Analysis and Design of DC- DC/AC Non Isolated Cuk Converter using Sliding Mode Controller

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***Abstract*—A DC-DC/AC Non isolated cuk converter is designed in this paper. This system comprises the centralized switching circuit, Non Isolated Cuk Converters, bidirectional port and battery. Renewable energy resources (Solar and Fuel cell) which are produced the DC outputs are given as inputs to this proposed system, whereas the output is either AC or DC without changing the structure of this system. This is done by proper pulses are given to the converter and inputs to the converters. It need not require additional devices like inverter, transformer and filter. Non Isolated cuk converter is used to improve the input voltage levels. The performance of this proposed system is analyzed by different controllers like Sliding Mode Controller (SMC) and Proportional Integral (PI) controller. Simulation results are shown that SMC provides good performance than PI controller. Moreover this derived controller is suitable for any changes at input voltage, it maintained constant load. MatLab/Simulation TM tool is used to perform this proposed system and the simulation outputs are viewed.**

***Index Terms*— Multi Input Converter, Sliding Mode Controller, Pulse Width Modulation, Multi Input Multi Output, Proportional Integral Controller, Proportional Integral derivative controller, Digital Signal Processor.**

I.INTRODUCTION

Now a day's renewable energy resources (Solar energy, Fuel cell, Wind energy) are used as input voltage sources of most of the electrical system. Multi input Multi Output (MIMO) is a most suitable system to use renewable energy resources absolutely. It can produce continuous output even if any one of the input voltage is interrupted. Previously this MIMO system developed a new topology is presented in [1].The Operating modes are analyzed by interfacing different type of voltage and current characteristics of input sources. Then, to get AC Output MIMO systems are used an inverter [2].Later Pulse Width modulation (PWM) Technique is used to control the output by feedback loop in [3-4].A frequency isolation transformer is used to regulate the output. Multiple Input Converter (MIC) is combined with either pulsating voltage source with PWM or Pulsating Current source with PWM to produce DC outputs. After that a new topology is used in multi input DC-AC converter for clean power energy system [6].It have been used to increase the voltage by converter and avoid the saturation of the transformer. Hybrid wind and photovoltaic system is designed using cuk and sepic converter in [7-8].This configuration is allowed the two sources to supply separately or simultaneously depends on the availability of energy source. A General design issues of DC-DC Converters using sliding mode controllers(SMC) is presented in [12].Parameter variation analysis and an optimized controller. A new approach for electronics converters based on energy shaping is presented in [13-14].To reduce the switching stresses a new structure is formed by using capacitor and diodes in [15].Using soft switching techniques the pulses of switches are controlled. To improve the transient response of fuel cell three port bidirectional converter and the modeling and control of Solar, Wind and battery is presented in [16-17] , the Bidirectional back up storage of fuel cell energy system is proposed in [18].Single Stage power conversion using renewable energy resources are presented in[19-20].Modeling of PWM DC-DC Converters using graft scheme and feasible topologies are presented in [21], [22]-[23]. A Novel topology with four port converter is presented in [24].It has three power path that can be provided by three ports, the forth port is left for unregulated to maintain the power balance of the entire system. Zero voltage Technique is used to control switches employed in these four ports.

In this paper inputs are given to the structure as DC voltages only. But the output is either DC or AC. The given DC inputs are fed to the Non- Isolated Cuk Converter which has connected at the centralized switching circuit in the middle part of the system. To control the action of switches, controllers like Proportional Integral Derivative controller (PID), Digital Signal Processor (DSP), PI and SMC are produced pulses. In this paper the performance of the proposed structure is analyzed with PI and SMC individually. To reduce the switching complexity in this proposed system controller is designed for converter1 only. The required pulses for converter2 are generated from converter1.The analyses are shown that SMC gives better performance than PI controller.

II. LITERATURE REIVIEW

Different Converter Topologies (DC-DC, DC-AC) and their performances are researched by many researchers. Some of them reviewed here.

978-1-4799-7075-9/15/$31.00 ©2015 IEEE

In 2006 Tao et al.[1] discussed about a family of multiport bidirectional DC–DC converters. This topology has combination of Dc link and magnetic coupling. This combination is used to control the power management of the system. In 2009 Yuan-Chuan Liu et al.[3] proposed a general approach for developing multi-input converters. In this topology, PWM converters' synthesizing an MIC is inspired by adding an extra pulsating voltage or current source to a PWM converter with appropriate connection.

