

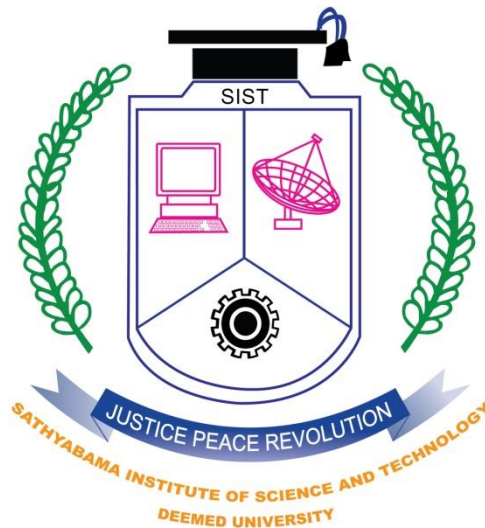
POWER FACTOR CORRECTION USING BRIDGELESS CUK CONVERTER TOPOLOGY

Submitted in partial fulfillment of the requirements for the award of
Bachelor of Engineering Degree in
Electrical and Electronics Engineering

By

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**DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING
SCHOOL OF ELECTRICAL AND ELECTRONICS**

SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

Accredited with Grade “A” by NAAC

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APRIL 2021



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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **RAJAMANICKAM G** (Reg. No. 37140068) and **SUNDARRAJ R** (Reg. No. 37140086) who carried out the project entitled "**POWER FACTOR CORRECTION USING BRIDGELESS CUK CONVERTER TOPOLOGY**" under our supervision from December 2020 to April 2021.

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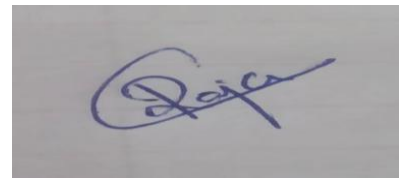
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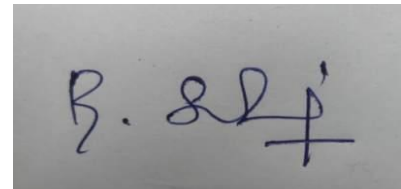
DECLARATION

We **RAJAMANICKAM G** (Reg. No. 37140068) and **SUNDARRAJ R** (Reg. No. 37140086) hereby declare that the Project Report entitled "**POWER FACTOR CORRECTION USING BRIDGELESS CUK CONVERTER TOPOLOGY**" done by us under the guidance of **Mrs. M. PREETHI PAULINE MARY** is submitted in partial fulfillment of the requirements for the award of Bachelor of Engineering degree in Electrical and Electronics Engineering.

1.



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DATE: 09/04/2021

PLACE: Chennai

SIGNATURE OF THE CANDIDATES

ACKNOWLEDGEMENT

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ABSTRACT

A Bridgeless CUK converter with less conducting components over a single switching cycle is proposed as an improved PQ-based EV charger. Using single voltage feedback power, the proposed PFC CUK converter provides excellent PFC characteristics in DCM mode. As a consequence, the charger's size is decreased. The proposed topology also eliminates the unwanted capacitive coupling loop, as well as unwanted conduction through the body diode of the inactive switch, which was present in the previously established BL CUK converter. This boosts the charger's performance greatly.

Improved PQ-based EV chargers, which draw a sinusoidal input current with high PF and output voltage is controlled stiffly at constant value, have been extensively studied in the literature to address these issues. In the literature for EV chargers, multiple topologies of front end PFC converters are discussed, depending on whether they are off-board or on-board. Various on-board EV chargers have been registered, all of which benefit from high power density and efficiency.

TABLE OF CONTENTS

CHAPTER NO.	TITLE	PAGE NO.
	ABSTRACT	v
	LIST OF FIGURES	ix
	LIST OF TABLES	x
	LIST OF SYMBOLS AND ABBREVIATIONS	xi
1	INTRODUCTION	
	1.1 INTRODUCTION	1
	1.2 AIM OF THE PROJECT	4
	1.3 LITERATURE SURVEY	5
	1.4 ADVANTAGES	7
2	PROJECT DESCRIPTION	
	2.1 BLOCK DIAGRAM	8
	2.2 CONCEPT EXPLANATION	9
	2.3 CIRCUIT DIAGRAM	11
3	PROPOSED SYSTEM	
	3.1 DESCRIPTION	12
	3.2 MODES OF OPERATION	13
	3.2.1 <i>Operation of BL Cuk PFC Converter</i>	13
	3.2.1.1 Mode P-I	14
	3.2.1.2 Mode P-II	15
	3.2.2 <i>Differential Aspect of Converter</i>	16
	3.2.3 <i>Operation of FLYBACK Converter</i>	17

3.2.4	<i>Control of Proposed EV Charger</i>	19
3.2.4.1	<i>Control of BL PFC Converter</i>	19
3.2.4.2	<i>Control of FLY BACK Converter</i>	19
3.3	DESIGNED PROPOSED EV CHARGER	20
3.3.1	<i>Design of Proposed Circuit</i>	21
3.3.2	<i>Proposed Circuit Values</i>	22
4	HARDWARE DESCRIPTION	
4.1	DC TO DC CONVERTER	23
4.1.1	<i>Overview</i>	23
4.1.2	<i>Applications</i>	24
4.2	CUK CONVERTER	25
4.3	TRANSFORMER	26
4.3.1	<i>Working Principle</i>	26
4.3.1.1	Transformer Theory	
4.4	FLYBACK CONVERTER	28
4.4.1	<i>Principle Of Flyback Converter</i>	28
4.4.2	<i>Advantages</i>	28
4.4.3	<i>Applications</i>	29
4.5	ARDUINO	
4.5.1	<i>General pin functions</i>	30
4.5.2	<i>Communication</i>	31
4.6	DRIVER CIRCUIT	31
4.7	MATLAB	
4.7.1	<i>What is Simulink?</i>	32
4.7.2	<i>Simulation design</i>	32

	4.8 SIMULATION RESULT	33
5	CONCLUSION	41
	REFERENCES	42

LIST OF FIGURES

FIGURE No.	TITLE	PAGE No.
2.1	Block Diagram of Proposed System	8
2.2	Proposed circuit diagram	11
3.1	Circuit diagram for mode-I	14
3.2	Circuit diagram for mode-II	15
3.3	Differential Proposed PFC Converter	17
3.4	Operation of Flyback Converter	18
4.1	Operational States of DC-DC Circuit	25
4.2	DUALITY principle on the buck-boost converter	26
4.3	CUK Converter	25
4.4	Working Principle of a transformer	27
4.5	Open loop Simulation	33
4.6	Output of the CUK Converter	34
4.7	Output of the Flyback Converter	35
4.8	State of Charging (SOC)	36
4.9	Closed loop Simulation	37
4.10	Output of the CUK Converter	38
4.11	Output of the Flyback Converter	39
4.12	State of Charging (SOC)	40

LIST OF TABLES

TABLE NO	TITLE	PAGE NO
1	Design of proposed circuit	21
2	Proposed Circuit Values	22

LIST OF SYMBOLS AND ABBREVIATIONS

PQ	-	Power Quality
BL	-	Bridge Less
PFC	-	Power Factor Correction
DCM	-	Discontinuous Conduction
EV	-	Electric Vehicle
BEV	-	Battery Powered Electric Vehicle
THD	-	Total Harmonic Distortion
ZVS	-	Zero Voltage Switching
LLC	-	Limited Liability Company
EMI	-	Electromagnetic Interferences
C	-	Capacitor
AC	-	Alternative Current
DC	-	Direct Current
S	-	Switches
SAE	-	Society of Automotive Engineers
PHEVs	-	Plug-Hybrid Electric Vehicles
V_o	-	Output Voltage
V_i	-	Input Voltage
L	-	Inductor
D	-	Diode
T	-	Time
SMPS	-	Switching Mode Power Supply
HEV	-	Hybrid Electric Vehicle
CCFL	-	Cold Cathode Fluorescent

SCR	-	Silicon Controlled Rectifier
GUI	-	Graphical User Interface

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

A Bridgeless CUK converter with less conducting components over a single switching cycle is proposed as an improved PQ-based EV charger. Using single voltage feedback power, the proposed PFC CUK converter provides excellent PFC characteristics in DCM mode. As a consequence, the charger's size is decreased. The proposed topology also eliminates the unwanted capacitive coupling loop, as well as unwanted conduction through the body diode of the inactive switch, which was present in the previously established BL CUK converter. This boosts the charger's performance greatly. For the long-term growth of the modern transportation market, battery-powered electric vehicles (BEVs) have surpassed traditional gasoline-powered vehicles. The significant supporting equipment of the electric vehicle is an AC-DC converter based on board or off board charger to allow battery charging in BEVs (EV). Various off-board and on-board topologies of EV battery chargers with unidirectional or bidirectional configuration are discussed in the literature under level 1, level 2, or level 3 categories.

To enhance energy utilization during charging, an off-board charger must have improved power quality (PQ) characteristics in addition to high power density and small form factor. The traditional EV charger with a diode bridge rectifier (DBR), on the other hand, draws a peaky current from the mains, lowering the input power factor (PF) and causing complete harmonic distortion (THD) of up to 55.3 percent. Table-I lists the battery rating and specifications for the electric vehicle under evaluation. These reported waveforms clearly show that the DBR fed charger's output does not meet international regulations such as the IEC 6100-3-2 standard.

Improved PQ-based EV chargers, which draw a sinusoidal input current with high PF and output voltage is controlled stiffly at constant value, have been extensively studied in the literature to address these issues. In the literature for EV chargers, multiple topologies of front end PFC converters are discussed, depending on whether they are off-board or on-

board. Various on-board EV chargers have been registered, all of which benefit from high power density and efficiency. However, because of the decreased vehicle weight and capacity to charge at high power levels, an off-board design is a more realistic option. Different PFC converter topologies with interleaved front-end input and zero voltage switching (ZVS) technique are discussed. The advantages of interleaving two phase inputs include decreased output ripple current and inductor size reduction. Furthermore, since the semiconductor devices are working in parallel, there are less conduction losses. Interleaved PFC converters, like traditional boost PFC converters, do not offer a solution for low thermal utilization of PFC switches. The use of an LLC resonant converter fed EV charger is addressed, which has the added benefits of low EMI (Electromagnetic Interference) noise and low switching loss. However, the resonant converter's complex mathematical analysis makes it unsuitable for EV charging over a broad input voltage range. The most promising solution for EV chargers is a full-bridge PFC converter [11], but designing individual gate drivers for four semiconductor switches has the downside of increasing size and complexity. As a result, various unidirectional PFC off-board EV chargers are addressed in order to provide ease of deployment while maintaining the benefits of high power density and reliability.

