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A dual input buck converter with one cycle control for efficient utilization of solar power

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Abstract--- **Renewable energy sources such as photovoltaic (PV) solar energy and wind energy rely heavily on the climate and weather conditions. As a consequence, the available power is intermittent and stochastic. So, multiple renewable energy sources that are mutually complementary could be combined to maintain continuous power delivery to the load. Such a system is referred to as a hybrid power system. In hybrid power systems, the use of a MIC instead of several single-input converters has a simpler circuit and lower cost. However, the MIC is a typical multiple-input multiple-output coupling system and has many operating modes under the power management strategy, so the closed-loop design is complicated. This work proposed and evaluated a new power circuit that can deal with the problem of the intermittent nature and slow response of the renewable energy. The proposed circuit integrates different renewable energy sources with energy storage devices .This paper explains an one cycle control method for MIC which is simpler compared to other control methods. The working of OCC is explained in details. It is seen that with OCC, no current regulator is required, and the design conditions of the output voltage regulator in different operating modes are the same. Thus, control design is simple.**

Ke*ywords---One cycle control, double input buck converter, renewable energy sources, multiple input converters*

I. INTRODUCTION

In recent years, there has been lot of developments by renewable energy. While considerable improvement on renewable energy has been made, there are some inherent limitations for these renewable energies. For example for solar and wind power there is an intermittent nature. This will not be acceptable for modern electric application, which requires constant voltage of constant frequency.

The proposed circuit utilizes renewable energy. Also this circuit integrates renewable energy source as well as commercial ac grid. Multiple renewable energy sources that are mutually complementary could be combined to maintain continuous power delivery to the load. This system is known as hybrid power system. By integrating renewable energy sources with statistical tendency to compensate each other, the effect of intermittent can be greatly reduced. This integration will increase the reliability and utilization of the overall system. A number of independent converters can be used to interface hybrid power system [1]-[2].In this case, there are many input sources. So the losses in the circuit are high. Also the cost is high. Recently, multiple input converter (MIC),have received increased attention, and they are replacing several single input converters in order to reduce the cost and complexity of the system [3]-[4].[5] paper proposes converter topology that interfaces four power ports. This converter is derived by simply adding two switches and two diodes to the traditional half bridge topology. Topology promises significant savings in component count and losses for renewable energy power harvesting system.MIC constructed of a multiwinding transformer based on half bridge or full bridge topologies. They can meet the isolation requirement and also have bidirectional capabilities. MIC's major problem is that they use too many active switches, in addition to the bulky transformer which cannot justify the unique feature of low component count and compact structure for the integrated multi port converter.

There are many control method is used before one cycle control. [6] uses the supervisory control strategies. In that, three modes of operation are explained. The control parts consist of MPPT control, Wind turbine control, battery control and grid inverter control. All these control methods are controlled using a supervisory control. Hence the system is more complicated.

Decoupling matrix is another effective method for control the parameters. Decoupling matrix reduces the original transfer function matrix into a diagonal matrix. As a result the coupling loops can be treated as a number of single input single output control loops and their regulators can be designed independently. Due to the fact that decoupling matrix highly depends on the original transfer function matrix which is determined by topology of MIC and controlled variables. So different decoupling matrix have to be introduced when the MIC operates under several operating modes [7]. Moreover the parameters of original TF will vary with input voltages and load even in the same operating modes [8]-[9]. So the parameters of the decoupling matrix must be tuned accordingly. Thus the implementation is quite difficult.

Previously mentioned methods are based on linear feedback. So they need both voltage and current regulators. Here the control method used is one cycle control (OCC). In the first mentioned control the input or load change is first identified, sensed and corrected using a regulator. So that is a slow response process. OCC is a non linear technique. The average value of the switched variable can follow its control reference within one switching cycle. This concept is known as one cycle control [10]. Moreover the one cycle control concept solves the problem of slow dynamic response of renewable energy. The advantage of OCC is that regulator is not required [11].It has been widely applied in dc-dc conversion [12], power amplifier [13]. The objective of this paper is to employ the OCC for dual input buck converter to improve dynamic response and reject disturbance in input sources.