In 2012, NeerajTiwari et al.[5] proposed a cuk converter for photovoltaic system which is controlled by Pulse Width Modulation (PWM) Technique. The cuk converter is most suitable to track Maximum Power. In 2013 S.S.Myley et al.[9]described about Sliding Mode Controller for boost converter. The performance of the boost controller is analyzed by with/without controllers. More over different controllers are designed for boost converter and their performance is compared with SMC. Boost converter is a second order system for higher order level, another converter topology is required.

In 2014 Saeed Danyali et al.[10] proposed a new extendable multi input DC to DC and DC to AC converter for boost converter. This paper consists, the single power switch of each unidirectional boost converter is controlled to regulate the dc power of its corresponding input source, while in the converter central part both upper and lower power switches of the bidirectional boost converters are complementary switched to produce their corresponding output reference voltages of converter. At the same time in 2014 P.NagalakshmiKanna et al.[11] proposed a topology of non invertedcuk converter which can produced DC or AC output from the DC inputs. The Bidirectional switching arrangement is used to provide the respective outputs.

III. Operation of Proposed System

The Block Diagram of Proposed DC-DC/AC Converter System is shown in figure1.It contains three input DC Sources(Solar Energy, Fuel Cell and Battery),two parallel Non Isolated Cuk Converters. In the middle part of this system bidirectional port is connected. This port is connected to the load as well as the centralized switching circuit.

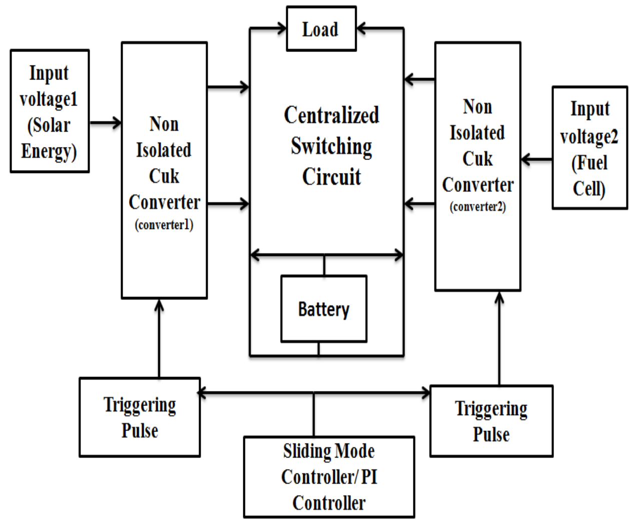

Fig.1:BlockDiagram of the Proposed DC-DC/AC Converter System

The Triggering pulses for the respective switches are generated from the controller. In this paper PI and SMC is designed separatelyfor providing pulses to the switches and the performance of the proposed structure is analyzed with these controllers using simulation results.

The Circuit Diagram of the proposed converter is shown in figure 2.Solar energy is given as input to the converter1 and fuel energy is given to the converter2.The Voltage from these two input sources are improved by the Non Isolated Cuk Converter. This converter is a Combination of Buck and Boost Converter [11]. In this system Battery is used for energy storage purpose when the input sources are more than the specified level and it is also give supply to the load when the input sources are not available during weather change.

The Input voltage sources are connected in parallel, hence the voltages across the converters are subtracting from each other and this voltage has appeared across the load. There are six switches are used in this system. Each Converter has only one switch and remaining four switches are connected to the centralized switching circuit. At the end of the converter has output filter arrangement, thus it need not require additional filter arrangement. By Proper pulses are given to the switches and (pure or biased DC sinusoidal) inputs to the converters this proposed structure has produced AC or DC Output.