At the input of these chargers, various single-stage and two-stage converters with power factor correction (PFC) produce perceivable PQ indices. There have been numerous single-stage PFC converter-based EV charger topologies published in the literature. Because of the low component count, the single-stage charger has been found to be very effective. The existence of 100 Hz ripple material in output current, on the other hand, necessitates a very high DC-link capacitance. A two-stage charger with PF correction converter is a widely viable solution in the EV market for medium power ratings up to 1kW. Due to significant conduction loss incurred by four input diodes, the DBR (Diode Bridge Rectifier) fed PFC converter has an impact on the charger performance. As a result, bridgeless PFC converters provide the most feasible solution for improving PQ in EV chargers due to the lower number of components conducting over one switching cycle and lower conduction loss. Various single phase unidirectional improved PQ based converters have been investigated in this context, since they can both buck and raise the input voltage, the bridgeless buck-boost converter is the most appealing solution for PFC in EV chargers. Different buck-boost converters, such as Cuk and SEPIC converters, are identified and

analyzed. Despite the fact that Zeta, Cuk, and SEPIC PFC converters have low input current ripple and a large duty cycle variation range, the SEPIC converter, unlike the Cuk converter, has a discontinuous output current restriction. As a result of the low ripple in battery current, the Cuk converter gives more feasible charging characteristics to the battery. Many BL Cuk converter topologies are based on traditional PFC Cuk converter, are discussed in the literature [10-13]. All of these topologies have limitations in terms of the number of components, losses, performance, and coupling requirements, which are discussed in the following section.

Offers benefits such as lower input current, decreased EMI, and ease of use. However, due to the interconnection of two intermediate capacitors, C1 and C2, it suffers from a circulating current problem, which results in additional losses in two halves of the supply voltage. Makes extensive use of equipment, such as two output capacitors, which has the disadvantage of a floating terminal for the load between the two capacitors at the output. Moreover, it has the disadvantage of floating neutral due to arrangement of switches for independent half of supply voltage. Since the inactive switch S2's body diode is always conducting current during the positive half cycle of the input voltage, through L_{i2} , the circuit always incurs some losses across the body diode of the inactive switch. Due to a partial return current flow through it during the other half of the cycle. The other BL Cuk converters in [11] and [13] have the same advantages of low part count and reduced semiconductor system stress as traditional Cuk converters. Coupling in both the input and output inductors is not possible for any of these converters.

As a consequence, in this work, a new power quality improved, bridgeless (BL) Cuk converter is proposed for EV charging, which follows the recommended SAE standard J1772. The following are the main features of the proposed charger that will help to resolve the issues listed above. Due to the applied power, there is no return current through the body diode of inactive switches in the other half cycle. As a result, switch losses are minimized. The PFC converter's control is straightforward thanks to the use of the same gate drive and control circuitry for each half cycle. The output inductors of the proposed Cuk converter are small enough to ensure converter operation in DCM (Discontinuous conduction mode), lowering the converter's cost and size. During BL operation, the line voltage still has a ground return path through the line diodes D_p and D_n .

1.2 AIM OF THE PROJECT

Because of the low ripple in battery current, the Cuk converter gives more feasible charging characteristics to the battery. The significant features of the proposed charger to alleviate the above issues are summarized in the following topologies of BL Cuk converters based on traditional PFC Cuk converters.

Since the intermediate capacitors work independently in both halves, circulating losses are removed, resulting in increased charger performance. Due to the applied power, there is no return current through the body diode active switches in the other half loop. As a result, switch losses are minimized. Since the PFC converter uses the same gate drive and control circuitry for each half cycle, control is easy. The output inductors of the proposed Cuk converter are small enough to ensure converter operation in DCM (Discontinuous conduction mode), lowering the converter's cost and size.

There is no problem with floating neutrals, and EMI noise is minimized. The proposed converter's conduction loss is reduced thanks to the BL structure, which improves the charger performance. Over one switching cycle, the number of components is reduced; as a result, the charger's performance is increased with the proposed converter.

Various single phase unidirectional improved PQ based converters have been investigated in this context, since they can both buck and raise the input voltage, the bridgeless buck-boost converter is the most appealing solution for PFC in EV chargers. Different buck-boost converters, such as Cuk and SEPIC converters, are identified and analyzed. Despite the fact that Zeta, Cuk, and SEPIC PFC converters have low input current ripple and a large duty cycle variation range, the SEPIC converter, unlike the Cuk converter, has a discontinuous output current restriction. As a result of the low ripple in battery current, the Cuk converter gives more feasible charging characteristics to the battery.

1.3 LITERATURE SURVEY

Radha kushwaha et al.,(2019) as proposed as the current state of battery chargers, charging power levels, and infrastructure for plug-in electric vehicles and hybrids, as well as their implementation. Off-board and on-board charger systems with unidirectional or bidirectional power flow are divided into two categories. The use of unidirectional charging reduces the amount of hardware needed and simplifies interconnection issues. Battery energy injection back to the grid is made possible by bidirectional charging. Because of weight, space, and cost constraints, most on-board chargers limit capacity. To prevent these issues, they can be combined with the electric drive. The availability of charging infrastructure decreases the need for and cost of on-board energy storage. Conductive or inductive on-board charger systems are available. An off-board charger is less limited by size and weight and can be built for high charging speeds. The power levels of Level 1 (convenience), Level 2 (primary), and Level 3 (fast) are addressed. Aspects of the future, such as roadbed charging, are discussed. The amount of power, charging time and location, cost, equipment, and other factors are presented, compared, and evaluated for various power level chargers and infrastructure configurations. Industrial electronics for electric transportation: Current state-of-the-art and future challenges.

T.J Liang, et al., (2018) as proposed the current research trends and future issues for industrial electronics related to transportation electrification Electric and plug-in hybrid electric vehicles (EVs/PHEVs) and their vital drivetrain components are given special attention. The paper discusses concerns relating to EV energy storage systems, EV charging, power electronics, and traction motor drives in the automotive industry. For series-connected lithium-ion (Li-ion) batteries, the value of battery cell voltage equalization for extended life time is discussed. A detailed overview of the classification, standards, and criteria for EV/PHEV battery chargers is also given. The topologies of many traditional EV/PHEV front-end ac/dc charger converter topologies, as well as isolated DC/DC topologies, are discussed. Finally, this paper reviews various EV propulsion system architectures and efficient bidirectional DC/DC converter Topologies. Also discussed are novel DC/AC inverter modulation

techniques for EVs. The architectures are determined by the voltage, power, and driving range of the batteries. The use of unidirectional charging reduces the amount of hardware needed and makes interconnection problems easier to resolve. Bidirectional charging allows for battery energy injection into the grid. Most on-board chargers have a capacity limit due to weight, space, and cost considerations.

Chuan Shi, et al., (2017) as proposed as the front-end ac-dc converter, a critical component of a plug-in hybrid electric vehicle (PHEV) charging system, must achieve high efficiency and power density. This paper presents a topology survey testing topologies for use in front-end ac-dc converters for PHEV battery chargers. The topology study focuses on a number of boost power factor corrected converters that provide high performance, high power factor, high density, and low cost. The experimental results for five prototype converters that convert universal ac input voltage to 400 V dc are described and interpreted. The findings show that the phase shifted semi-bridgeless PFC boost converter is well-suited for automotive level I residential charging applications in North America, where the average supply is 120 V and 1.44 kVA or 1.92 kVA. The bridgeless interleaved PFC boost converter is an ideal topology candidate for automotive level II residential charging applications in North America and Europe, with power levels of 3.3 kW, 5 kW, and 6.6 kW. For various power level chargers and infrastructure configurations, the amount of power, charging time and location, cost, equipment, and other factors are presented, compared, and evaluated.

1.4 ADVANTAGES

- The usable input voltage may be decreased or increased to save battery room.
- The available voltage can be boosted or bucked to drive a device.
- The proposed PFC Cuk converter provides excellent PFC characteristics in DCM mode using single voltage feedback control, preventing system damage or breakdown. As a result, the charger's size is decreased.
- Another benefit of the proposed topology is that it eliminates the unwanted capacitive coupling loop, as well as unwanted conduction through the body diode of an inactive switch, as seen in previous BL Cuk converters.
- In the previously formed BL Cuk converter, the body diode of an inactive switch is avoided. This boosts the charger's performance greatly.
- The proposed charger has demonstrated satisfactory charging characteristics in both steady state and grid voltage variations of more than 50 percent.
- There is no problem with floating neutrals, and EMI noise is minimized. The proposed converter's conduction loss is reduced thanks to the BL structure, which improves the charger performance.
- Over one switching cycle, the number of components is reduced; as a result, the charger's performance is increased with the proposed converter.

CHAPTER 2

PROJECT DESCRIPTION

2.1 BLOCKDIAGRAM

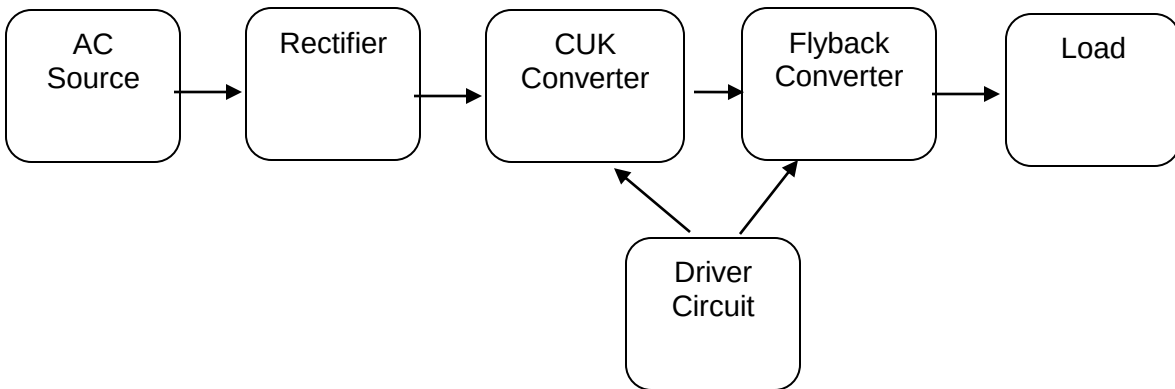


Fig:2.1 :Block diagram of proposed system

2.2 CONCEPT EXPLANATION

The conventional EV charger with a diode bridge rectifier (DBR) draws a peaky current from the mains, worsening the input power factor (PF), with total harmonic distortion (THD) as high as 55.3%. Several topologies of front end PFC converters depending upon the off-board or on-board configuration, are discussed in the literature for EV chargers. Various on-board EV chargers are reported in [6], which have significant advantage of high power density and efficiency. However, an off-board configuration offers more practical solution due to reduced vehicle weight and suitability to charge at high power range. Different PFC converter topologies with interleaved input at front-end and zero voltage switching (ZVS) technique are reported. The interleaving of two phase inputs, comes with the benefits of reduced output ripple current and reduced size of the inductor. Moreover, the semiconductor devices are operated in parallel, which results into reduced conduction losses, comparatively. However, the interleaved PFC converters do not provide the solution for poor thermal utilization of PFC switches, similar to the conventional boost PFC converter. The use of an LLC resonant converter fed EV charger is addressed, which has the added benefit of low EMI (Electromagnetic Interference) Noise and switching loss. However, the resonant converter's complex mathematical analysis makes it unsuitable for EV charging over a broad input voltage range. The full-bridge PFC converter appears to be the most promising solution for EV chargers, but designing individual gate drivers for four semiconductor switches increases the size and complexity of the device. There have been numerous single-stage PFC converter-based EV charger topologies published in the literature. Because of the low component count, the single-stage charger has been found to be very effective. The existence of 100 Hz ripple material in output current, on the other hand, necessitates a very high DC-link capacitance. The intermediate capacitors are acting independently, in both halves; therefore, circulating losses are eliminated, which results into improved efficiency of the charger. There is no return current through the body diode active switches in the other half cycle due to applied control. Therefore, losses in the switch, are reduced. The control of the PFC converter is simple owing to use of same gate drive and control circuitry for each half cycles. The output inductors of proposed Cuk converters are designed small enough to

