filter to have low noise, be less bulky, and be cost-effective—all essential for space applications.

$$C_{out} = \frac{D \cdot I_o}{f_{SW} \cdot \Delta(V_o)} = 220 \mu\text{F} \quad (14)$$

H. Efficiency, Line Regulation And Load Regulation

$$\text{Efficiency} = \frac{\text{output voltage} \times \text{output current}}{\text{input voltage} \times \text{input current}} * 100 \quad (15)$$

$$\% \text{Line regulation} = \frac{V_{\text{out@max input(300V)}} - V_{\text{out@min input(85V)}}}{V_{\text{out@nominal input(190V)}}} * 100 \quad (16)$$

$$\% \text{I.line regulation} = \frac{V_{\text{out@min load(0.1A)}} - V_{\text{out@max load(0.5A)}}}{V_{\text{out@nominal load(0.22A)}}} * 100 \quad (17)$$

I. Secondary Diode Selection

The choice of output diode is influenced by secondary voltage and current. These diodes must operate at a high frequency to function. Schottky diodes will have almost no reverse recovery time. In contrast, regular signal or p-n diodes typically have a reverse recovery period of hundreds of nanoseconds when switching from ON to OFF and less than 100 for fast recovery diodes. Thus, Schottky diodes are ideal due to their low reverse recovery time (Trr), high current capability (IF), and extremely low forward voltage drop (VFD). MBR0540 is the chosen diode.

IV. RESULTS AND DISCUSSIONS

A. LT-Spice Simulation Results

The output current ($I_{R_{\text{load}}}$) and output voltage (V_{out}) are displayed in Fig. 4. The output is controlled to retain that value while the voltage increases to 12 volts and the current increases to 0.5 amps. The findings of this simulation demonstrate that the fly-back converter can supply low-powered devices with 12v of voltage and 0.5a of current. The $I_{R_{\text{load}}}$ and V_{out} are 12V and 0.5A, respectively, at Full load for 230 V AC input voltage shown in Fig. 5.

B. Effective Voltage Clamping For Mosfet Protection In Flyback Clamp Circuit

The clamp circuit in a fly-back converter is essential for shielding the MOSFET from voltage spikes brought on by leakage inductance. The clamp circuit, consisting of a Zener diode, diodes, resistors, and capacitors, absorbs excess energy when the MOSFET (M1) shuts down and brings the drain-source voltage to a safe level. This lowers the chance of MOSFET failure by maintaining control over the drain-source voltage (VDS) waveform, as shown in Fig.

6. The clamp circuit does not affect the gate-source voltage (VGS), which follows the intended switching waveform. The clamp circuit increases circuit reliability by reducing excessive voltage stress.