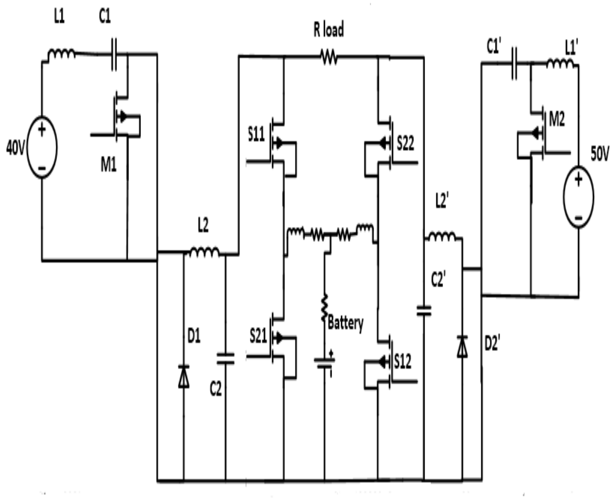

Fig:2 Circuit Diagram of the Proposed DC-DC/AC Converter system [11].

IV.Types Of Operating Mode

In this Paper there are two modes of Operations are discussed.

A.DC-DC Mode
B.DC-AC Mode

A. DC-DC Mode

In this mode the inputs for the converters are pure DC voltage form. The given input voltages are improved by the Non isolated Cuk Converter. The sources are connected in parallel, So that the voltage across the converters are subtracting with each other [10], then this voltage can be appeared across the load. Thus the input and output both are in DC mode[10-11].

$Vo_{dc}=Vc_1-Vc_2$ (1)

$Io_{dc}=(Vc_1-Vc_2)/R$ (2)

Vo_{dc} = Output Voltage across the load
Vc_1=Voltage across the Converter1
Vc_2=Voltage across the Converter2
Io_{dc} =Output current across the load
R= Resistive Load

B. DC-AC Mode

In this mode the two dc biased sinusoidal voltages are given as input to the converters. In addition to that pulses are given the converters are 180 degree phase shift. Like DC-DC mode the input voltages are improved by the proposed converters and the subtracting voltages of these converters are appeared across the load. This output voltage as in AC mode[10-11].

$Vc_1(t)=Vo_{dc}+Vm/_2\sin\omega t$ (3)

$Vc_2(t)=Vo_{dc}-Vm/_2\sin\omega t$ (4)

$Vo_{ac}=Vc_1(t)-Vc_2(t)$ (5)

$Vo_{ac}=Vm\sin\omega t$ (6)

$Io_{ac}=Im\sin\omega t$ (7)

$Im=Vm/R$ (8)

Vo_{ac}= Output Voltage across the load

Io_{ac} = Output current across the load

Vm=Peak value of converter voltage while giving biased dc input.

Im=Peak value of converter current while giving biased dc input.

R=Resistive Load

In this mode without need of an inverter arrangement AC output is produced from the DC input.

V. Control Techniques

Generally the switching pulses of converters are controlled by controllers. These controllers are maintained the constant output voltage and current across the load. Various control techniques are available such as Proportional Integral (PI)controller, Proportional Integral Derivative controller (PID),Sliding Mode Controller (SMC),Digital Signal Processor (DSP). In this paper PI and SMC are discussed.

A. Proportional Integral (PI) Controller

PI controller is one of the conventional controller techniques for DC-DC converters. Previously Proportional (P) controller is used to control the pulses and improve the performance of the system. But it cannot stabilize the higher order process.

Two control strategies proportional and integral are combined to get proportional integral (PI) controller. Its name suggests that PI controller output is equal to the summation of Proportional and Integral of the error signal. Proportional Integral (PI) controller can eliminate forced oscillation and steady state error. Due to lack of derivative term system becomes steadier in steady state operation, it is less responsive to real and fast changes in state.

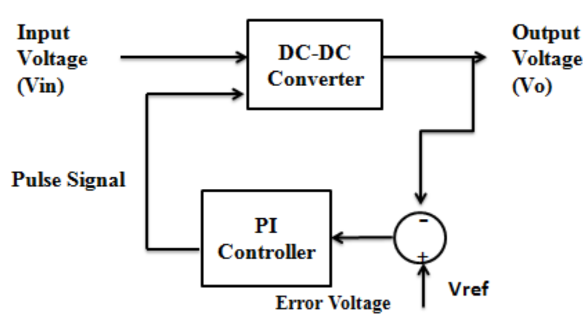

Fig.3 General Representation of PI Controller

The General representation of the PI Controller is shown in block diagram figure.3.In this controller the actual output voltage from the load is compared with the reference voltage.