Section II illustrates the power circuit and section III explains the modes of operation. The simulation results are presented in section IV. Finally, conclusions are given in section V.

II.CIRCUIT TOPOLOGY

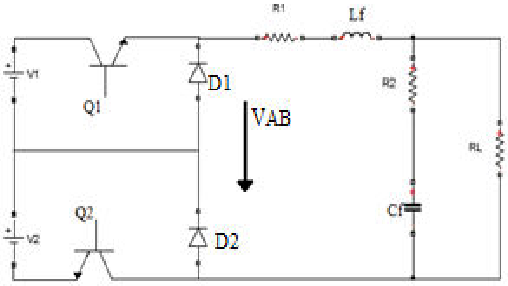

Fig1.Dual input buck converter

Fig 1 explains the basic of dual input buck (DIBC) converter. Here two input sources are V_1 and V_2. Q_1 and Q_2 are the switches; D1 and D_2 are freewheeling diodes. L_f and C_f are the filter inductor and capacitor. Two input sources of DIBC can deliver energy to the load simultaneously or individually. Suppose the losses are neglected then according to Fig 1,

$$V_0= V_{AB}= D_{y1}V_1+D_{y2}V_2 \tag{1}$$

$$I_1= D_{y1}\ I_L \tag{2}$$

$$I_2= D_{y2}\ I_L \tag{3}$$

D_{y1} and D_{y2} are two duty cycles, I_L is the average inductor current, Vo is the output voltages. Because there are two duty cycles, besides the output voltage another variable could be regulated. This gives the possibility of the power management. For example in this paper, the PV-commercial ac grid system, solar energy is a renewable energy that serves as the main power source, while commercial grid is a backup power source. The objective of power management is that the demanded power of the load should be provided by PV array as much as possible and the rest are provided by the commercial grid.

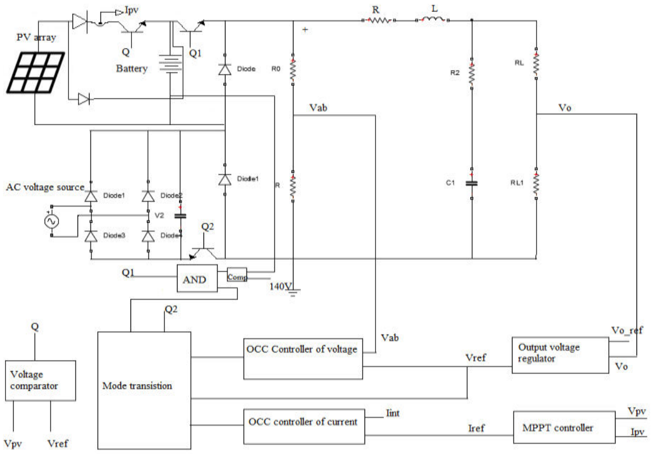

Fig.2.Block diagram of the proposed system

Fig.2.shows the block diagram of proposed system. It consists of two inputs, one is PV array and the other one is commercial grid. The solar power is stored in the battery when the solar power is higher than the demanded load power. The main objective of the circuit is that the demanded power of the load must be satisfied from PV array as much as possible and the rest is taken from the second source. Suppose that the demanded load power is P_0 and the available power of input source 1 is P_{1max}, two operating modes of DIBC are defined as follows:

Operating mode 1: When $P_{1max} > P_0$, that means the solar power is higher than the demanded load power. So the load power is provided by solar panel. In this case the switch Q_1 is turned on and Q_2 is shutdown completely. Also the solar panel charges the battery through the buck converter switching circuitry. This implies that PV array regulates the output voltage, which indicates that the one cycle control of V_{AB} takes the control of switch Q_1.

Operating mode 2: When $P_{1max} < P_0$, the load power is provided by solar panel and the commercial grid. In this case, the battery starts to discharge when the load power is higher than the solar power. So in this case the load power is satisfied by using the stored renewable energy from battery as much as possible and the rest are provided by the commercial grid.