ensure converter operation in DCM (Discontinuous conduction mode), therefore, the cost and size of the converter, are reduced. There is no floating neutral issue seen as well as EMI noise is reduced. The conduction loss in proposed converter, is reduced due to BL structure, which in turn, improves the charger efficiency. The number of components, is reduced over one switching cycle; therefore, the efficiency of the charger is improved with proposed converter, comparatively. Since the PFC converter uses the same gate drive and control circuitry for each half cycle, control is easy. The output inductors of the proposed Cuk converter are small enough to ensure converter operation in DCM (Discontinuous conduction mode), lowering the converter's cost and size. The current state of battery chargers, charging power levels, and infrastructure for plug-in electric vehicles and hybrids, as well as their implementation. Off-board and on-board charger systems with unidirectional or bidirectional power flow are divided into two categories. The use of unidirectional charging reduces the amount of hardware needed and simplifies interconnection issues. Battery energy injection back to the grid is made possible by bidirectional charging. Because of weight, space, and cost constraints, most on-board chargers limit capacity. There have been numerous single-stage PFC converter-based EV charger topologies published in the literature. Because of the low component count, the single-stage charger has been found to be very effective. The existence of 100 Hz ripple material in output current, on the other hand, necessitates a very high DC-link capacitance. A two-stage charger with PF correction converter is a widely viable solution in the EV market for medium power ratings up to 1kW.

2.3 CIRCUIT DIAGRAM

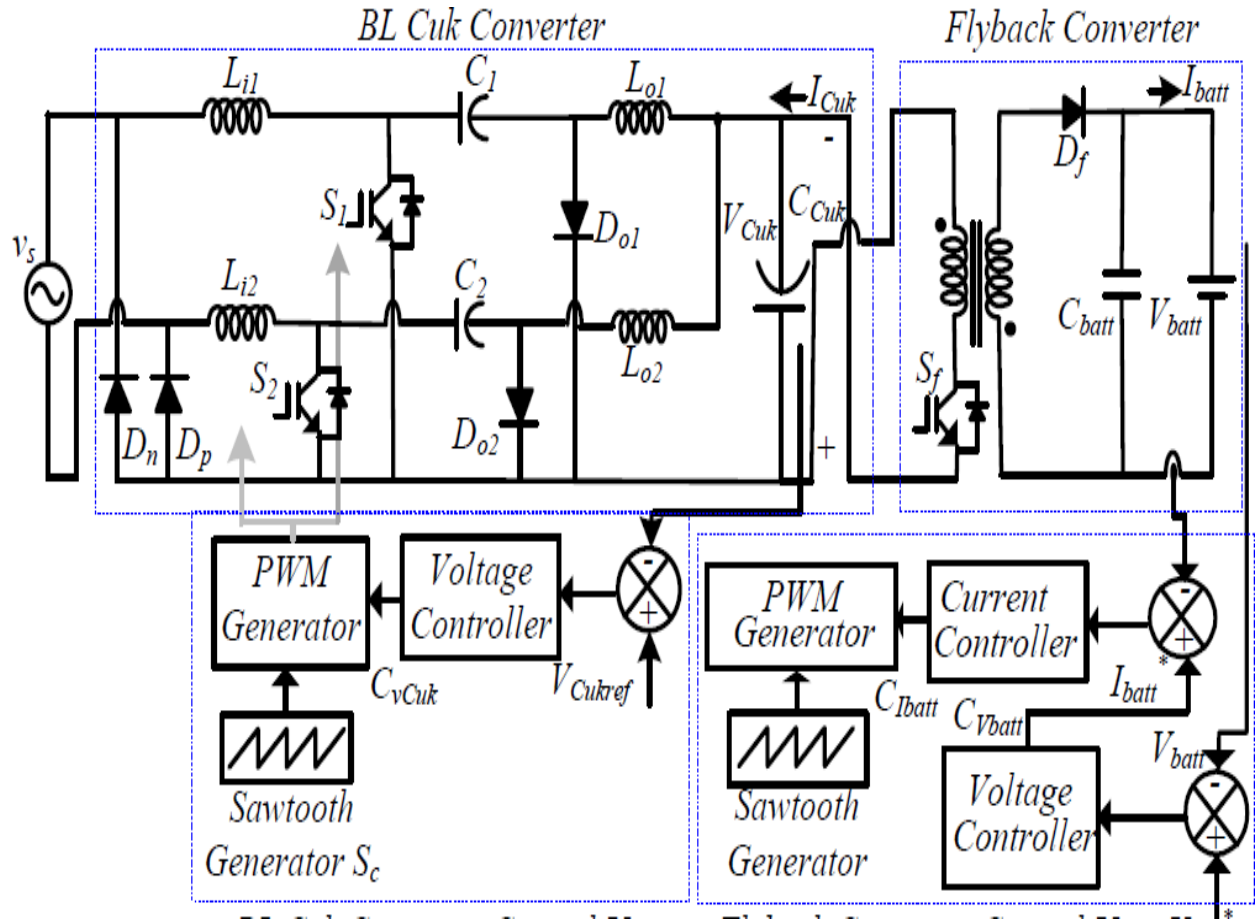


Fig:2.2 :Circuit diagram of proposed circuit

In Fig :2.2: The proposed circuit diagram is shown in details.

CHAPTER 3

PROPOSED SYSTEM

3.1 DESCRIPTION

Cuk converter provides more feasible charging characteristics to the battery due to low ripple in battery current. Many topologies of BL Cuk converter based upon conventional PFC Cuk converter, the significant features of proposed charger to mitigate above issues, are summarized as follows. The intermediate capacitors are acting independently, in both halves; therefore, circulating losses are eliminated, which results into improved efficiency of the charger. There is no return current through the body diode active switches in the other half cycle due to applied control. Therefore, losses in the switch, are reduced. The PFC converter's control is straightforward due to the use of the same gate drive and control circuitry for each half cycle. The output inductors of the proposed Cuk converter are small enough to ensure converter operation in DCM (Discontinuous conduction mode), lowering the converter's cost and size. The conduction loss in the proposed converter is reduced due to the BL structure, which increases the charger performance. The conduction loss in the proposed converter is reduced due to the BL structure, which increases the charger performance. Over one switching cycle, the number of components is reduced; as a result, the charger's performance is increased with the proposed converter. There have been numerous single-stage PFC converter-based EV charger topologies published in the literature. Because of the low component count, the single-stage charger has been found to be very effective. The existence of 100 Hz ripple material in output current, on the other hand, necessitates a very high DC-link capacitance. A two-stage charger with PF correction converter is a widely viable solution in the EV market for medium power ratings up to 1kW.

3.2 MODES OF OPERATION

Fig:3.1 and Fig:3.2 demonstrate the design and function of the proposed power quality improved EV charger. The Cuk converter cell, which consists of L_{i1} - S_1 - D_{o1} - L_{o1} - D_p , is in action during the positive half cycle. The other Cuk converter cell, L_{i2} - S_2 - D_{o2} - L_{o2} - D_n , is active during the negative half line. For both Cuk converter cells, the input inductors L_{i1} and L_{i2} are set to work in CCM. However, the output inductors L_{o1} and L_{o2} are designed in such a way that the output diode current, i_D , is zero after one switching cycle, and the converter enters DCM. The intermediate capacitors C_1 and C_2 are chosen so that the voltage across the capacitors remains constant throughout the switching period. Since only a single voltage sensor is used, the output voltage of the PFC Cuk converter is kept constant using single loop voltage feedback control [7-8], which lowers the charger cost. During the CC (Constant Current) and CV (Constant Voltage) charging regions, the flyback converter is programmed to work in DCM [9] with a cascaded PI controller that controls the battery charging commands.

3.2.1 Operation of BL Cuk PFC Converter

Due to symmetry in waveforms, only positive half cycle of BL converter is taken into consideration, as depicted in Fig:3.2. To explain the working of proposed EV charger, the operating modes of Cuk converter, are illustrated in this section. During the CC (Constant Current) and CV (Constant Voltage) charging regions, the flyback converter is programmed to work in DCM with a cascaded PI controller that controls the battery.

3.2.1.1 Mode P-I [switch ON period, $0 \leq t \leq DC_{uk}T_s$]:

When the gate pulse to switch S1 is applied at t_1 , the first mode of positive half cycle operation (PI) begins. With the slope of $V_{spk}(t)/L_{i1}$, the current through the input inductor L_{i1} increases linearly. As the positive line diode D_p is in the conducting state, the current follows the direction v_s - L_{i1} - S_1 - D_p - v_s . Fig. 3.1 shows the primary switching waveforms associated with all three modes. Via the switch S_1 and output inductor L_{o1} , the voltage across the intermediate capacitor C_1 begins to decrease, providing the needed load current to the fly back converter. Due to the polarity of the intermediate capacitor voltage, C_1 , the output diode D_{o1} remains in reverse bias throughout this time. The peak current stress through switch S_1 during this mode, is given as, $s_{1pk} = \frac{V_{D T I L}}{L_{eq}} = (1)$ where L_{eq} represents an equivalent circuit inductance of proposed converter, i.e. input inductor L_{i1} , and the output inductor L_{o1} . V_{spk} is the maximum value of input AC voltage, DC_{uk} is the ON period for switch S_1 , and T_s is the total switching period.