Then the error voltage is evaluated. This error voltage is applied to the PI Controller. This controller compares the input and output voltage levels. Then the signal produced from the controller is compared with the carrier signal. Finally the switching pulses are generated from the controller is given to the respective switches.

Drawbacks of PI Controller:

a.)PI Controller has limited dynamic performance because it cannot react until the output voltage gets disturbed.

b.)It has maximum overshoot and high settling time.

B. Sliding Mode Controller (SMC)

In the formulation of any practical control problem, there will be always between the actual plants its mathematical model for the control design. These discrepancies (or mismatches) arise from unknown external disturbances, plant parameters and parasitic/ unbalanced dynamics. Designing the control laws that provide the desired performance of the closed-loop system in the presence of these disturbances/uncertainties is the very challenging task. This has led to intense in the development of the so-called control robust control methods which are supposed to solve this problem. One particular approach to the robust controller design is the so-called *sliding mode control (SMC) technique.*

Advantages of SMC:

- The main advantage of SMC is low sensitivity to load parameter variations and disturbances which eliminates the necessity of exact modeling.
- Robust Controller because behavior of the sliding mode depends on the sliding surface only and it is independent on the structural properties.

The Sliding Mode Control approach is recognized as one of the efficient tools to design robust controllers for complex high-order nonlinear system operating under uncertainty conditions.The converter switches are driven as a function of the instantaneous values of the state variables in a way that forces the system trajectory to stay on a suitable selected surface in the same space called the sliding surface. Usually the SMC is combined with two loops. One is inner current loop and another one is outer voltage loop.

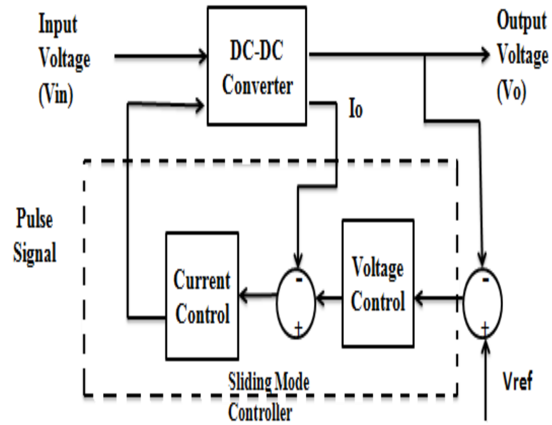

Fig.4 General Representation of SMC

The General representation of SMC is shown in block diagram in figure4.The output voltage is controlled by the voltage control block and the output current is controlled by the current control block. The combinations of these two blocks are known as SMC Controller. Then this controller gives pulses to the converter.

SMC is an established method to deal with uncertainty-inevitable in most practical system. However, any practical system, the input is always limited magnitude. Therefore it is necessary to consider this limitation a priori while designing the SMC.

VI.SIMULATION RESULTS

A. Simulation Block Diagram of Proposed System inDC-DC Mode

MatLab/Simulation Block Diagram of proposed system in DC-DC Mode is shown in figure.5.The input voltages are 40v &50v.The Resistive load R=50Ω.As per equation (1) and (2) the output voltage and the output current are produced.

The simulation block diagram of Non isolated cuk converter with R load for DC-DC Mode [11]is shown in figure.5. In this Mode the two parallel converters are increase the input voltages and then the output voltages across the converters fed to the load. If any one of the source is not available the battery source is used to balance the load requirement. Thus the load gets continuous supply.

The switching pulses and the load are controlled by the controller. In this paper the proposed structure is first performed with SMC and then PI controller for both DC-DC and DC-AC mode. For this analysis, in the simulation block diagram subsystem part is replaced by both the controllers. The subsystem arrangement of SMC and PI are shown in figure.6 and figure.7 respectively. By comparing these two controllers which one is suitable for proposed system is further evaluated.