Here the battery voltage is also measured. When battery reaches its lower limit that is below 140V then the switch Q1 is turned off through the AND gate output. Hence the circuit is safe from other hazards.

III.MODES OF OPERATION

According to the power management and the operating modes defined previously the implementation of the OCC for DIBC is given below.

A. Mode 1

In operating mode 1 the solar power is higher than the demanded load power. When the solar power is higher than the output power the gate pulses for the battery becomes high. So the battery starts to charge through a buck converter circuitry. At the same time solar panel provides the output power. So the switch Q_1 is turned on and Q_2 is turned off. From equation (1) it is clear that the output power depends on the two duty ratios, D_{y1}, D_{y2}. From equation (2) and (3), I_1 can be controlled by D_{y1} and D_{y2} is used to regulate the output voltage. But here Dy2 is zero, since the switch Q2 is turned off. It indicates that the OCC controller of V_{AB} takes the control of switch $Q_{1.}$ So that the output voltage is calculated from the solar panel voltage.

Fig.3 shows the OCC controller in mode I. It consists of an inverter, integrator, comparator, reset switch and an RS flip flop. As in Fig 1, the average value of the voltage V_{AB} is equal to the output voltage if the voltage drop of the filter is neglected. The output voltage Vo is not the actual average value of V_{AB} due to voltage across the filter, so a voltage regulator is needed. As V_{AB} is determined by both the duty ratios, If V_{AB} is only integrated when switch Q_1 is conducting, the integral value does not represent the average value of $V_{AB.}$ So it is necessary to activate the integration immediately after the integrator being reset.

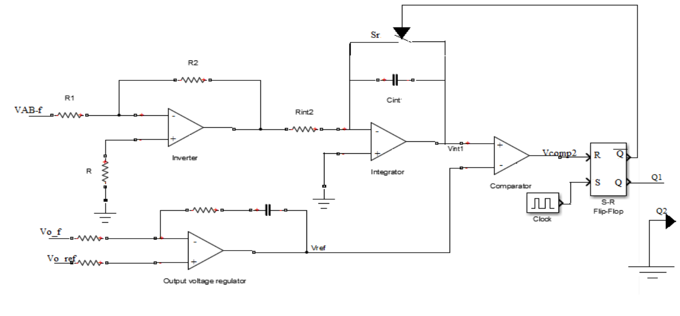

Fig.3.OCC controller in mode 1

The constant frequency clock turns on Q_1 at the beginning of each switching cycle. The integrator is activated at the turn off instant of the switch in previous cycle. When integral value reaches the control value comparator changes its state and turns Q_1 off. The integrator is rest to zero at the same time since the reset signal is a pulse with very short width.

$$(V_{AB})_{Ts}=1/Ts \int V_{AB}(t)\, dt = k_v v_{ref} \qquad (4)$$

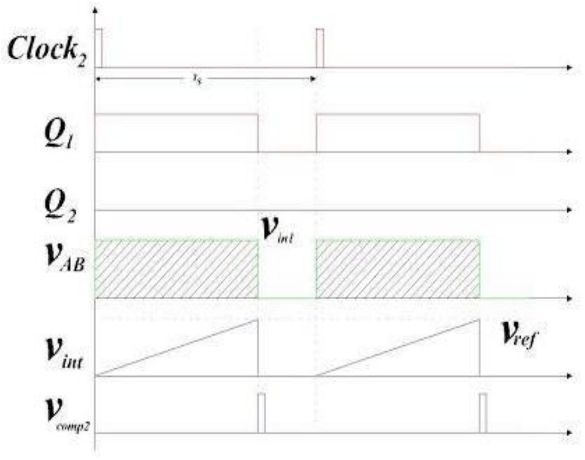

Fig.4.Waveform of OCC controllers in mode I

Equation 4 indicates that the average value of the average value of V_{AB} exactly follows its control reference in a switching cycle. Specifically; it rejects perturbations from its input sources and load side. The output voltage Vo is not the actual average value of V_{AB} due to the voltage drop across the filter inductor, so a voltage regulator is necessary to guarantee well-regulated output voltage. The voltage reference of this regulator is V_{o_ref} and its output Vref serves as the reference for the OCC controller of V_{AB} . The waveforms are given in Fig.4.

