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Design, Analysis and Implementation of Buck-Sepic Fused Converter for Electric Water Pump

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Abstract— Converters are electrical circuits that convert a voltage level to another. Inverter is used in different purposes of lives. DC-DC converters are also known as switching converters, switching power supplies or switches. DC-DC converters are important in portable device such as cellular phones and laptops. To avoid unnecessary damage to the equipment and devices, the voltage level need to be converted to suitable voltage level for the equipment to function properly. It is required in a variety of applications including electric water pump, electric vehicle, etc,.This generated power is fed to a boosting load across which the boosted output voltage is being received. This output voltage is then fed to operate a PMDC motor, driving a pumping system.

Keywords—DC-DC Converter, Water pump

1. INTRODUCTION

In recent years, studies show that over 900 million people in various countries do not have water for consumption. This occurs by the difficulty on the access of this resource, because a large amount of these people are isolated, located on rural areas, where the water supply comes from rain or distant rivers. These regions do not have access to the national grid system to pump water for irrigation purpose in farming and consumption. As an example, the lack of electricity is one of the main hurdles in the development in rural India, where electrical and diesel-powered water pumping systems are widely used for the applications cited.

To improve the life quality of people in rural areas, water pumping systems are widely used to provide a sustainable water supply, which in turn is also in line with the Nations' that aims to promote sustainable agriculture. In the last few years, there has been an increasing water demand in such rural areas, particularly in the highland areas of the country that have been affected by severe draughts. In the highlands, pumping (and thus power) is generally needed to assist in water supply and distribution, both for storage and direct use.

Power conversion relies on type of the input and output power [1-4]. Converter driven applications are widely used. Many wind-farm, ship drives, several boiler feed water pumps and many other applications operate much more efficiently and economically in case of variable speed solutions. The boundary conditions for a motor and generator will change if a converter supplies it. Converter driven applications are widely used. Many wind-farm, ship drives, several boiler feed water pumps and many other applications operate much more efficiently and economically in case of variable speed solutions. The boundary conditions for a motor and generator will change if a converter supplies it.

DC to DC converters developed to maximize the energy harvest for photovoltaic systems and for wind turbines are called power optimizers. Transformers used for voltage conversion at mains frequencies of 50–60 Hz must be large and heavy for powers exceeding a few watts. This makes them expensive, and they are subject to energy losses in their windings and due to eddy currents in their cores.

DC-to- DC techniques that use transformers or inductors work at much higher frequencies, requiring only much smaller, lighter, and cheaper wound components. Consequently, these techniques are used even where a mains transformer could be used; for example, for domestic electronic appliances it is preferable to rectify mains voltage to DC, use switch-mode techniques to convert it to high-frequency AC at the desired voltage, then, usually, rectify to DC. The entire complex circuit is cheaper and more efficient than a simple mains transformer circuit of the same output.

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DC- DC converters are power electronic circuits that convert a given dc voltage level to a different voltage level. It interfaces the number of energy sources with the load along with the energy storage elements. With these comes the question of how to interface the DC-DC converters with renewable energy sources, whether it is one or all of these sources simultaneously. As reported by [5-7] the interface systems for renewable energy sources were constructed using the topology which consists of multiple energy inputs connected to a respective DC-DC converter with its own controller and storage element. Each DC-DC converter is connected to a common dc link. The common dc link is where the energy from each input is combined and then distributed to the loads through another DC-DC converter for each load.

In a system of this nature, each DC-DC converter communicates with each other in order to control the power transferred from each input to its respective output. With this type of topology if one were to add multiple input modules, the overall system would become too large for its particular application where size and weight are an issue. This conventional topology can also be used for multiple output systems [8,9].This topology is becoming interesting where there are multiple inputs/outputs. The overall size of the system is still bulky as number of DC-DC converters is more. There are various topologies for multi-port DC-DC converters in today’s market. These will be placed into two categories, isolated converters and non-isolated converters. An isolated converter is presented [10,11].This converter is made up of grid tied solar inputs, rectifier and inverter topologies.

A double ended galvanic isolated converter to process solar and wind system has been discussed in [12]. The converter uses one output inductor which reduces the volume of the converter. Though these types of converters have high isolation voltage from hundreds to thousand volts, it has high noise and less interference blocking capability and high cost. According to [13], a single multi input converter can replace several numbers of parallel connected converters.

To obtain high performance control of a DC-DC converter, stability analysis of the converter is needed. Most DC-DC power converters have a feedback system to regulate the output voltage/current. The performance of this feedback system depends on the design of control loop, which is in turn based on the small signal behaviour of the converter. Literature presented small signal analysis wherein the small signal behaviour around a steady state operating point of the system is carried out. The information obtained from this investigation can be used to predict the system transfer functions that are useful in the feedback loop design.