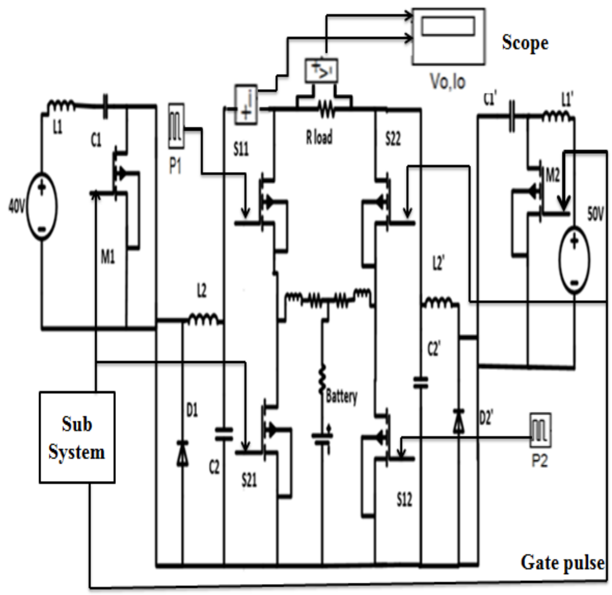

Fig.5 Simulation Block Diagram of Proposed System inDC-DCMode

Generally SMC has inner current control loop and outer voltage control loop [9],[15].The subsystem arrangement of SMC is shown in figure.6.To reduce the complexity, SMC is designed for one side of the converter. In this paper SMC is designed for Converter1.

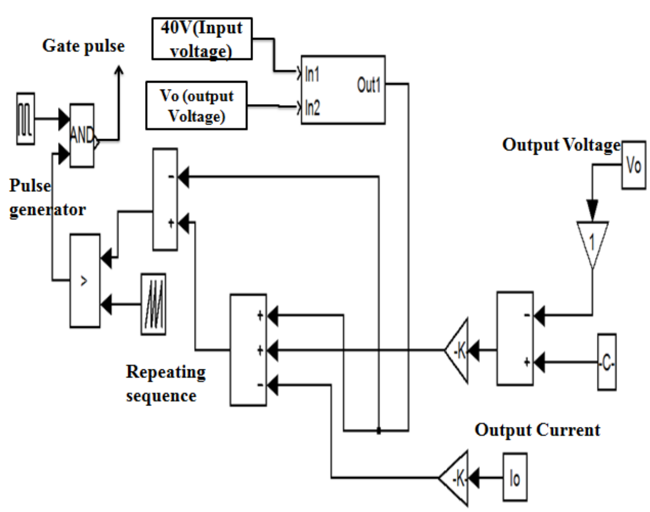

Fig.6Subsystem block diagram of SMC

The Output Voltage is compared with the reference value. Then the error voltage, output current are compared with the comparator which has converter1 input voltage and output load voltage. Finally the gate pulses are generated from this controller is supplied to the respective switches. The pulses for converter2 are getting signals from converter1.To analyze the performance of SMC, subsystem block diagram shown in figure.6 is replaced in Simulation block diagram of both DC-DC and DC-AC mode which are shown in figure.5 and figure.10.The simulation output results of proposed system using SMC are shown in figure.8 for DC-DC mode and figure.11 for DC-AC mode.

The subsystem arrangement of PI Controller is shown in figure.7.To reduce the complexity PI is designed for one side of the converter. The output voltage is compared with the reference signal. Then the error value is given to the PI controller.Then finally the generated pulses from the controller are given to the respective switches. The conversion process of DC-DC and DC-AC mode are similar to SMC.

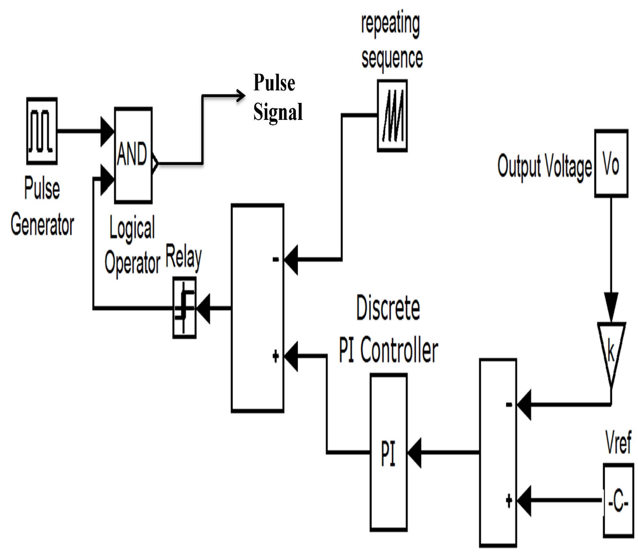

Fig.7 Subsystem block diagram of PI Controller

The simulation block diagram shown for DC-DC and DC-AC mode are shown in figure.5 and figure.10 respectively. To analyze the performance of PI controller the subsystem block is replaced by the PI controller arrangement which is shown in figure.7. The simulation results in DC-DC mode and DC-AC mode using PI controller are shown in figure. 9 and figure.12 respectively.