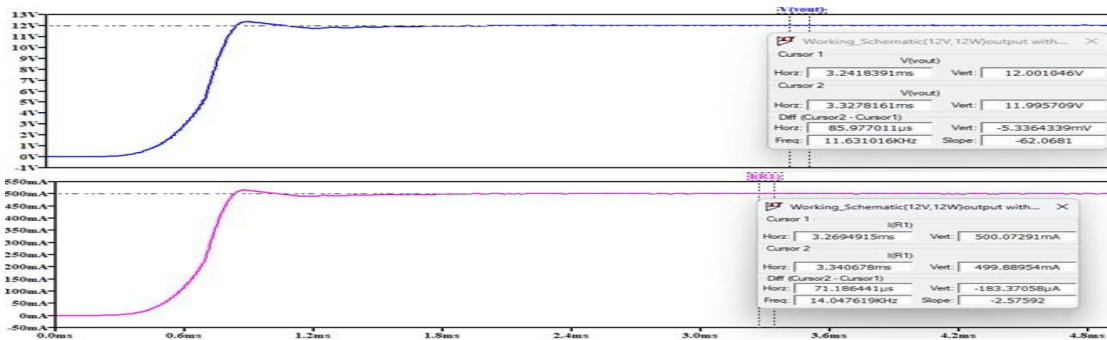


Figure 4. Output voltage and Output current waveform at full line voltage

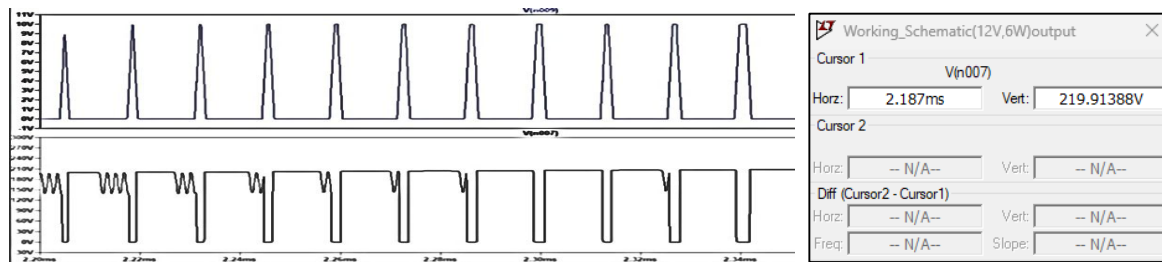


Figure 5. Output voltage and Output current waveform at 230V line voltage

C. Uncontrolled Voltage Spikes And Mosfet Stress In Absence Of A Clamp Circuit

When switching takes place and the clamp circuit is removed, the transformer's leakage inductance causes large voltage spikes between the MOSFET drain-source terminal, as shown in Fig. 7. This causes uncontrollable voltage transients that surpass the breakdown voltage of the MOSFET, potentially failing.

Every time the MOSFET shuts off, the VDS waveform will exhibit abrupt, high-amplitude spikes, increasing EMI and possibly causing damage. Because it depends on the gate drive circuit, the VGS waveform stays the same, but an excessive drain voltage could cause unexpected switching actions. The MOSFET's overall circuit stability and longevity significantly decrease without a clamp circuit.

D. Output Voltage Ripple Waveform

Voltage ripple in an SMPS is the term used to describe the little variations in the DC output voltage brought on by filtering and switching constraints. Peak-to-peak changes for a 12 V output with 1% ripple are 120 mV.

V. CONCLUSION

This paper introduces the design and implementation of an EMI-filtered fly-back SMPS optimised for consumer electronic applications. The converter is designed to efficiently convert an AC input voltage range of 85v to 300v to a stable 12v DC output at 0.5a with a switching frequency of 132 kHz. The circuit design, component selection, and transformer calculations are detailed to ensure safe operation with high efficiency and EMI compliance. Simulation output confirms the converter's efficiency, showing zero voltage ripple and successful MOSFET voltage clamping, averting excessive stress and failure. Adding a PI filter, a Snubber circuit, and a transformer design for optimisation dramatically enhances the stability and reliability of the system. The results validate that the designed fly-back SMPS can efficiently supply a regulated output voltage over a wide range of input voltages, making it an ideal candidate for many consumer electronics applications. Future research may include further efficiencies achieved and real-world testing to assess long-term reliability and thermal performance.