B.Mode II

In operating mode II, the output power is higher than the solar power. So the demanded load power is provided by stored energy and the commercial grid source. So both the switches are ON. In this case battery starts to discharge. Here more power is drawn from the battery and the remaining part is taken from the commercial grid. So that more renewable energy is utilized.

In operating mode II, two duty cycles of the DIBC are used to regulate solar panel current and output voltage. Equations (2) & (3) implies I_1 can only be controlled by $D_{y1.}$So D_{y2} is used to regulate the output voltage. The control circuit and waveforms are shown in Fig.5 & 6.

1) OCC controller of I_1:Fig 8, consists of inverter, integrator, comparator, RS Flip-flop and a rest switch. The sensed solar current is given to inverter. A constant frequency clock turns on the Q_1 at the beginning of each switching cycle and activates the integrator simultaneously.

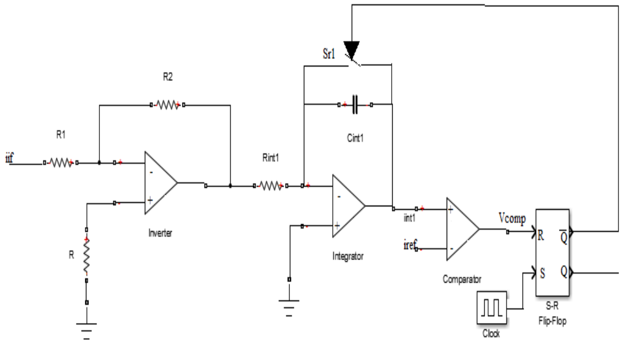

Fig.5.OCC controller in mode II, OCC controller of I_1

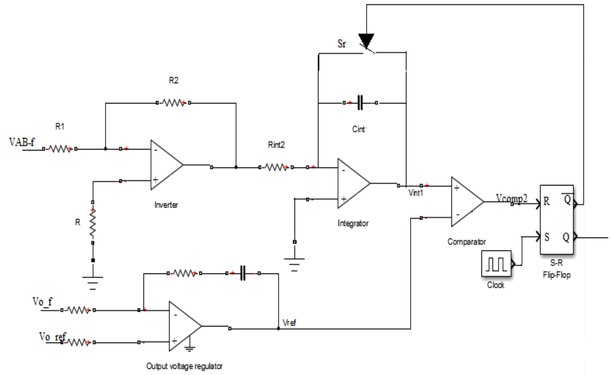

Fig.6.OCC controller in mode II, OCC controller of V_{AB}

When the integral value grows from zero and reaches the reference value the comparator changes its state and resets the RS FF and turns Q_1 off. S_{r1} is turned on at the same time and kept on until the next clock comes. The average value of I_1 in one switching cycle is

$$(I_1)_{Ts}=1/Ts \int i_L\,(t)\,dt = k_i\, i_{\mathrm{ref}} \tag{5}$$

Equation (5) indicates that the average value of I_1 exactly follows the reference value I_{ref} in a switching cycle. The current reference I_{ref} is obtained from the MPPT controller. P and O method is used in the MPPT controller.

2) OCC controller of V_{AB} : This is same as in the mode I except that the switch Q2 controlled by OCC controller of $V_{AB.}$

C. Mode transition

Here there are two different switches which are controlled by different one cycle controllers in different modes of operation. So a mode transition circuit is needed. So one of the simplest methods is to add Schmitt trigger and a multiplexer as in Figure: 7.When the enable signal is high, $A_0=A_Y$,$B_0=B_Y$. So the switch Q_1 is controlled by OCC controller of V_{AB} and Q_2 is shutdown completely.

