Stand-Alone Solar Power Generation System with Constant Current Discharge

Mr. Karthick R.T and Dr. Ashok Kumar L

Abstract— In this paper the current of 10 A is discharged constantly from battery. The constant current of 10 A is drawn using MOSFET as a variable resistor. The discharged current is used for an inverter application. The battery is charged with the help of solar panel. The energy wasted during the battery testing process is converted into useful energy. To achieve the high AC voltage similar to power that would be available at an electrical wall outlet, we go for boost converter, which converts low voltage DC to high voltage DC. The method used to obtain high DC voltage is voltage multiplier technique applied to the classical non-isolated dc–dc converters. The duty ratio of the converter is also maintained at safe limits while obtaining the required voltage gain. The topology has been designed for a 100 V, 1 kW application operating from 12 V input. The reactive elements are designed for a switching frequency of 50 kHz. Various operating modes, design equations, simulation results are presented. The wind energy can also be integrated for more power generation in future.

Keywords: MOSFET, DC and AC power

I. INTRODUCTION

This paper focuses on DC to AC power inverters, which aim to efficiently transform a DC power source to a high voltage AC source of 120 V, similar to power that would be available at an electrical wall outlet. Inverters are used for many applications, as in situations where low voltage DC sources such as batteries, solar panels or fuel cells must be converted so that devices can run off of AC power. One example of such a situation would be converting electrical power from a car battery to run a laptop, TV or cell phones.

In battery manufacturing industries battery is tested with discharger coil. Thus the useful energy is wasted as heat. Thus it should be converted into useful one. This paper focus on charging battery from solar panel and discharging it for 10 A. when load is connected to battery there will be sudden raise in current which drains the battery soon. It should be minimized. Thus we go for constant current discharge circuit. Moreover charge controller will have LED's to intimate status of battery.

DC-DC converters with high voltage gain are usually required in battery powered applications like renewable energy system, fuel cells, embedded system, uninterrupted power supply (UPS) and automotive applications [1]-[4].These applications demand high step-up static gain, high efficiency and high power density. Hence, it is preferable for the high voltage boost converters to possess high voltage gain (more than 10), high efficiency and high power density. The step-up DC-DC converter needs to be highly efficient and usually deals with high output voltage. Therefore a careful study must be done in order to select a particular topology for a high step-up application. Some classical converters with magnetic coupling such as fly back Converter can easily achieve high step-up voltage gain [1]. The power transformer volume is a problem for the development of the compact converter. The energy of the transformer leakage inductance can produce high voltage stress, increases the switching losses and the electromagnetic interference (EMI) problems, reducing the converter efficiency.

Active clamping soft communication technique can be used to reduce the switching losses and the EMI generation [2]. However the voltage stress is higher than in the hard switching structure, the cost and circuit complicity are increased. Thus the weight, volume and losses of power transformer are limiting factors for the isolator DC-DC converters used in particular applications. Voltage multiplier cell based non-isolated DC-DC topologies were proposed in [3]-[4]. The required voltage gain was obtained by adding required number of multiplier cells consisting of capacitors and diodes. However, the required output voltage depends on the number of multiplier cells. Further, soft switching was not achieved in these topologies.

A new alternative for the implementation of high step-up structures are proposed in this paper with the use of the voltage multiplier cells integrated with classical non-isolated dc–dc converters and constant current discharge circuit.

II. MOSFET DRIVER FOR CONSTANT CURRENT DISCHARGE

Battery should always be operated in its operating voltage level. so that we can increase its life. It is helpful for

Karthick R.T. working as an Assistant Professor, P.S.G College Of Technology, Coimbatore, India, rtk@eee.psgtech.ac.in, Dr. Ashok Kumar L. working as an Associate Professor, P.S.G College Of Technology, Coimbatore, India, lak@eee.psgtech.ac.in

monitoring purpose also. Suppose when the battery goes below the operating level i.e. voltage of the battery drains the current also varies accordingly to it. Thus the current should be made constant. The current is controlled using MOSFET.

MOSFET is used as a switch to draw the constant current of 10 A from each battery for the load. A positive (for N-Channel) or negative (for P-Channel) VGS produces a conducting channel between the Drain and Source. The are two operating region of MOSFET. They are linear and saturation region. I linear region MOSFET behaves like a resistance and in saturation region it behaves like a current source.