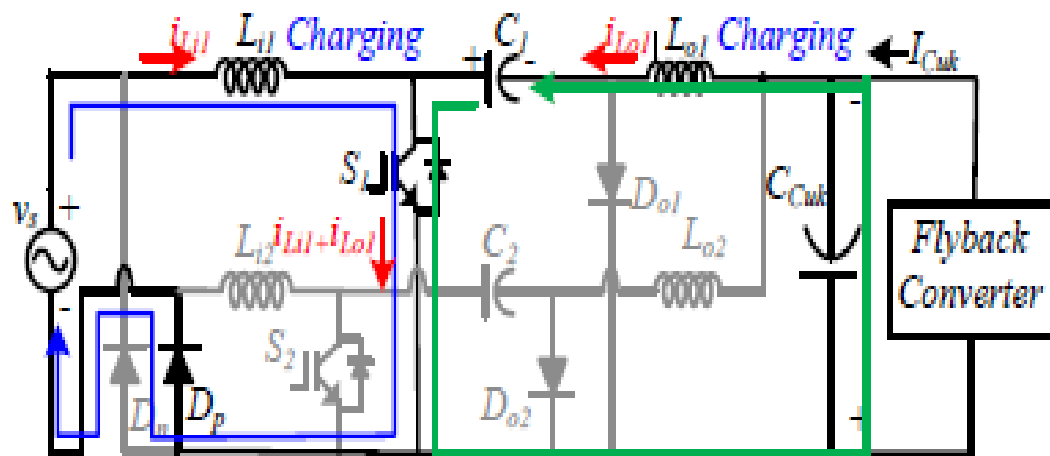


Fig:3.1 :Circuit diagram for Mode P-I

3.2.1.2 Mode P-II [switch OFF period, $D C_{uk} T_s \leq t \leq D_1 T_s$]:

When switch S_1 is switched off at instant t_2 , this mode begins. As the input inductor L_{i1} begins to release the stored energy via C_1 and D_{o1} , the output diode D_{o1} comes into conduction and the voltage across the intermediate capacitor begins to increase, as shown in Fig.3.2. As the stored energy is released via the output diode D_{o1} and the DC connection capacitor C_{Cuk} , the output inductor L_{o1} provides the necessary load current. $L_{o1} C_{uk} \frac{dV}{dt}$ is the current $i_{L_{o1}}$ through the output inductor, where V_{Cuk} is the BL Cuk converter's output voltage. When the current through the output diode reaches zero at instant t_3 , the switching time is over.

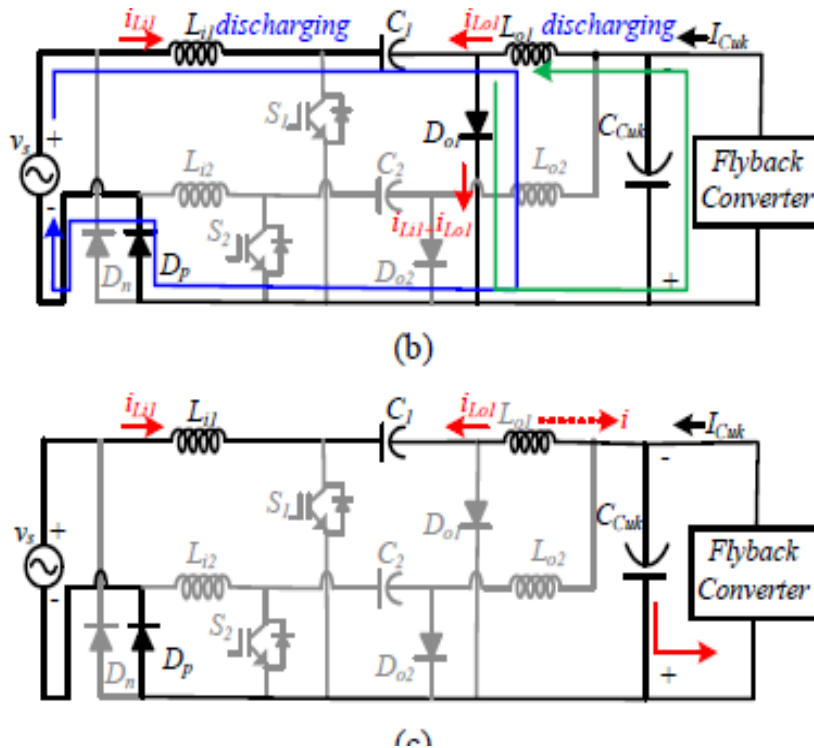


Fig.3.2 :Circuit diagram for Mode P-II

3.2.2 Differential Aspect of Proposed PFC Converter

The differential aspects of proposed PFC converter as compared to BL Cuk topology-1 and topology-3, are discussed as follows.

The intermediate capacitors are acting independently in both the halves; as there is no interconnection between C1 and C2, unlike Fig:3.3, therefore, circulating losses are eliminated which, results into improved efficiency of the charger. Topology-3, is found to be loss as the body diode of the inactive switch S2 is always conducting current during the positive half cycle of the input voltage, via Li2, as shown in Fig.3.3. Due to conventional control. This implies that during +ve half cycle operation, when switch S1 is ON, the current flows not only through Dp but also part of this current returns through the body diode of switch S2 and inductor Li2. Similarly, when switch S1 is turned OFF, the current not only flows through the line diode Dp via output diode Do1, but some current also goes through inductor Li2 via body diode, Dp. Similar case happens for the -ve half cycle operation with switch S2. This happens due to the single PWM signal being applied to only one of the switch during one half. i.e S1 or S2 and other switch is kept OFF for other half thoroughly. Therefore, the circuit always incurs some losses across the body diode of the inactive switch (S1 or S2) due to partly return current flow through it during the respective half cycle operation.

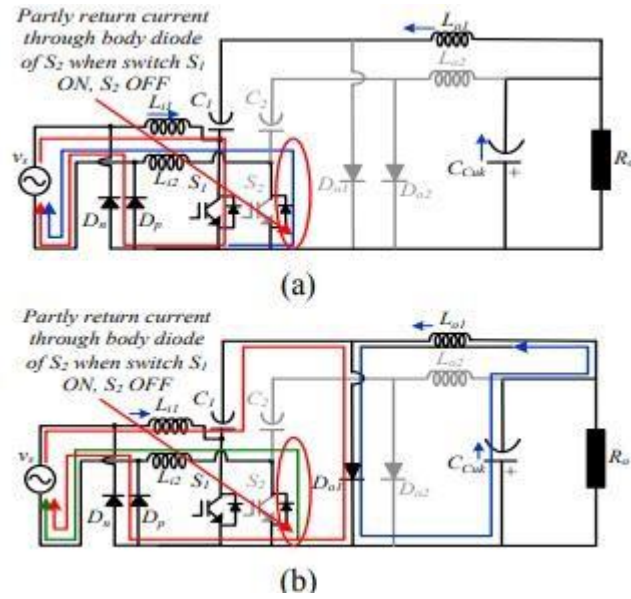


Fig:3.3:Differential Aspect of Proposed PFC Converter

Due to applied power, there is no return current through the body diode of inactive switches in the respective half cycle, unlike Fig:3.3. PFC converter control is easy due to the use of the same gate drive and control circuitry for each half cycle, i.e. both switches S_1 and S_2 operate in synchronism with the same driver signal. To put it another way, the same driver signal and Inter leaved driver signal can be used to power switches S_1 and S_2 to minimize conduction loss through the body diode of the inactive switches. As a result, losses in the body diode are minimized. With the same driver signal, the real operating modes are slightly different.

3.2.3 Operation of Flyback Converter

The operation of flyback converter is analyzed based on DCM of magnetizing inductance of the high frequency transformer (HFT). During mode-I, the current through the magnetizing inductance emf rises linearly and it stores the energy when the flyback switch S_f is made ON. The output diode, D_f is reverse biased due to the dot convention of HFT, during this instant. The current through the switch S_f

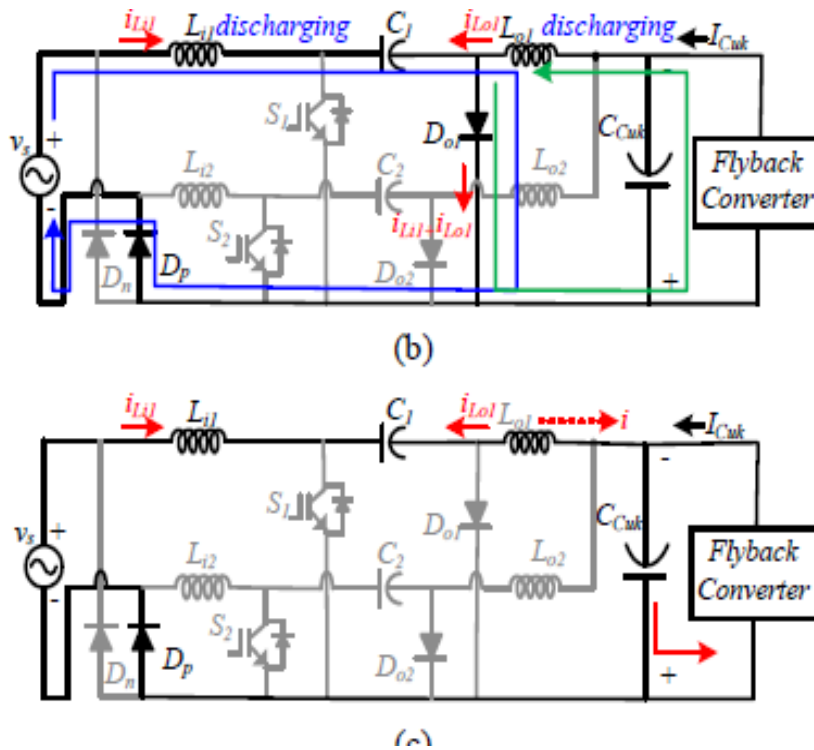


Fig:3.4:Operation of Fly back Converter

When switch S_f is switched off at instant t_2 , mode-II starts. During the turn OFF moment, the polarity of the HFT is reversed, and the output diode D_f becomes forward biased, supplying the output power to the battery. The diode voltage V_{Df} and the switch current i_{sf} are both zero. When both the switch and the diode are switched off, Mode-III, also known as discontinuous conduction mode, begins. At the end of the switching cycle, the stored energy in the magnetising inductance is fully transferred to the output. The output capacitor C_{batt} provides the necessary battery charging current in CC mode at this time.

3.2.4 Control of Proposed EV Charger

The control strategy for proposed charger is discussed under the following subparts.