When enable switch is low, $A_0=A_X$, $B_0=B_X$. In that case Q_1 is controlled by OCC controller of I_1 and Q_2 is controlled by OCC controller of V_{AB}. When $P_{1max} < P_0$ the DIBC is operated in mode II. If the available power of solar increase or load current reduces suddenly, which leads to $P_{1max} > P_0$, the output voltage will increase, and thus the output of voltage regulator V_{ref} will keep on reducing until the DIBC is switched to mode I. By sending V_{ref} to a Schmitt trigger enable signal is obtained. So changing from mode II to mode I enable becoming high.

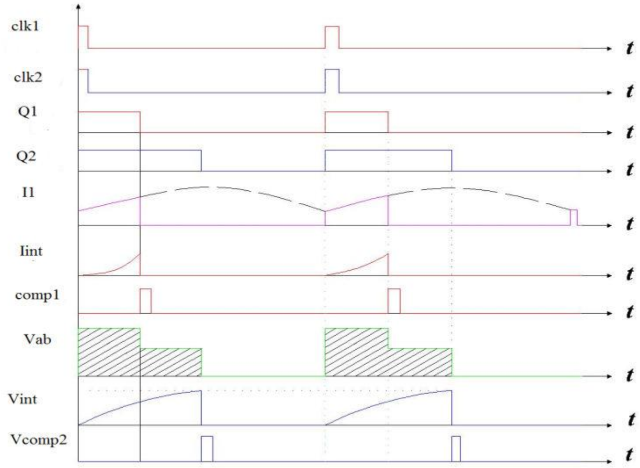

Fig.7.Waveform of OCC controllers in mode II

Similarly, when P1max >Po, the DIBC is operated in mode I, If the available power of the solar panel is reduced or load current increases, which makes P1max< Po, the output voltage will keep on reducing, and thus the output of the voltage regulator V_{ref} will keep on increasing until it changed to mode I. So changing from mode I to mode II enable switch become low.

IV. SIMULATION RESULTS

The specifications of simulation circuit:
1. PV array are formed using series connected solar panels with short circuit current 5A, open circuit voltage 350V,and maximum output power of 950W, voltage varied between zero to 350V.
2. AC commercial grid 220V/50Hz commercial grid.
3. Output voltage: 180 V
4. Output power: 800W
5. Switching frequency: 100 KHz
6. Battery: 200V lead acid battery.