There are two types of drive configuration to drive the MOSFET. They are low side drive (LSD) and high side drive (HSD) configurations. Thus HSD is used for drawing constant current of 10 A from each battery. The PSPICE circuit (Fig 1) is shown here that is used for constant current discharge. Here the MOSFET switch is connected between supply and load. Shunt resistor is connected across the switch and load to take the low voltage drop. This small voltage drop is the input for the differential op-amp. The output from this op-amp is added with 0.3 V (small voltage drop) in adder op-amp. This adder op-amp is with unity gain. Thus we achieve the gate to source voltage nearer to supply voltage. This makes the MOSFET to behave in linear region that is as resistor. So we can now draw 10 A from each battery. So that when the battery voltage decreases from 12 V the MOSFET supplies the required resistance and we get the constant current according to the load.

Now the batteries are connected in parallel to increase the current rating. The output from the DC source is inverted as AC source using inverter.

Consider

TABLE I. BATTERY VALUES

Parameters	**Units**
Internal resistance of MOSFET	0.6 Ω
Load resistance	0.5 Ω
Battery Voltage	12 V
Current	10 A

When the battery in full voltage level consider 12 V

$$V = IR$$

$$R = 12/10$$

$$R = 1.2\ \Omega$$

The load resistance is 0.5 Ω, it cannot be changed. Thus MOSFET varies its resistance as 0.7 Ω. This happens due to change in the drain current when the battery in full voltage level consider 10 V

$$V = IR$$

$$R = 10/10$$

$$R = 1.0\ \Omega$$

The load resistance is 0.5 Ω, it cannot be changed. Thus MOSFET varies its resistance as 0.5 Ω. This happens due to change in the drain current.

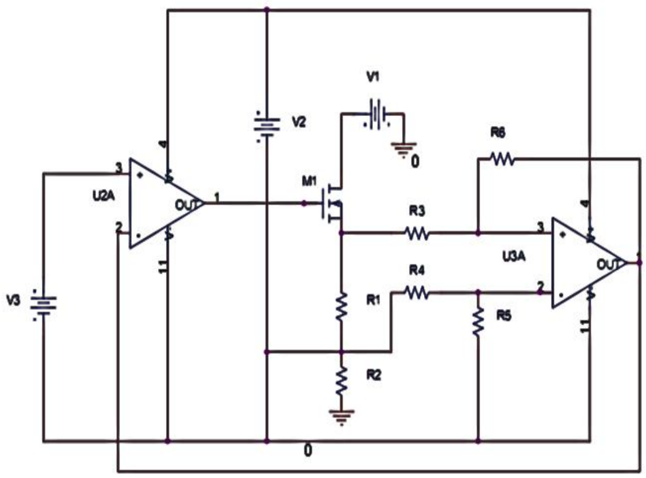

Fig 1. MOSFET driver

III. VOLTAGE MULTIPLIER CELL TOPOLGY.

Another alternative to overcome the limitations of classical DC-DC converters for high performance and large conversion ratio based applications is to develop voltage multiplier cells [5] and integrate them with non-isolated DC-DC converters. The voltage multiplier cell (Fig 8) increases the static gain of a classical boost by a factor (M+1), where M is the number of multiplier cells.

The output of the converter is equal to the output voltage of the classical boost multiplied by the factor (M+1) while the switch voltage is always equal to the output voltage of the classical boost and is independent of the factor M. When properly designed, it allows the power switch to operate with zero current switching (ZCS) turn off and negative effects of the reverse recovery current of all diodes are minimized. This characteristic reduces the converter commutation losses, allowing the operation with high switching frequency and provides high efficiency. The voltage multiplier cell topology is shown Fig 2

A. Analysis of Single Phase Boost Converter

Better operation characteristics are obtained when the converter operates in continuous conduction mode (CCM). Thus the operation stages are presented for CCM operation and considering the use of only one multiplier stage (M=1).

1) *First Stage*: At the instant, switch S is turned-off and the energy stored in the input inductor is transferred to the output capacitor through the diode and also transferred to the multiplier capacitor through the diode. The resonant inductor current increases linearly until it reaches the value of the input inductor current and the current in the diode is reduced at same proportion. The current variation can be considered linear because the capacitor voltage increases and decreases approximately at the same rate, maintaining constant the voltage applied to the resonant inductor.