3.2.4.1 Control of Bridgeless PFC Converter

The proposed BL PFC converter is set up to work in discontinuous conduction mode with voltage follower mode power. The voltage follower is regulated by a PI (Proportional-Integral) controller, which forms the mains current to match the input voltage, and the output of the BL converter remains constant despite large input voltage variations. A voltage sensor is used to detect any difference in voltage (V_{Cuk}) that occurs as a result of the sudden shift in mains voltage. The sensed voltage is compared to the reference voltage that is required (V_{Cukref}). The voltage feedback controller receives the obtained error V_{Cuk} . The proposed control is novel in that it simplifies the control of the PFC converter by using the same gate drive and control circuitry for each half cycle. Both switches, S_1 and S_2 , operate in synchronism with the same driver signal. To put it another way, to minimise conduction loss through the body diode of inactive switches, the same driver signal is used, which decreases losses in the body diode of inactive switches during the respective halves, as shown in Fig:3.4.

3.2.4.2 Control of Flyback Converter

The Flyback converter is controlled using a cascaded dual PI controller at the output to provide CC charging to the battery at all operating conditions. For this purpose, battery voltage, V_{batt} is sensed and it is compared to a constant reference voltage, V_{batt}^* . The voltage error, V_{batt} is given to a voltage PI controller. The output obtained from the PI controller, is made to saturate at the maximum charging current limit such that the output of the outer PI controller loop, sets the reference I_{batt}^* for current for the inner current loop. However, sensed charging current, I_{batt} of EV battery is compared to this reference value and the error is fed to the inner current PI controller. When the output of voltage controller is saturated at the

reference charging current value and the voltage PI controller loop is inactive. The required pulses are achieved using PWM generator block by comparing the current PI controller output to a Saw tooth wave to charge the battery in CC mode. The governing error signal, I_{batt} and the control signal

Since the current PI controller loses power, the charger control is switched to CV mode once the battery reaches an appropriate SOC limit (near 80%). The voltage PI controller maintains a constant reference value in this mode, and the battery charges to the maximum voltage cap, which corresponds to 100 percent SOC. This mode is known as constant voltage mode because at the end of each cycle, the battery is fully charged and the current drawn from the source is reduce.

3.3 DESIGN OF PROPOSED PFC CONVERTER BASED CHARGER

The cost of an EV charger is directly related to the PF correction converter's sensing requirements. The current multiplier approach is used in CCM's control scheme to include an intrinsic wave-shaping function as well as DC-link regulation. The number of sensors needed in CCM is higher due to the need to sense output voltage as well as input voltage and current. Lower current stress on PFC converter switches and components is the primary benefit of CCM operation.

The number of sensors needed in DCM operation is reduced because the control scheme is based on a voltage follower method, and the only quantity to be sensed is the converter output voltage.

3.3.1 Design of Proposed Circuit

Table 3.1: Design of Proposed Circuit

1	Input inductor	3.86mH	4mH	CCM
2	Output inductor	0.222mH	0.15mH	DCM
3	Intermediate Capacitor	2.712 μF	3μF	CCM
4	DC link Capacitor	3mF	4.7mF	-
5	HFT Magnetizing Inductance	164.37μF	30μF	DCM
6	Output Capacitor	1.585mF	2mF	-

3.3.2 Proposed Circuit Values

Table 3.2: Proposed Circuit Values

S.No	Components	Specifications
1	Input Inductance, $L_{i1,2}$	4mH
2	Output Inductance, $L_{o1,2}$	150μH
3	Magnetizing Capacitor $C_{1,2}$	3μF
4	Magnetizing Inductor, L_f	130μH
5	Transformer Turns Ratio	0.333
6	Battery Specifications	48V,100Ah
7	DC-link Capacitor C_{cuk}	2000,400V
8	Output Capacitor	2000,100V

In table 3.1: The designed values of the proposed Circuit is given and Table 3.2: The specifications of components are given.

CHAPTER 4

HARD DESCRIPTION

4.1 DC TO DC CONVERTER

Portable electronic devices that are powered by batteries, such as cellular phones and laptop computers, need DC to DC converters. Such electronic devices also contain several sub-circuits, each of which needs a different voltage level than that supplied by the battery (sometimes higher or lower than the battery voltage, and possibly even negative voltage). Additionally, as the battery's stored power is depleted, the battery's voltage drops. Instead of using several batteries to supply various parts of the system, DC to DC converters provide a way of producing several regulated voltages from a single variable battery voltage, saving energy.

4.1.1 OVERVIEW

DC sources, such as batteries, solar panels, rectifiers, and DC generators, may also provide power. DC to DC conversion is a process that converts one DC voltage to another DC voltage. A boost converter is a DC to DC converter that generates a higher output voltage than the input voltage. Since it “step-up” the source voltage, a boost converter is also known as a step-up converter. The output current is lower than the source current since power ($P = VI$) must be conserved.

A 'Joule robber' is another term for a boost converter. This term is typically reserved for very low-power battery applications, and refers to a boost converter's ability to 'steal' the remaining energy in a battery. This energy would otherwise be wasted since a normal load wouldn't be able to handle the battery's low voltage.

The SMPS switch must be able to turn on and off easily and with minimal losses in order to achieve high performance. The invention of a commercial semiconductor switch in the 1950s was a landmark moment in the development of SMPSs like the boost converter. Other switches, such as vacuum tubes and electromechanical relays, switched on and off faster and operated longer than semiconductor switches. When semiconductor switches became available in the early 1960s, the major DC to DC converters were built. The converter's rapid development was prompted by the aerospace industry's need for compact, lightweight, and reliable power converters.

Switched systems, like SMPS, are difficult to design because their model is dependent on whether a switch is open or closed. Caltech's R.D. Middlebrook released the models for DC to DC converters that are still used today in 1977. Middlebrook used a technique called state-space averaging to average the circuit configurations for each switch state. Two systems were merged into one as a result of this simplification. The new model resulted in useful design equations that aided SMPS expansion.

4.1.2 APPLICATIONS

To achieve higher voltage, battery-powered systems often stack cells in sequence. However, due to a lack of space, adequate cell stacking is not possible in many high voltage applications. Boost converters can minimize the number of cells while increasing the voltage. Hybrid electric vehicles (HEV) and lighting systems are two battery-powered applications that use boost converters. A 500 V motor powers the Toyota Prius HEV. The Prius would need approximately 417 cells to power the motor if it didn't have a boost converter. A Prius, on the other hand, uses only 168 cells and raises the battery voltage from 202 to 500 volts. Boost converters may also be used to control devices on a smaller scale, such as portable lighting systems. A boost converter will step up the voltage from a single 1.5 V alkaline cell to power a white LED, which needs 3.3 V to emit light. Boost converters can also generate higher voltages for devices like LCD backlights and certain flashlights that use CCFL.

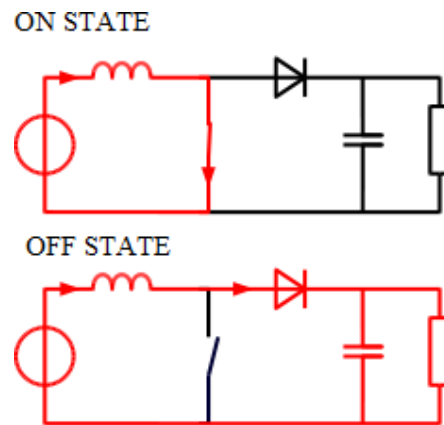


Fig:4.1 :Operational states of DC-DC Circuit

4.2 CUK CONVERTER

The inductor is used in both buck, boost, and buck-boost converters to transfer energy between input and output; analysis is based on voltage balance around the inductor. The CUK converter employs capacitive energy transfer, and its analysis is dependent on the capacitor's current balance.

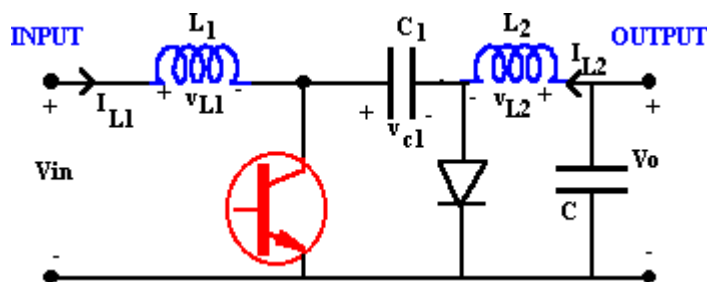


Fig:4.2:Derived from DUALITY principle on the buck-boost converter

As a result, the voltage ratio is identical to that of a buck-boost converter. The CUK converter has the advantage of creating a steady current on both sides of the converter, while the buck, boost, and buck-boost all have at least one side with pulsed current.

4.3 TRANSFORMER

A transformer is a type of passive electrical system that uses electromagnetic induction to convert electrical energy from one circuit to another. It's most widely used to step up ('step up') or step down ('step down') voltage levels between circuits.

4.3.1 *WORKING PRINCIPLE OF TRANSFORMER*

A transformer's function is very straightforward. Electrical energy is transferred between circuits by mutual induction between two or more windings (also known as coils). Below, we'll go over this idea in more depth.

4.3.1.1 Transformer Theory

Assume you have a single winding (also known as a coil) that is driven by an alternating current. The alternating current that passes through the winding generates a flux that is continuously changing and alternating. If a second winding is brought next to this one, some of the alternating flux would be transferred to the second winding. Since the amplitude and direction of this flux are constantly changing, there must be a changing flux connection in the second winding or coil. There will be an EMF induced in the second winding, according to Faraday's law of electromagnetic induction. If the secondary winding's circuit is closed, current can pass through it. A transformer's basic working theory is as follows: To better visualise this, let's use electrical symbols. The 'primary winding' is the winding that receives electrical power from the source. This is the 'First Coil' in the diagram below. The 'secondary winding' is the winding that produces the desired output voltage due to mutual induction. In the diagram above, this is the 'Second Coil'. A step-up transformer is a transformer that raises the voltage between the primary and secondary windings. A step-down transformer, on the other hand, is a transformer that lowers the voltage between the main and secondary windings. The number of turns on the primary and secondary sides of the transformer decide whether the transformer increases or decreases the voltage level. The voltage would decrease if the primary coil has more turns than the secondary coil (step down). The voltage would rise if the primary coil has fewer turns than the secondary coil (step up). Although the transformer diagram shown above is theoretically feasible in an ideal

transformer, it is not very practical in practise. Because only a small fraction of the flux emitted by the first coil can link with the second coil in the open air, this is the case. As a result, the current flowing through the secondary winding's closed circuit would be very tiny (and difficult to measure). The sum of connected flux with the second winding determines the rate at which flux linkage changes. As a result, nearly all of the flux from the primary winding can preferably bind to the secondary winding. Winding in the secondary A core style transformer is used to do this effectively and efficiently.