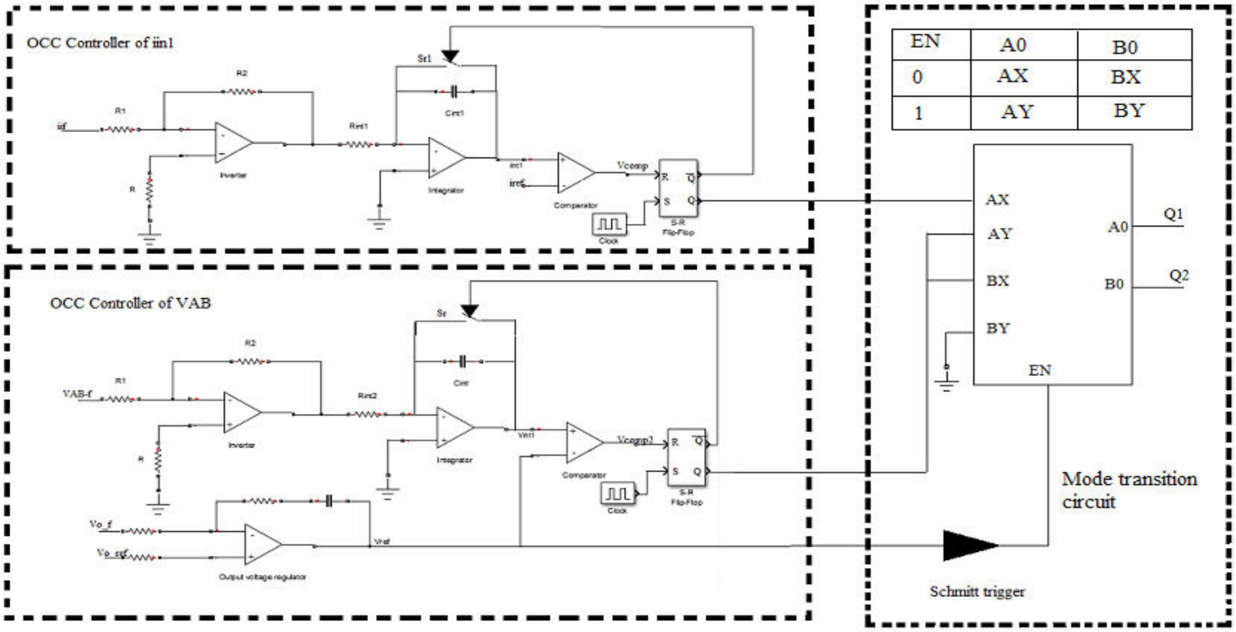

Fig 7. Different operating mode

Fig 8 is the simulation circuit. It consists of solar panel, storage battery and a commercial grid. Each of the circuit is made in different subsystem. Fig 9-10 are different subsystems that included in the main simulation part.OCC controller of I_1 is shown in Fig 9 and fig 10 contains OCC controller of V_{AB} .

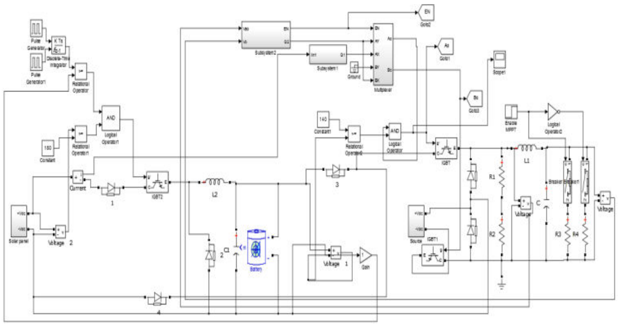

Fig.8.Simulation circuit

Both the subsystem consist of inverter, integrator, comparator, RS FF and a rest switch. Unlike an additional voltage regulator is given in Fig 10. Voltage regulator compares the desired output with actual output, and this output is V_{ref} which is an input of comparator.

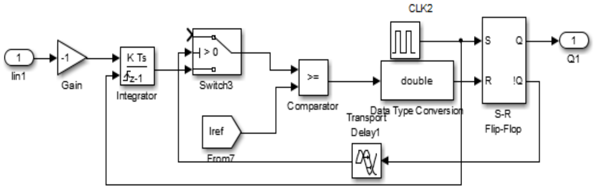

Fig.9. OCC controller of I_1

At the same time this reference value determines the modes of operation. This mode transition circuit is included in Fig 11.According to the values of enable switch the mode is changed from mode I and mode II.

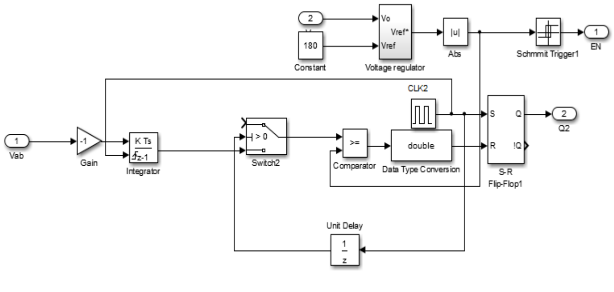

Fig.10.OCC controller of V_{AB}

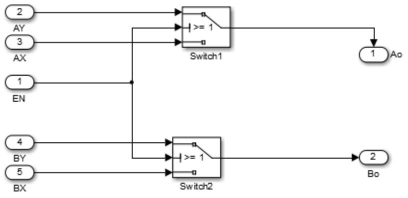

Fig.11..Mode transition

In mode I, Q_1 is on and Q_2 is off. Here the Q_1 switch is controlled by V_{AB}. So when the V_{int} value reaches the reference value comparator changes its output. Here according to the V_{int} Q_1 is turned on and off. This is shown in Fig 12.