2) *Second Stage*: At the instant, the current in the diode is zero. The resonant inductor current is equal to the input inductor current during this stage (4) and the energy of the input inductor is transferred to the load through the diode.

3) *Third Stage*: At the instant, the switch S is turned-on with ZCS commutation and the current in the resonant inductor and in the output diode reduce linearly to zero at that instant. Thus the output diode also is blocked with low reverse recovery current. The capacitor voltage can be considered constant.

4) *Fourth Stage*: When the output diode is blocked, the diode conducts transferring the energy stored in the multiplier capacitor to the output capacitor, in a resonant way. When the energy stored in the capacitor is transferred to the capacitor, the diode is blocked (instant). The average voltage stored in the output capacitor is equal to the output voltage of the classical boost converter plus the voltage. The average voltage of the capacitors equals to the output voltage of the classical boost converter, and this is the maximum voltage applied in all diodes and power switch.

5) *Fifth Stage*: At the instant, the current in the inductor becomes zero and the diode is blocked. The input inductor stores energy as a conventional boost until turn-off returning to the first stage.

The switch turn on is ZCS. The resonant inductor limits the current variation (di/dt) in all diodes, reducing the reverse recovery current. The voltage in all semiconductors is half of the output voltage, considering a low voltage ripple in the multiplier capacitors. The configuration proposed is used for an integration of the step-up dc–dc converter with a full-bridge inverter.

B. Design Considerations of Single-Phase Boost Converter

The main equations to design the single-phase converter are presented with an example, considering the following specifications.

TABLE II.DESIGN VALUES

Parameters	Units
Output power	100 W.
Input Voltage	12 V.
Output Voltage	100 V.
Switching Frequency	50 kHz.
Number of multiplier stages:(M)	1

1) *Static Gain*: The multiplier capacitor is charged with the output voltage of the classical boost converter at the fourth operation stage. As this capacitor is connected in series with inductor the energy is transferred to this capacitor. The output capacitor is charged with the boost converter output which is two times the output voltage. V_{CM1}, V_{CM2} are voltage across multiplier cell capacitors, V_{IN} is input voltage, D is Duty Cycle

$$V_{CM2}=V_{CM1}=V_{IN}[1/ (1-D)] \quad (3.1)$$

$$V_O=V_{CM2}+ V_{IN}[1/ (1-D)] \quad (3.2)$$

2) *Switch Duty-Cycle*: The nominal duty is given as below where M=1

$$D= [V_O-V_{IN}(M+1)]/V_O \quad (3.3)$$

$$D= (100-12(2))/100=0.76$$

Where V_O is output Voltage.

3) *Switch Voltage*: The maximum voltage in all diodes and power switch is equal to the C_{M1} voltage that is equal to the output of the classical boost is calculated by given formula. The voltage in all components is half of the output voltage.

$$V_{CM1}=V_S=V_D= V_{IN}*[1/(1-D)] \quad (3.4)$$

$$=12*[1/(1-0.76)]$$

$$=50 V$$

4) *Input Inductance*: The design of the input inductance is the same of the classical Boost converter where P_O is output Power, I_L is the Inductor current. Considering a current ripple equal to 45% of the nominal input inductance is equal to

$$I_L= (P_O/V_{IN})*0.45 = 3.75 A$$

$L_{IN}=(V_{IN}*D/I_L*f)= 48\ \mu H$

5) *Voltage Multiplier Capacitor C_M*: The minimum capacitance of the voltage multiplier capacitor depends of the maximum output power, the multiplier capacitor voltage and the switching frequency. The maximum output power considered in this example is equal to 150 W for a nominal output power equal to 100 W.

$$C_{M1} \geq (P_{OMAX}/ (V_{CM1})^2*f) \quad (3.5)$$

$$=1.2\ \mu F$$

The maximum output power is limited by the energy stored in the multiplier capacitor. If the load power is increased above of P_{OMAX} value, the output voltage will be reduced, limiting the output power at the value of P_{OMAX}. Therefore, the proposed converter will operate with constant output power in an overload condition until the output voltage reaches the value of the output voltage of the classical boost is calculated. Thus, for a too small multiplier capacitance, the proposed structure will operate as a classical boost converter and the voltage multiplier will operate only as a non-dissipative snubber.