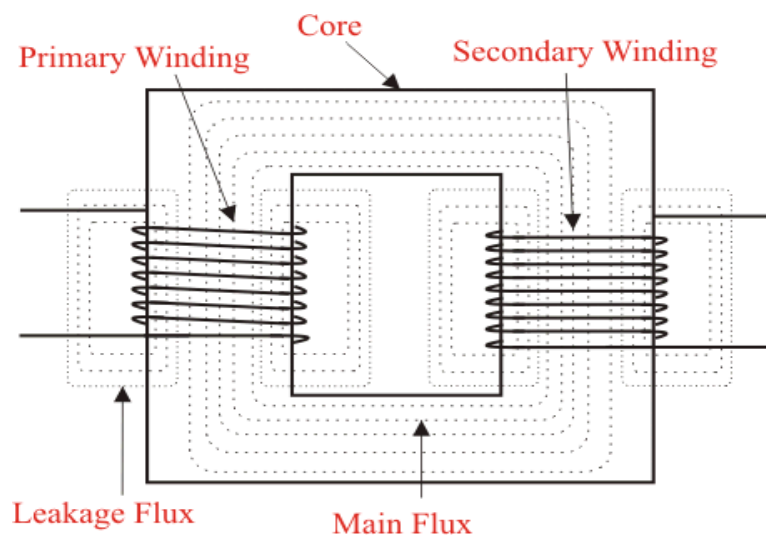


Fig:4.3: Working principle of a transformer

The transformer core's function is to provide a low-reluctance path through which the primary winding's maximum amount of flux is passed through and connected to the secondary winding. The transformer inrush current is the current that flows through the transformer as it is turned on for the first time.

4.4 FLYBACK CONVERTER

The Flyback converter is a power supply topology that uses a mutually coupled inductor to store energy as current flows through it and release it when the power is turned off. In terms of design and performance, flyback converters are identical to booster converters. The primary winding of the transformer, on the other hand, acts as an inductor, while the secondary provides the output. The main and secondary windings are used as two separate inductors in the fly back configuration.

4.4.1 Principle of Operating of a Flyback Converter

A sudden reversal of the terminal voltage releases the energy contained in the magnetic field when the current flowing through an inductor is cut off. A fly back diode is a diode that is used to conduct the stored energy to a useful location. Since the inductor only requires one winding, it is referred to as a fly back transformer. When the main switch is off, this arrangement has the unique property of passing energy to the secondary side of the power supply.

The basic flyback converter is made up of a few simple components. The energy in the primary is passed to the secondary via the switching transformer after a switching system chops the input DC voltage. The secondary voltage is rectified by a diode, and the rectified voltage is smoothed by the capacitor. A feedback circuit is used to track the output voltage in a practical circuit, while a control circuit switches the system. A switching unit, such as a transistor, is typically switched on and off by a pulse-width-modulated signal in a typical application. When the transistor is turned on, current flows in the primary winding; however, the secondary diode is reverse biased, and current does not flow in this winding. The energy is retained in the transformer until the MOSFET is switched off, at which point it is released. The stored energy generates a current, which forward biases the diode, rectifying it and resulting in a DC output.

4.4.2 Advantages of Flyback Converter

- Capable of providing multiple output voltages, with the primary isolated from the output.
- Multiple output voltages can be controlled with a single control.

- Can deal with a number of input voltages
- In contrast to other types of SMPSs, Flyback Converters use very few components.

4.4.3 Applications of Flyback Converters

The flyback converter is used in a variety of electronic applications, including:

- Television sets that use a limited amount of electricity (up to 250W)
- Television sets that use a limited amount of electricity (up to 250W)
- High-voltage supplies in TV and Display CRTs, Lasers, Xenon flashlights, copiers.

4.5 ARDUINO UNO

The Microchip ATmega328P microcontroller and developed by Arduino. The board includes digital and analogue input/output (I/O) pins that can be used to connect to expansion boards (shields) and other circuits. The board has 14 digital I/O pins (six of which are capable of PWM output), 6 analogue I/O pins, and is programmable via a type B USB cable using the Arduino IDE (Integrated Development Environment). [Number four] It can be powered by a USB cable or an external 9-volt battery, with voltages varying from 7 to 20 volts. It's identical to the Arduino Nano and Leonardo microcontrollers. The hardware reference design is available on the Arduino website under a Creative Commons Attribution Share-Alike 2.5 license. In Italian, the word "uno" means "one," and it was chosen to signify the first release of Arduino Software. The Uno board was the first in a series of USB-based Arduino boards, and it, along with version 1.0 of the Arduino IDE, served as the reference version of Arduino until later updates. The ATmega328 on the board is pre-programmed with a boot loader, allowing new code to be uploaded without the use of an external hardware programmer.

While the Uno uses the original STK500 protocol, it does not use the FTDI USB-to-serial driver chip, unlike all previous boards.

4.5.1 General pin functions

- LED: A built-in LED is powered by digital pin 13. The LED is turned on when the pin has a high value, and it is turned off when the pin has a low value.
- VIN: When using an external power source, the Arduino board's input voltage (as opposed to 5 volts from the USB connection or other regulated power source). This pin may be used to supply voltage or to access voltage if it is supplied through the power jack.
- 5V: This pin receives a controlled 5V from the board's regulator. The DC power jack (7 - 20V), the USB connector (5V), or the board's VIN pin can all be used to power the board (7-20V), the USB connector (5V), or the VIN pin of the board (7-20V). Supplying voltage via the 5V or 3.3V pins bypasses the regulator, and can damage the board.
- Under software control (using pin Mode(), digital Write(), and digital Read() functions), each of the Uno's 14 digital pins and 6 analogue pins may be used as an input or output. They are powered by 5 volts. Each pin has a 20-50K ohm internal pull-up resistor (disconnected by default) and can provide or receive 20 mA as the recommended operating condition.
- To prevent permanent damage to the microcontroller, a limit of 40mA on any I/O pin must not be exceeded. The Uno has six analogue inputs, numbered A0 through A5, each with a resolution of 10 bits (i.e. 1024 different values). By default, they measure from ground to 5 volts, though it is possible to change the upper end of the range using the AREF pin and the analog Reference() function.[7]

In addition, some pins have specialized functions:

- Pins 0 (RX) and 1 (TX) of the serial / UART connector (TX). TTL serial data is received (RX) and transmitted (TX) using this unit. These pins are wired to the ATmega8U2 USB-to-TTL serial chip's corresponding pins.
- Pins 2 and 3 are used for external interrupts. On a low value, a rising or dropping side, or a shift in value, these pins can be programmed to cause an interrupt.
- Pins 3, 5, 6, 9, 10, and 11 are used for PWM (pulse-width modulation).

With the analogue Write() feature, you can get an 8-bit PWM output.

- Pins 10 (SS), 11 (MOSI), 12 (MISO), and 13 (SPI) (Serial Peripheral Interface) (SCK). The SPI library is used to communicate with these pins. TWI (two-wire interface) / I²C: pin SDA (A4) and pin SCL (A5). Support TWI communication using the Wirelibrary.
- AREF (analog reference): Reference voltage for the analog inputs.

4.5.2 Communication

A processor, another Arduino board, or other microcontrollers can all be communicated with using the Arduino Uno. On optical pins 0 (RX) and 1 (TX), the ATmega328 supports UART TTL (5V) serial communication (TX).

This serial communication is channeled over USB by an ATmega16U2 on the board, which appears to software on the device as a virtual com port. There is no need for an external driver because the 16U2 firmware uses normal USB COM drivers. On Windows, however, a.inf file is required. A serial monitor is included in the Arduino Program (IDE), allowing simple textual data to be sent to and from the board. As data is transmitted via the USB-to-serial chip and USB link to the device, the RX and TX LEDs on the board will flash (but not for serial communication on pins 0 and 1) any of the Uno's digital pins can be used for serial communication with the aid of a Software Serial library.

4.6 DRIVER CIRCUIT

Just tens of milliamps (milliamps) of current can be supplied by a standard digital logic output pin. Small external devices such as high-power LEDs, motors, speakers, light bulbs, buzzers, solenoids, and relays may require hundreds of milliamperes, even though they require the same voltage levels. Larger devices can require multiple amps. A transistor-based driver circuit can be used to raise the current to the levels needed for controlling smaller DC devices. When the voltage and current levels are within acceptable limits, the transistor functions as a high-current switch operated by a lower-current digital logic signal. In older or low-voltage circuits, a discrete BJT is often used instead of a newer MOSFET transistor, as shown below. Any GPIO pin on

the bed may be used as the logic control input to the Digital Out circuit. Special purpose driver ICs that can control several devices are now available as an alternative to discrete transistors. Internal transistor driver circuits similar to the one mentioned above are found in these ICs. The ULN2803 8-channel 500mA 50V driver, shown below, is still available in a DIP box that can be plugged into a breadboard, but most recent ones are surface mount ICs that will require a breakout board to use on a breadboard.

4.7 MATLAB

MATLAB is a software package for computation in engineering, science, and applied mathematics.

4.7.1 What is Simulink?

Mathworks Inc.'s Simulink (Simulation and Link) is a MATLAB extension. It integrates with MATLAB to provide graphical user interface (GUI) modelling, simulation, and analysis of dynamical systems. The creation of a model is made easier by using mouse click-and-drag operations. Simulink comes with a wide library of toolboxes for both linear and nonlinear analysis. Models are hierarchical, allowing top-down and bottom-up approaches to be used, Since Simulink is a part of MATLAB, it is simple to turn back and forth during the analysis process, allowing the user to take full advantage of both environments' functionality. This tutorial focuses on control systems and presents the basic features of Simulink. It was written for students in my control systems class.

4.7.2 The Role of Simulation in Design

Electrical power systems are made up of circuits and electromechanical devices such as motors and generators. Engineers in this field are continuously working to enhance the systems efficiency. Power system designers have been forced to use power electronic equipment and advanced control system principles to meet performance requirements, which puts conventional measurement methods and techniques to the test. The analyst's work is made even more complicated by the fact that the method is often so nonlinear that simulation is the only way to understand it.