For a hybrid energy system, it is important to develop a power converter to integrate different power sources and storage elements. Existing systems use an individual isolated or non-isolated power converter for each individual power source thus leading to a relatively complex configuration, larger component count and reduced system efficiency. Increased part count and part stress poses always a reliability issues in the existing system. To address these issues, dual input smart converters are used in this paper. A detailed component wise analysis of the fused DC-DC converters presented using Matlab/Simulink.

2. PROPOSED METHODOLOGY

The block diagram of the proposed system is shown in figure 1. The proposed system is physically composed of a DC sources, buck-sepic fused converter, PWM controller.

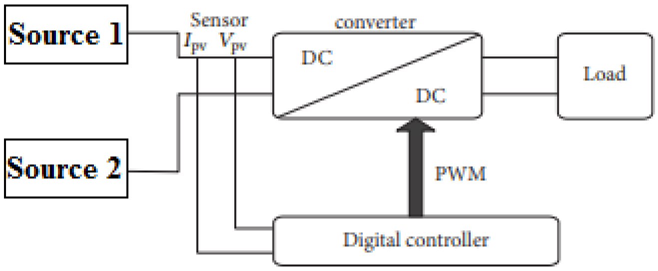

Fig. 1. **Block diagram for the proposed system**

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The proposed circuits for different applications are having 4 modes and operate in 3 modes depending on availability of sources. The outline of proposed system for stand-alone configuration is as shown in Fig. 4.2 The proposed BUCK-SEPIC converter operates as BUCK converter at the point when just DC source 1 is accessible. It acts as a SEPIC converter at the point when just DC source 2 is accessible. When both the sources are available the switches will turn ON. When both sources are unavailable the switches will tum OFF. The proposed BUCK-SEPIC converter operates as BUCK converter when only DC source 1 is available BUCK converter at the point when just DC source 1 is accessible. It functions as a SEPIC converter at the point when just DC source 2 is accessible. When both the sources are available the switches will turn ON. When both sources are unavailable the switches will tum OFF.
The proposed circuit diagram of buck-sepic converter is shown in Fig.2.

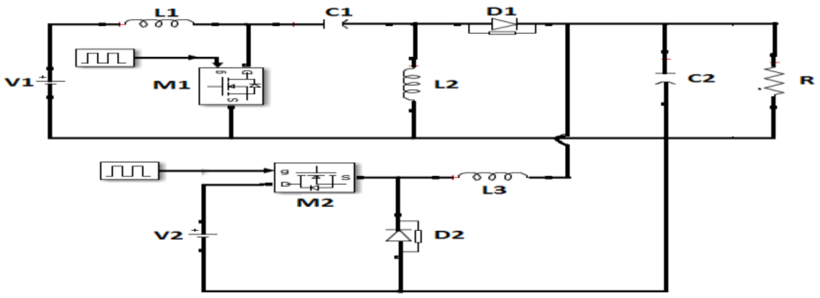

Fig. 2. **Circuit diagram**

The proposed system consists of solar source, battery backup (energy storage system), buck-sepic fused dc-dc converter. The proposed BUCK-SEPIC converter operates as BUCK converter at the point when just DC source 1 is accessible. It acts as a SEPIC converter at the point when just DC source 2 is accessible. When both the sources are available the switches will turn ON. When both sources are unavailable the switches will tum OFF. The proposed BUCK-SEPIC converter operates as BUCK converter when only DC source 1 is available BUCK converter at the point when just DC source 1 is accessible. It functions as a SEPIC converter at the point when just DC source 2 is accessible. When both the sources are available the switches will turn ON. When both sources are unavailable the switches will tum OFF.

3. MODES OF OPERATION OF BUCK-SEPIC FUSED DC-DC CONVERTER

There are four different modes of operation depending uponthe conduction states of the switches S1 and S2. The voltage and current waveforms of modesof operation is shown in Figure 3. The working principle of different modes fused converter is explained in Table 1 andits equivalent circuit is given in Figure 4.