These two controllers (PI, SMC) are designed for this proposed system individually. Their simulation results are obtained using MatLab / Simulation TM and their comparisons are listed in Table I.

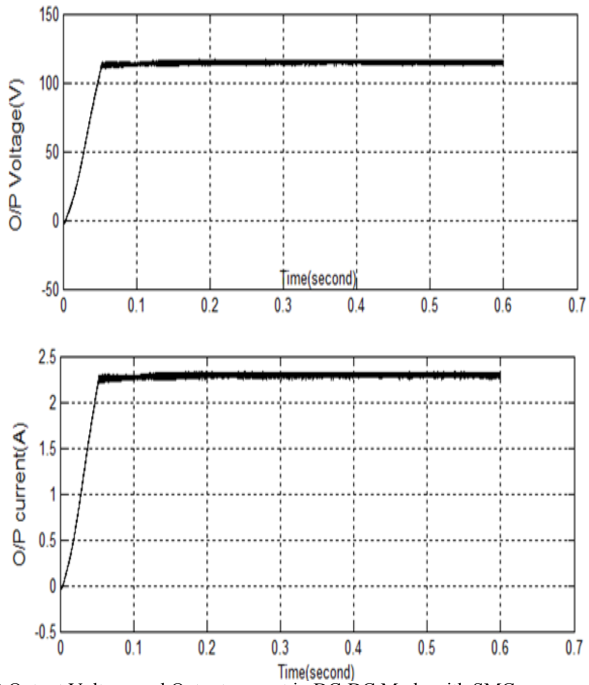

Fig.8 Output Voltage and Output current in DC-DC Mode with SMC

The Output Voltage and the Output Current in DC-DC Mode with SMC are shown in figure.8.The results have been produced by executing the simulation block diagram shown in figure.5 by applying input voltages are 40v and 50v and the Resistive Load is applied as50Ω.In this mode the subsystem block in figure.5 is replaced by SMC which is shown in figure.6

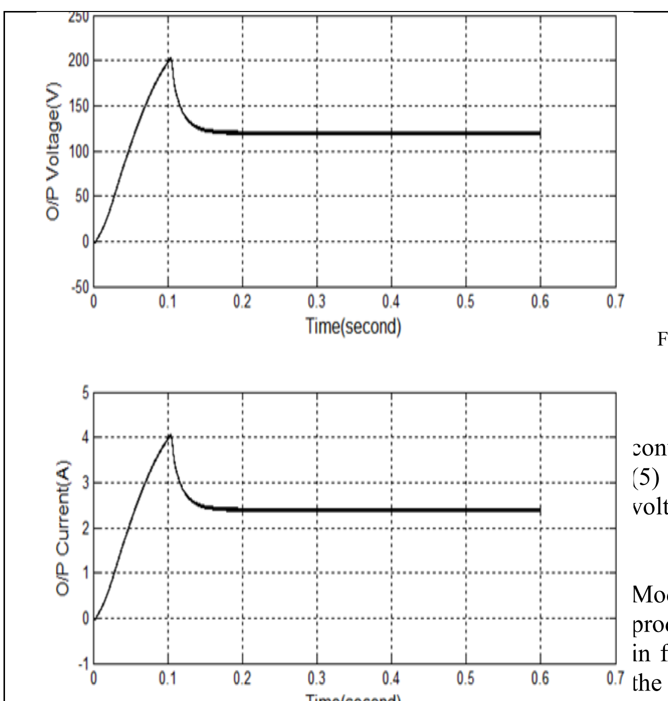

Fig.9Output Voltage and Output current in DC-DC Mode with PI

The Output Voltage and the Output Current in DC-DC Mode with PI are shown in figure.9.The results have been produced by executing the circuit diagram shown in figure.5by applying input voltages are 40v and 50v and the Resistive Load is applied as 50Ω.In this mode the subsystem block in figure.5 is replaced by PI controller arrangement which is shown in figure.7