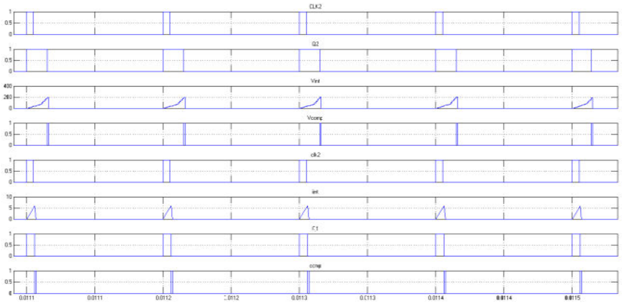

Fig 12. mode I gate pulses

In mode II Q_1 and Q_2 are on. Here when the integrated value reaches the control reference value it comparator changes its state, which is indicated by V_{comp} So Q_2 is controlled by V_{AB} and Q_1 is controlled by I_1 .This is indicated in fig 13.

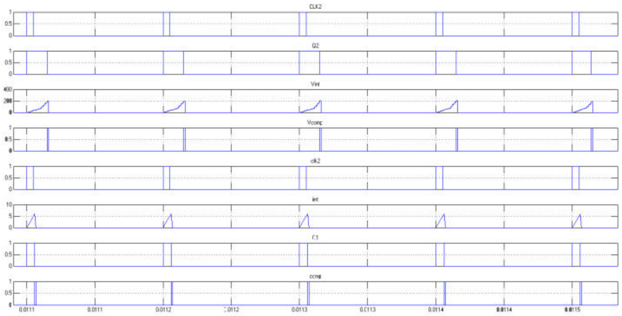

Fig.13. Mode II gate pulses

In mode 1,when the solar power is above 180 V then the battery starts charging upto 200V.The battery charging is shown in the Fig 18.In the same figure the output is also shown.It is constant value of 180V.Fig 15 shows the output voltage which is a constant value.

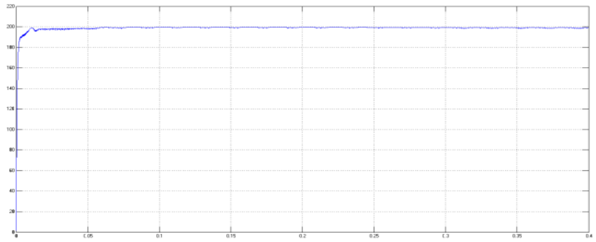

Fig 14. Battery charging.

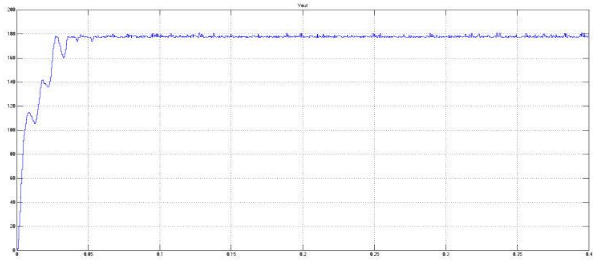

Fig 15.output voltage

V.CONCLUSION

In recent years, numerous investment and research have been put in renewable energy. Because of inherent intermittent characteristics and slow response of renewable energy, energy storage has to be used in the system to provide the energy when the energy from these renewable energy sources is low and supply when the energy from these energy sources is high. In order to reduce the requirement of energy storage, different kinds of renewable energy have to be integrated. To integrate different renewable energy sources and energy storage devices, a new power circuit is proposed because of the better performance, lower cost, higher efficiency and system-level control. The proposed circuit can integrate different renewable energy sources of different voltage levels efficiently. There are several desirable features of the proposed circuit. The one cycle control method avoids the disturbance from the input sources. The operation principles and the modeling were presented. Controller design is investigated. Furthermore, the function of the one cycle control was explained. In the end, different simulations were made and discussed.

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