6) *Resonant Inductor*: The resonant inductor can be defined by the maximum current variation (di/dt) at the turn-on commutation, in order to minimize the commutation losses. In the third operation stage presented there will be reduction of the resonant inductor current at the switch turn-on. The current variation is limited by the presence of the resonant inductor, defined by

$$di/dt=(V_o-V_{CM2})/L_r \quad (3.6)$$

Considering the maximum di/dt at the turn-on commutation equal to 25 A/µs, the resonant inductance is defined by

$$L_r=(100-50)/(25*10^6)= 2\ \mu H$$

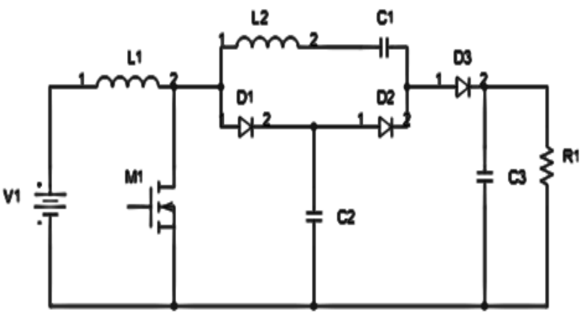

Fig 2. Voltage Multiplier Cell

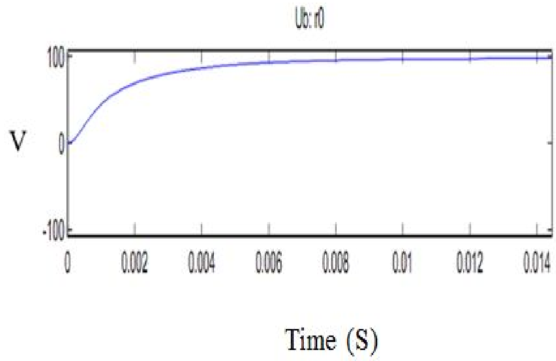

Fig 3. 100V DC Output

The conveter voltage (*see Fig.4*) is 100 V DC. This voltage can be boosted for any voltage by incresing the multiplier cell.

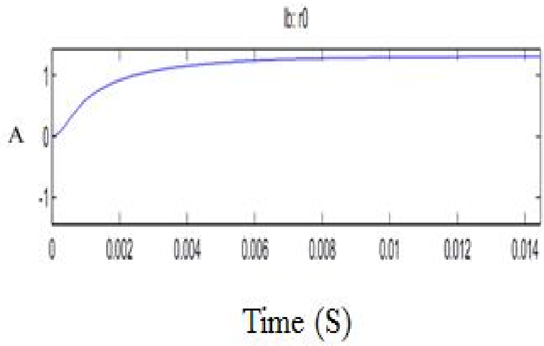

Fig 4. 1A of Boost converter current

The simulation result (*see Fig.4*) gives the current of 1 A from converter. As per the design the circuit delivers the current of 1 A.

IV. INVERTER

An HBridge [6]or full bridge converter in Fig 5is a switching configuration composed of four switches in an arrangement that resembles an H. By controlling different switches in the bridge, a positive, negative, or zero potential voltage can be placed across a load. When this load is a motor, these states correspond to forward, reverse, and off. The use of an HBridge configuration to drive a motor.

The HBridge circuit consists of four switches corresponding to high side left, high side right, low side left, and low side right. There are four possible switch positions that can be used to obtain voltages across the load. These positions are outlined in TABLE I. Note that all other possibilities are omitted, as they would short circuit power to ground, potentially causing damage to the device or rapidly depleting the power supply.