4.8 SIMULATION RESULT

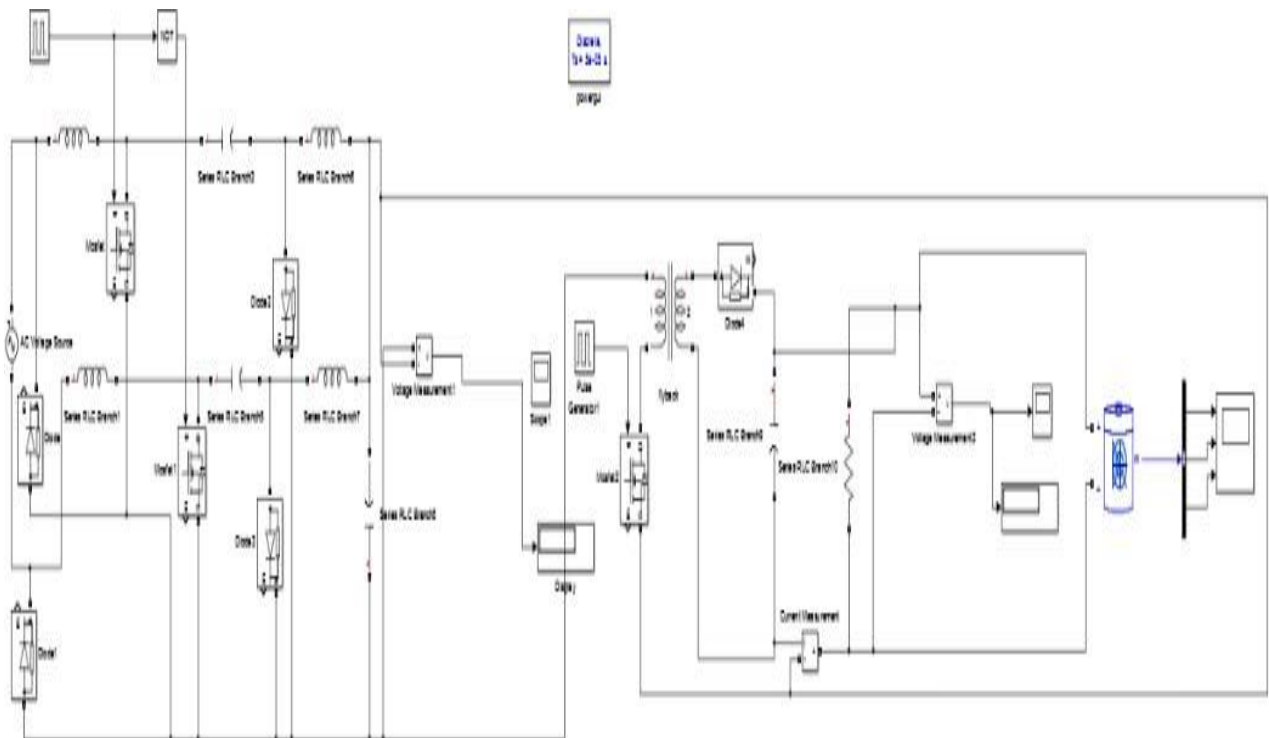


Fig:4.4 :Open loop simulation

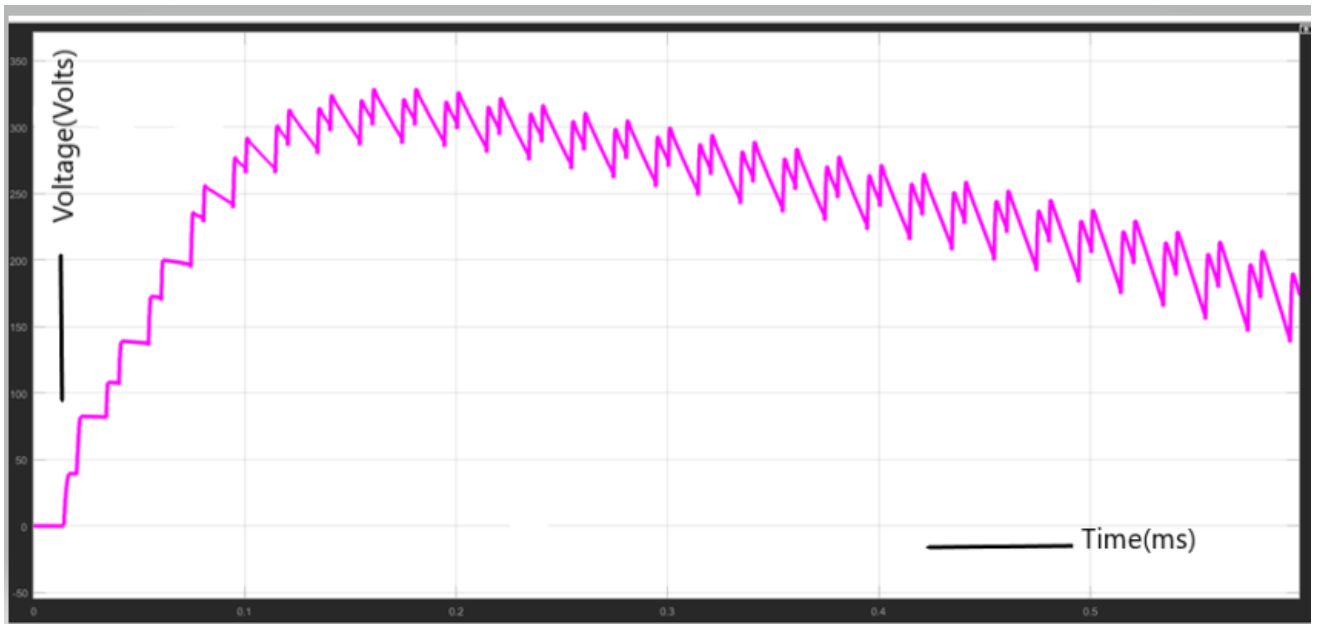


Fig:4.5:Output of the voltage CUK converter

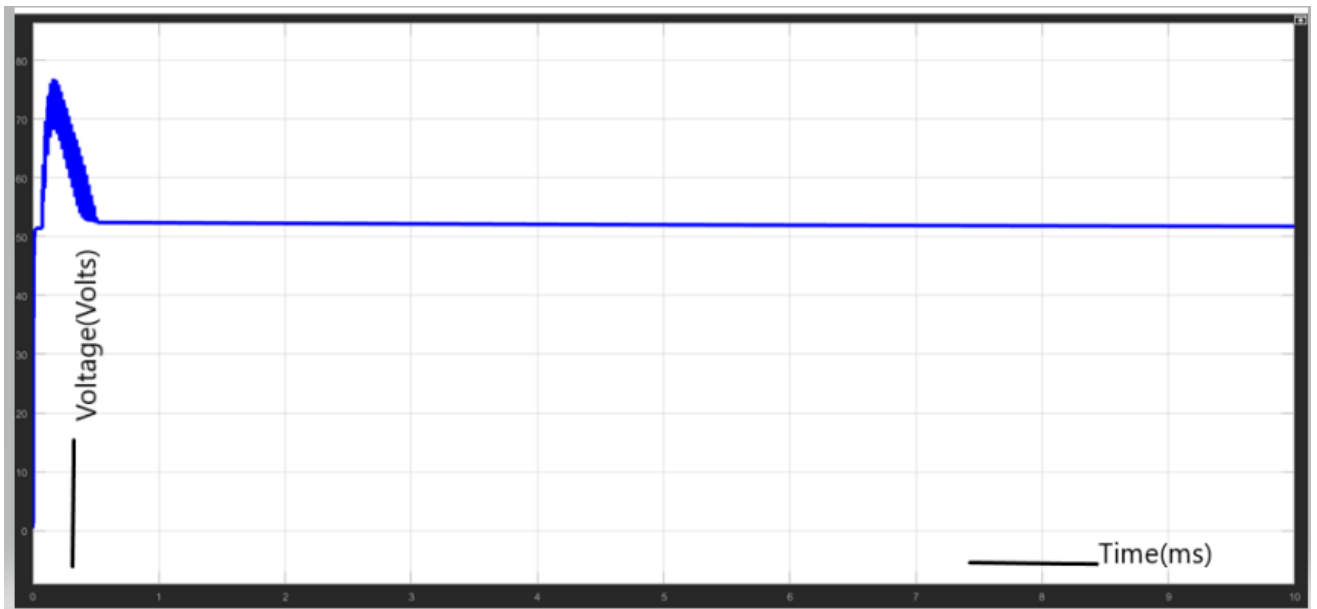
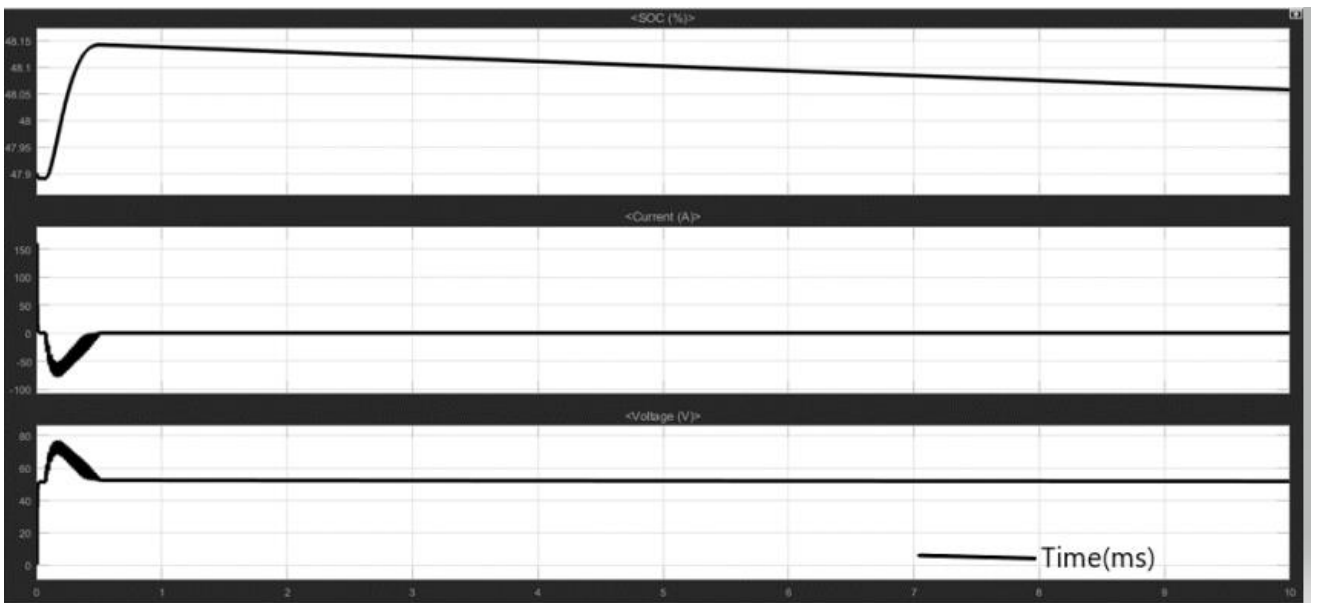


Fig:4.6:Output of the voltage Fly back Converter



Fig;4.7:State of charging (soc)