B. Simulation Block Diagram Of Proposed System inDC-AC Mode

MatLab/Simulation TM Block Diagram of proposed system in DC-AC Mode is shown in figure 10.The Controller is designed for DC-DC Converter (Non Isolated Cuk converter) so that it gives DC output at the load side. For providing AC outputs the output voltage is rectified using rectifier. Then this voltage is given to the subsystem arrangement. In this DC-AC Mode the inputs are given as Dc biased sinusoidal inputs.

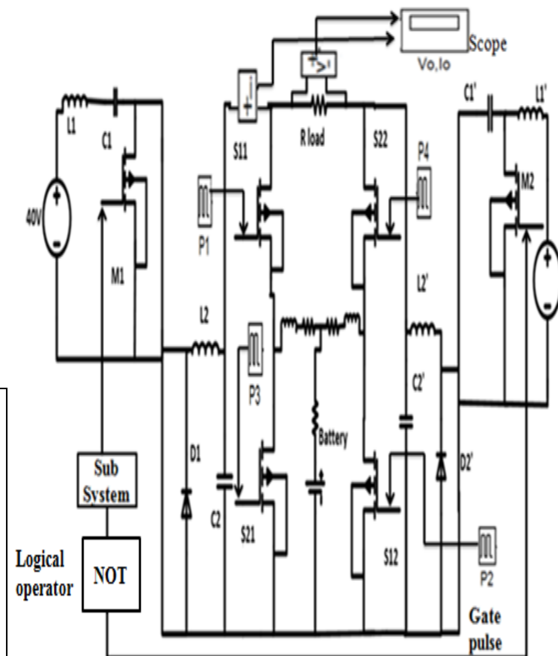

Fig.10 Simulation Block Diagram of Proposed System in DC-AC Mode

In this mode the switching pulses are given to the parallel converter in 180 degree phase shift. According to the equation (5) and (7) this proposed system is produced AC Output voltage and current.

The Output Voltage and the Output Current in DC-AC Mode with SMC are shown in figure.11.The results have been produced by executing the simulation block diagramis shown in figure.10 by applying input voltages are 40v and 50v and the Resistive Load is applied as 50Ω.In this mode the subsystem block in figure.10 is replaced by SMC which is shown in figure.6

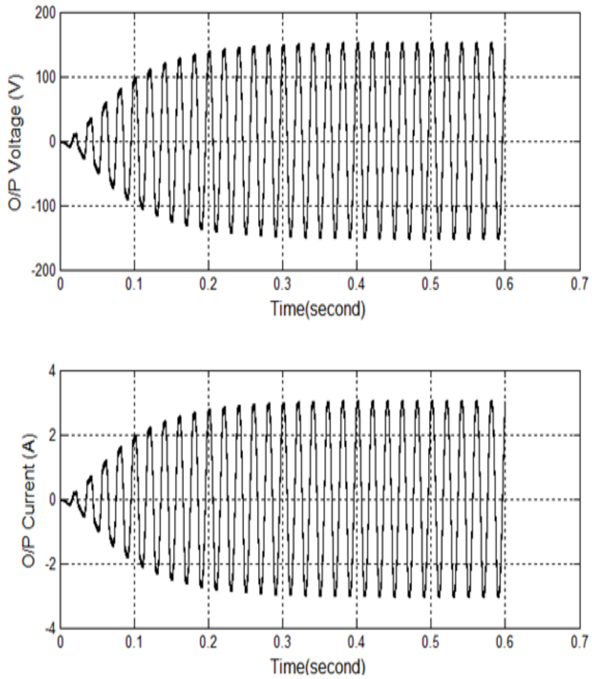

Fig.11 Output Voltage and Output current in DC-DC Mode with SMC

The Output Voltage and the Output Current in DC-AC Mode with PI are shown in figure.12.The results have been produced by executing the circuit diagram shown in figure.10 by applying input voltages as 40v and 50v are the Resistive Load is applied as 50Ω.In this mode the subsystem block in figure.10 is replaced by PI controller arrangement which is shown in figure.7.