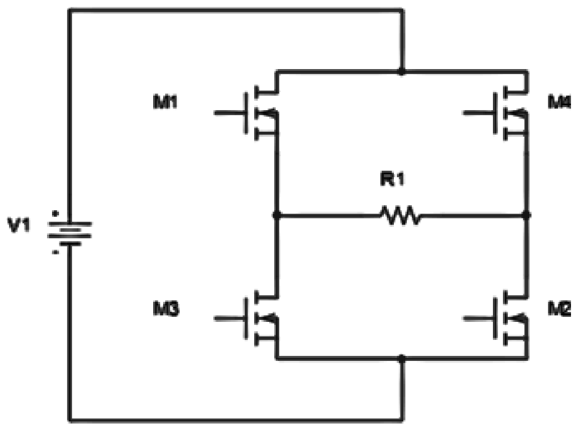

Fig 5. H Bridge inverter

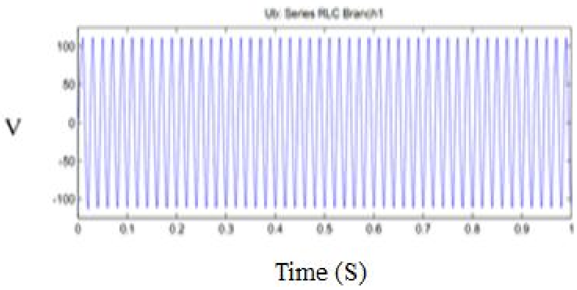

Fig 6. Inverter voltage of 100 V pk-pk

The AC Voltage (*see Fig.6*) of 100 V is Simulated with Dead Time PWM Pulse as mentioned earlier.

TABLE III. SPECIFICATIONS OF COMPONENTS

Components	Description		Quantity
Solar panel	Model	ESP040	1
	Power	40W	
	Working voltage	18V	
	Working current	2.23A	
Battery	Type	New technology Lithium battery	1
	System voltage	12V	
	Capacity	12Ah	
Controller	System voltage	12V	
	Rated current	10A	1

The above table gives the specification of the panel and battery used in the system.

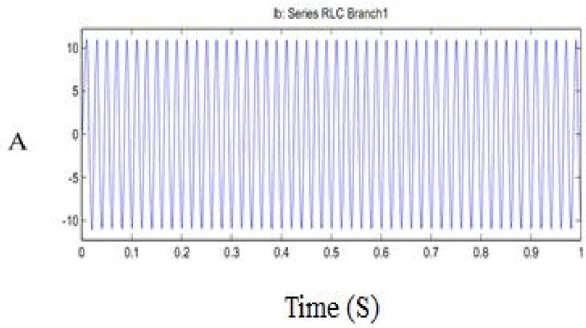

Fig 7. Inverter current of 10 Apk-pk

The AC current (*see Fig.7*) of 10 A is Simulated with Dead Time PWM Pulse as mentioned earlier.

TABLE IV. SWITCHING CONFIGURATION

High side left	High side right	Low side left	Low side right	Voltage across load
ON	OFF	OFF	ON	POSITIVE
OFF	ON	ON	OFF	NEGATIVE
ON	ON	OFF	OFF	ZERO
OFF	OFF	ON	ON	ZERO

V. SOLAR CHARGE CONTROLLER

Solar Charge controller is a device, which controls the battery charging from solar cell and also controls the battery drain by load. The simple Solar Charge controller checks the battery whether it requires charging and if yes it checks the availability of solar power and starts charging the battery. Whenever controller found that the battery has reached the full charging voltage levels, it then stops the charging from solar cell. On the other hand, when it found no solar power available then it assumes that it is night time and switch on the load. It keeps on the load until the battery reached to its minimum voltage levels to prevent the battery dip-discharge. Simultaneously Charge controller also gives the indications like battery dip-discharge, load on, charging on etc.Although any microcontroller with sufficient I/O is suitable for the job but for most suitable microcontroller to choose, we have to keep in mind the following things. It should have at least two analog I/O for measurement of Solar and Battery Voltage. Otherwise we have to add extra AD converter for the job and it will increase the complexity of the circuits and cost. It should have at least two digital I/O, capable of switching High Current MOSFET for battery charging and load. It should have at least three digital I/O capable of driving direct LEDs, otherwise we have to add extra LED driver for the purpose. It should have minimum circuit requirements for its self-operation to cut down the cost.

VI. RESULTS

The Stand-Alone Solar Power Generation System was designed for a 100 V, 1 kW application operating from 12 V input. The PWM signals were generated and controlled using microcontroller. PWM signals were generated using dead time concept, since to protect the MOSFET. We avoided the core saturation problem by doubling the switching frequency and reducing the inductance values in the filter. Through proper component selection in another revision, the switching frequency could be returned to 50 kHz. With the exception of the filter problems mentioned above, the circuit is functioning as designed and correctly inverts a DC voltage to an AC voltage. The circuit showed in Fig 8 is the solar power generation system with constant current discharge. There are two switches one for charging battery from panel and other is for connecting battery to load when no sun or battery is charged fully.