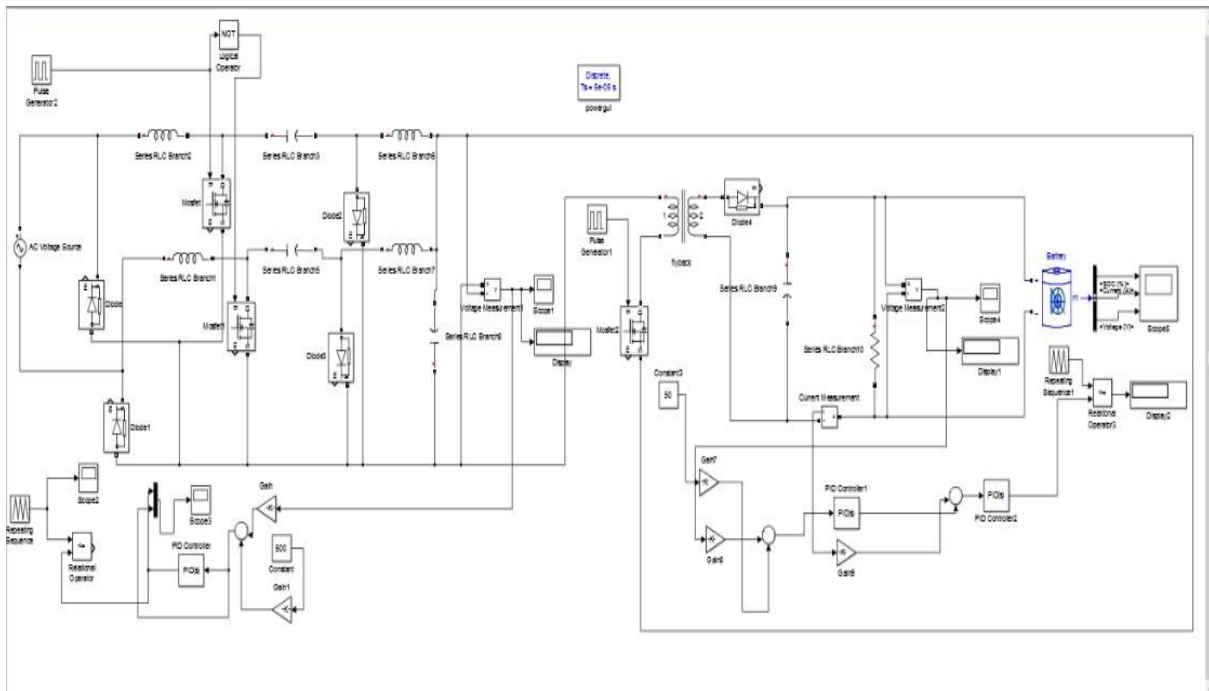


Fig:4.8:Closed loop simulation

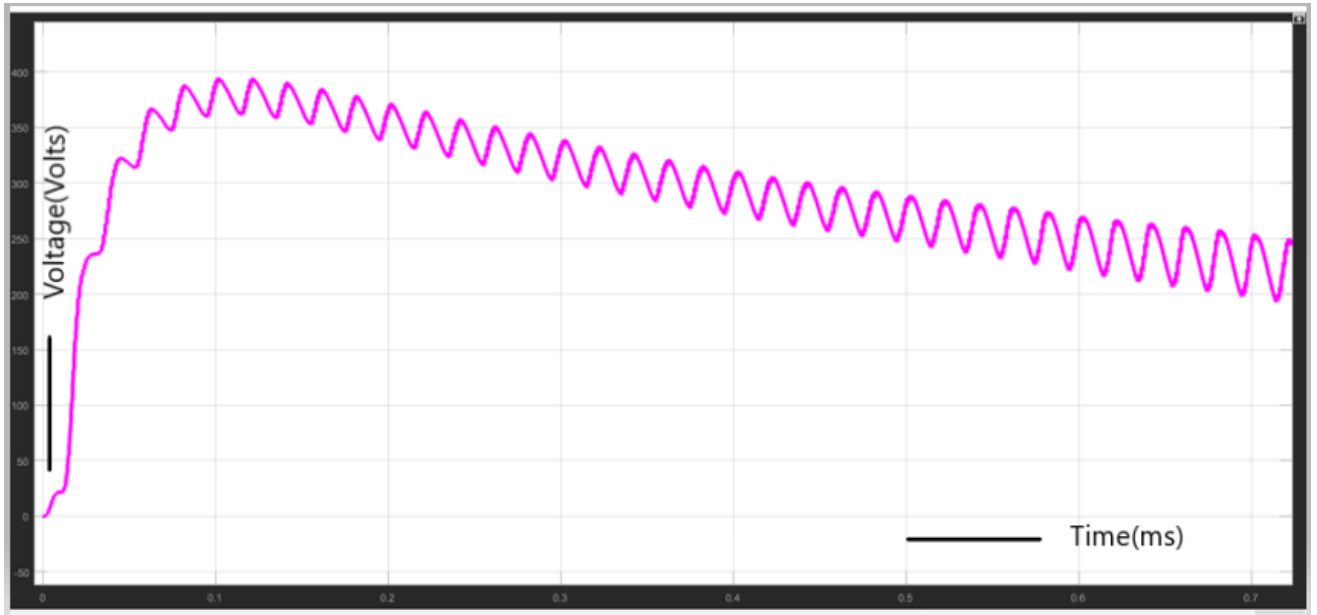


Fig:4.9:Output of the voltage CUK converter

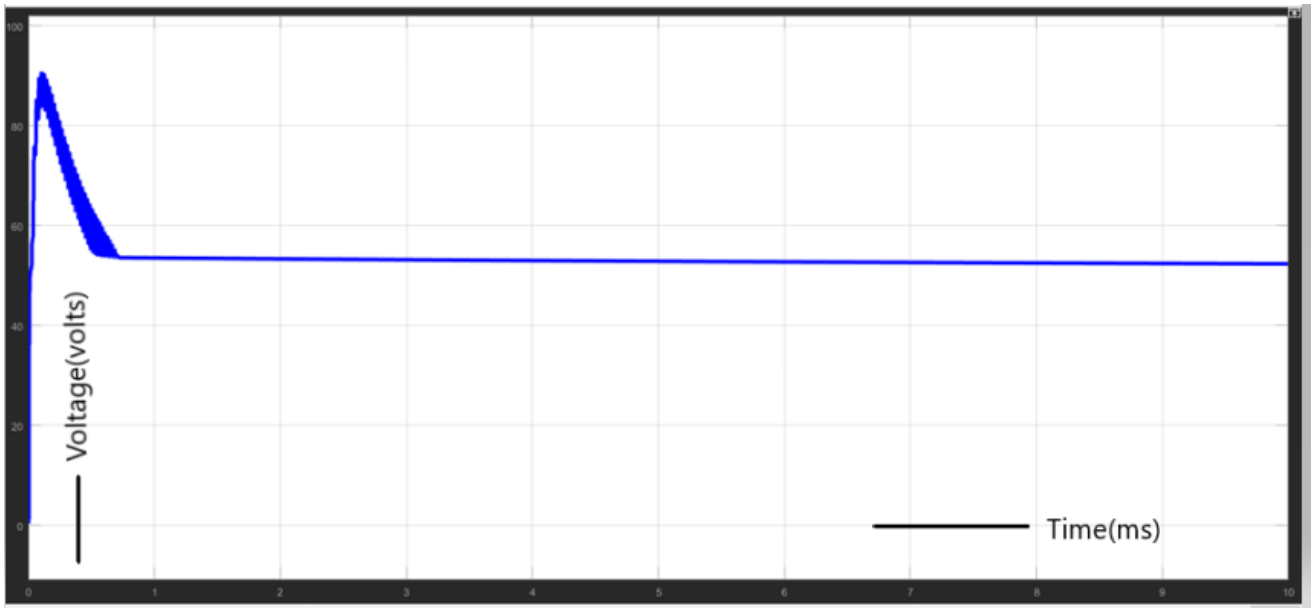


Fig:4.10: Output of the voltage Fly back Converter

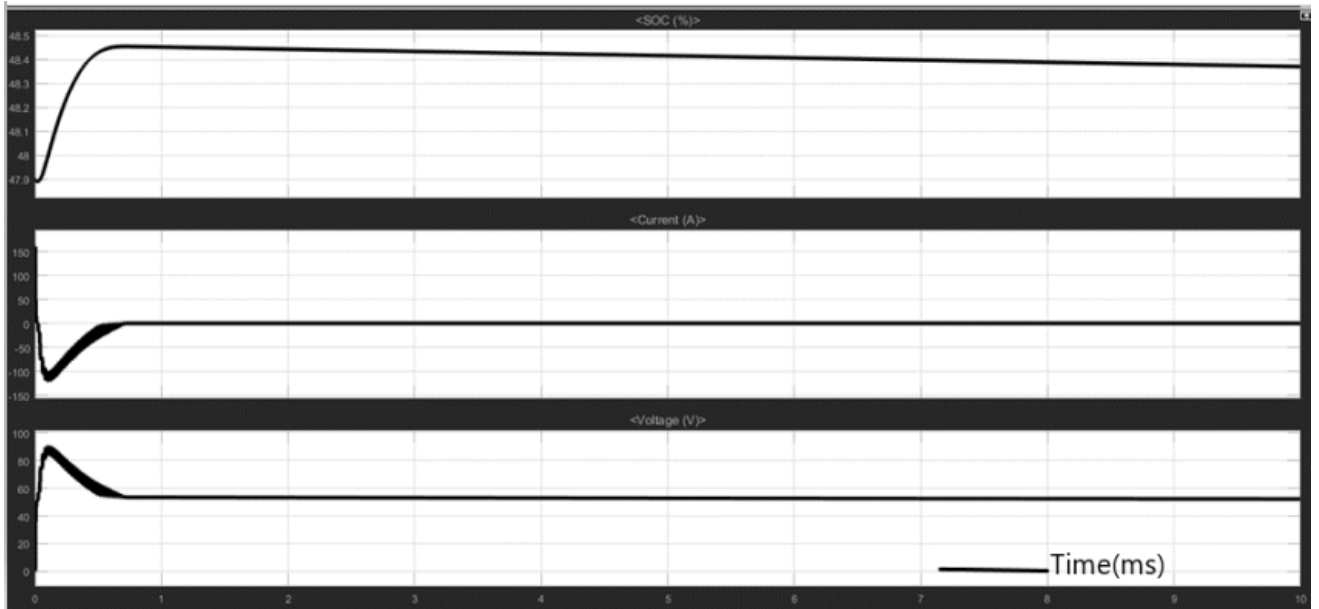


Fig:4.11 :State of charging (soc)

CHAPTER 5

CONCLUSION

With a BL CUK converter and less conducting components over a single switching period, an improved PQ-based EV charger is suggested. Using single voltage feedback power, the proposed PFC CUK converter provides excellent PFC characteristics in DCM mode. As a result, the charger's size is decreased. The proposed topology also eliminates the undesirable capacitive coupling loop, as well as unnecessary conduction through the body diode of the inactive switch in the previously formed BL CUK converter. This boosts the charger's performance greatly. During steady state and over 50% grid voltage variance, the proposed charger demonstrated satisfactory charging characteristics. However, the proposed charger's PQ is calculated using guidelines over a broad input voltage range. As a result, the proposed charger provides a viable EV charging option with improved power quality and performance.

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