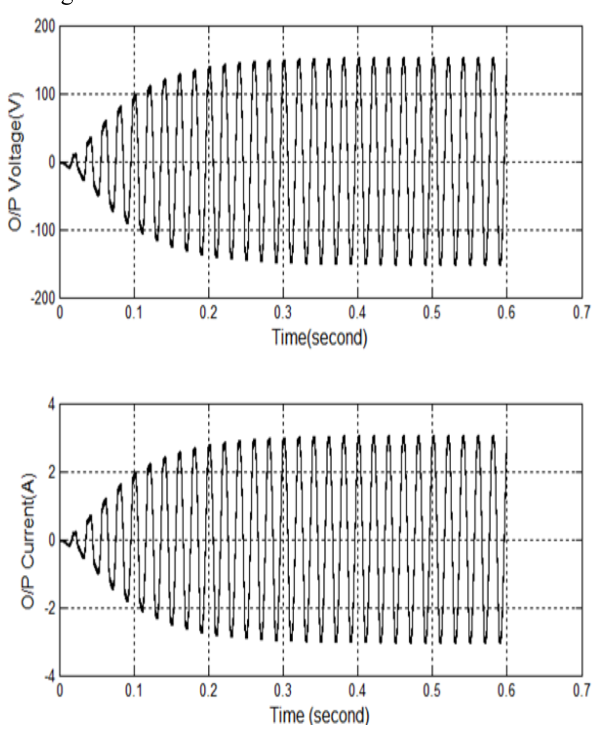

Fig.12 Output Voltage and Output current in DC-DC Mode with PI

VII.COMPARISON BETWEEN SMCANDPI CONTROLLER

A comparison between Sliding Mode Controller and PI Controller are to be evaluated under input voltage variation. Both the controllers are suitable for the proposed system but the difference is the PI controller has more voltage drop than the Sliding Mode Controller and the settling period of PI is Lower than the SMC and the non linearity of the converter is improved by the SMC than PI. To test the robustness of the SMC the input voltage is varied from 40V to 45V in the converter1 part and 50v to 60v in the converter2 part the output voltage and output current are maintained constant. The output voltage ,current and settling period is listed for PI and SMCin Table.I.

TABLE.I
PARAMETER EVALUATIONOF DC-DC AND DC-AC MODE
Input Voltage=40v & 50V, Resistive Load=50Ω

System Para Meters	**Controllers**			
	PI		SMC	
	DC-DC Mode	DC-AC Mode	DC-DC Mode	DC-AC Mode
Output voltage	119V	150V	118.6V	150V
Output Current	2.3A	3A	2.28A	3A
Settling period	0.18sec	0.34sec	0.1sec	0.28sec

In DC-DC Mode the output voltage and the output current for PI controller is 119V and 2.3 A and the Settling period is 0.18 secwhere as the SMC produced the output voltage and current is 118.6V, 2.28A and settling period is 0.1sec.

In DC-AC Mode the output voltage and current for PI controller is 150V and 3A, settling period is 0.34sec.For SMC the output voltage and current is 150V& 3A, settling period is 0.28sec.

From this analysis Table. I explained that both the controllers produced approximately same outputs but the PI has high settling period, so that PWM based SMC is shows that acceptable performance than the PI Controller. Mostly DC-DC Converters (Buck ,Boost ,Buck-Boost and Cuk) has non linear components. These components are affect the steady state performance of the system. Non Linearity of the proposed system can be improved by the Sliding Mode Controller than other controllers.

VIII.CONCLUSION

In DC-DC/AC Non isolated Cuk Converter system can produce the DC output or AC Output without changing the structure of the system. By giving proper pulses are given to the switches and inputs it can produced the outputs. Non Isolated cuk converter is a combination of buck and boost converter which can produced the output voltage is either lesser than or greater than input voltage. In the output side of Non isolated cuk converter has output filter arrangement itself. Thus it need not require extra filter arrangement. Even the input Voltages are varied the load maintained constant output. For wide range of load variation SMC has more stable than the PI Controller. Moreover SMC can be improved by non linearity. SMC has more advantages than other controllers: Robust, Simple Implementation. In Future this proposed system will be implemented in hardware with more than three inputs and further analysis will be made.

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