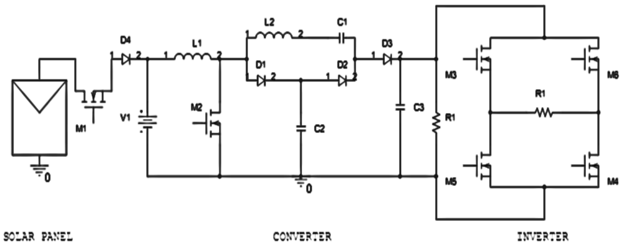

Fig 8. An integrated inverter with solar charge controller

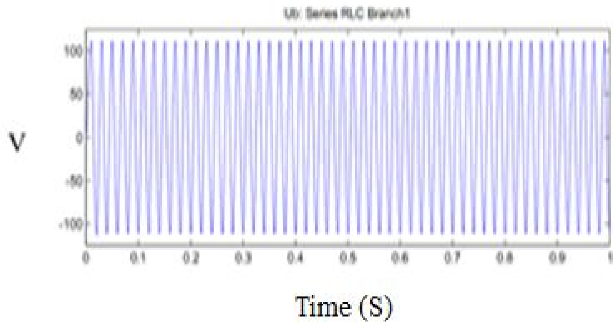

Fig 9. Inverter voltage

The AC Voltage of 100 V is Simulated with Dead Time PWM Pulse as mentioned earlier

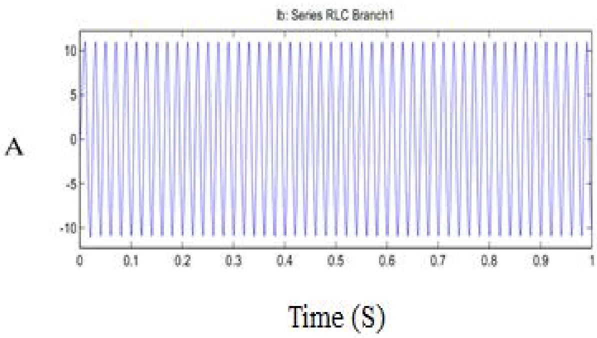

Fig 10 Inverter current

The AC current of 10 A is Simulated with Dead Time PWM Pulse as mentioned earlier

VII. CONCLUSION

As mentioned in section II the constant current discharge is connected to battery in order to minimize the sudden raise in current from battery when it is connected to load. It may drain the battery soon. Thus it should be controlled. The control signals for the switches are given from Atmega8 controller. There are three LED's connected to the system to mention the status of Battery. The Stand-Alone Solar Power Generation System was designed for an input voltage of 12 V 100 V, 1 kW application**.**

This proposed methodology is normally used in battery manufacturing industries and E-vehicles manufactures where the battery is discharged using discharging coil.

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Mr.Karthick R.T. was born on 21st May 1988 in Salem India. He completed his graduate programme in Electronics and Communication Engineering in 2009 from Anna University Chennai India. He did his post-graduation in Power Electronics and Drives from PSG College of Technology Coimbatore India in the year 2012. After completion of his UG he was worked as a Junior Production Engineer at Anand Electronics - Hosur for one year then after his PG he was worked as a Production Executive at Samsung Electronics – Chennai for three months. Now he is working as an Assistant Professor at PSG college of

Technology Coimbatore India in EEE (Sandwich). His major research work area is Renewable Energy.

Dr. Ashok Kumar l was born on 7th April 1976 in Coimbatore, India. He completed his graduate programme in Electrical and Electronics Engineering in 1997 from University of Madras, India. He did his post-graduation from PSG College of Technology, Coimbatore, India in the year 2005 with Electrical Machines as his major. He completed his MBA from IGNOU, New Delhi in the year 2008 with Specialization in HRD. He completed his PhD in the field of Wearable Electronics from Anna University, Chennai. After completion of his B.E. Degree he joined as Project Engineer in Serval Paper Boards Ltd., Coimbatore (now renamed as ITC unit, Kovai). Presently he is Associate Professor in Department of EEE, PSG College of Technology and also doing research work in Wearable Electronics, Smart Textiles, Solar PV and Wind Energy Systems