REFERENCES

- [1] H. K. Patel, "Critical Considerations for EMI Filter Design in Switch Mode Power Supply," 2006 IEEE International Conference on Industrial Technology, Mumbai, 2006, pp. 1843-1848.
- [2] Abraham I. Pressman, "Switching Power Supply Design," McGraw-Hill, International Editions, New York, 1999.
- [3] D. D.C. Lu, H. H.C. Iu, and V. Pievalica, "A single-stage AC/DC converter with high power factor, regulated bus voltage, and output voltage," IEEE Trans. on Power Electronics, vol. 23, no. 1, pp. 218-228, Jan. 2008.
- [4] C. Basso, Switch-Mode Power Supplies: Spice Simulations and Practical Designs, 2nd ed. New York, NY, USA: McGraw-Hill, 2014.
- [5] Jagdish and Dr. R. Jayapal, "Design and development of a universal SMPS", International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, Vol. 6, Issue 8, August 2017.
- [6] Danjiang Chen and Qiaowen Zhang, "Research of a Wide Input Range SMPS", International Journal of Computing Academic.
- [7] Datasheet. TNY274-280 Tiny-Switch-III Family Energy efficient Flexibility and Extended Power Range by Power Integration Corporation. B. Schweber, "The Flyback Power-Supply Architecture and Operation", December 2019. S. Maniktala, "Switching Power Supplies A-Z", p. 319-320, June 2006.
- [8] Venkatesh Boddapati, and S. Arul Daniel, "Performance analysis and investigations of grid-connected Solar Power Park in Kurnool, South India" Energy Sustain. Dev., Vol. 55, pp. 161-169, April 2020.
- [9] Jayanth, K. G., Boddapati, Venkatesh, and Geetha, R. S., "Comparative study between three-leg and four-leg current-source inverter for solar PV application", International conference on power, instrumentation, control, and computing (PICCC), India, January 2018.
- [10] Venkatesh Boddapati, Avinash Sree Ram Nandikatti, and S Arul Daniel, "Techno-economic performance assessment and the effect of power evacuation curtailment of a 50 MWp grid-interactive solar power park", Energy for Sustain. Dev. Vol. 62(1), pp. 16-28, June 2021
- [11] Venkatesh Boddapati, and S. Arul Daniel. "Optimal design and techno-economic analysis of a Microgrid for community load applications", International Conference on Innovations in Clean Energy Technologies (ICET-2020), pp. 361-374, May 2021.
- [12] M. A. Munjer, M. R. I. Sheikh, M. A. Alim, V. Boddapati, and M. A. Musaib., "Minimization of THD for MMC with a triangular injection approach", International Conference on Electrical, Electronics, Computers, Communication, Mechanical and Computing, India. January 2018.
- [13] M. A. Munjer, M. R. I. Sheikh, M. A. Alim, V. Boddapati, and M. A. Musaib., "Minimization of THD for Multilevel Converters with triangular injection approach", 3rd International Conference for Convergence in Technology (I2CT), Pune. 1-4, 2018.

- [14] Venkatesh Boddapati, and S. Arul Daniel, "Optimal Design and Technoeconomic Analysis of a Microgrid for Community Load Applications", *Advances in Clean Energy Technologies*, 2021. Dimitrios Thomas, Olivier Deblecker, Christos, and S. Ioakimidis, "Optimal design and techno-economic analysis of an autonomous small isolated microgrid aiming at high-RES penetration", *Energy*, Vol. 116(1), pp. 364-379,
- [15] Venkatesh Boddapati, Avinash Sree Ram Nandikatti, and S. Arul Daniel, "Design and feasibility analysis of a solar PV array installation during the construction of high-rise residential buildings" *J. Energy Sys.*, Vol 5(2), pp. 60-79, June 2021.
- [16] Venkatesh Boddapati, A Rakesh Kumar, S Arul Daniel, and Sanjeev Kumar Padmanabhan" Design and prospective assessment of a hybrid energy-based electric vehicle charging station" *Sustainable Energy Technologies and Assessments*, Vol. 53(A), October 2022.
- [17] Venkatesh Boddapati, T Sathish Kumar, N Prakash, and B Guna Priya" Current droop control of parallel inverters in an autonomous microgrid *Materials Today*" *Proceedings*: 45: pp. 2034-2039, October 2020.
- [18] Venkatesh Boddapati, A Rakesh Kumar, DB Prakash, and S Arul Daniel "Design and feasibility analysis of a solar PV and biomass-based electric vehicle charging station for metropolitan cities (India)", *Distributed Generation & Alternative Energy Journal*, Vol. 37(3), pp. 793–818, February 2021.