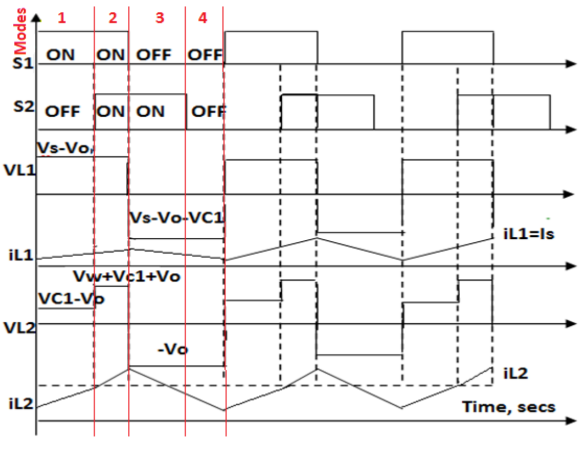

Fig. 3. **Modes of operation**

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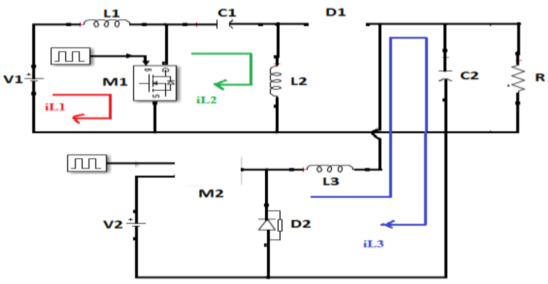
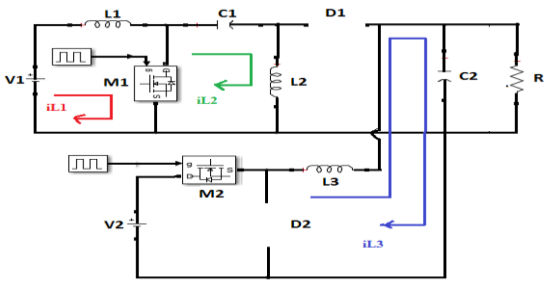
Mode	Switches	Working
Mode-1	S_1-ON,S_2-OFF	The diode D_1 is in reverse biased and D_2 is in forward biased. The power from DC 1 charges the inductor L_1, energy stored in inductors L_3 feeds the load and charges the battery
Mode-2	S_1, S_2-ON	Diodes D_1, D_2 are in reverse biased. The power from DC 1 charges the inductor L_1 and L_2. Energy stored in inductor L_3 feeds the load as well as charges the battery.
Mode-3	S_1-OFF S_2-ON	The diode D_1 is in forward biased and D_2 is in reverse biased. The power from DC 1 charges the inductor L_1 and L_2. energy stored in inductors L_3 feeds the load and charges the battery
Mode-4	S_1,S_2-OFF	The diodes D_1, D_2 are forward biased. Energy stored in L_1 is transferred to capacitor C_1 the inductor L_1 and L_2. Energy stored in L_3 feeds the load and charges the battery.

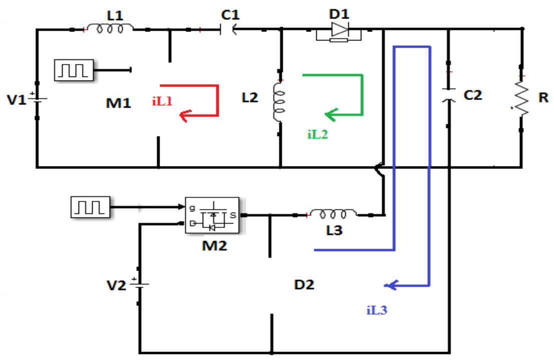
Table 1. Working principle of fused DC-DC converter



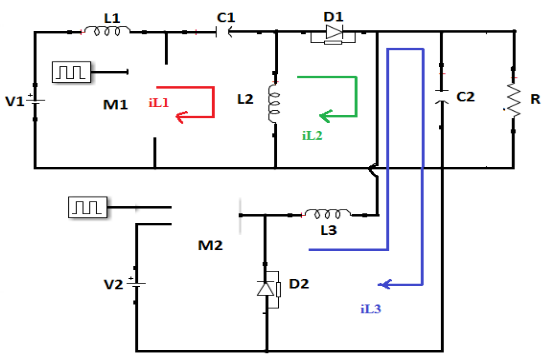
4(a)



4(b)



4(c)



4(d)

Figure 4 Various modes of fused DC-DC converter

(a:S1-ON, S2-OFF; b:S1-ON, S2-ON; c:S1-OFF, S2-ON; d:S1-OFF, S2-OFF)

4. SYSTEM MODELING

This section describes the mathematical modeling of various components involved in the proposed system.

Induction motor

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The voltage and torque equations that describe the dynamic behavior of an induction motor are time-varying. It is successfully used to solve such differential equations and it may involve some complexity. A change of variables can be used to reduce the complexity of these equations by eliminating all time-varying inductances, due to electric circuits in relative motion, from the voltage equations of the machine.

By this approach, a poly phase winding can be reduced to a set of two-phase windings (q-d) with their magnetic axes formed in quadrature. A more comprehensive three-phase induction motor dynamic mathematical model mainly those including fast motor speed changes, intermittent loading and in case of motors fed from non-sinusoidal voltages contributing to the energy conservation and power quality subjects. Also a step-by-step Matlab/Simulink implementation of an induction machine using dq0 axis transformations of the stator and rotor variables in the arbitrary reference frame was formulated.

The stator and the rotor variables (voltages, currents and flux linkages) of an induction machine are transferred to a reference frame, which may rotate at any angular velocity or remain stationary. Such a frame of reference is commonly known in the generalized machine analysis as an arbitrary reference frame.

The dynamic analysis of symmetrical induction machines in the arbitrary reference frame has been intensively used as a standard simulation approach. From this approach, any particular mode of operation may then be developed. The model equations are derived from the dq0 equivalent circuit of the induction machine shown in Figure 5. The flux linkages equations associated with this circuit can be found by the following equations.

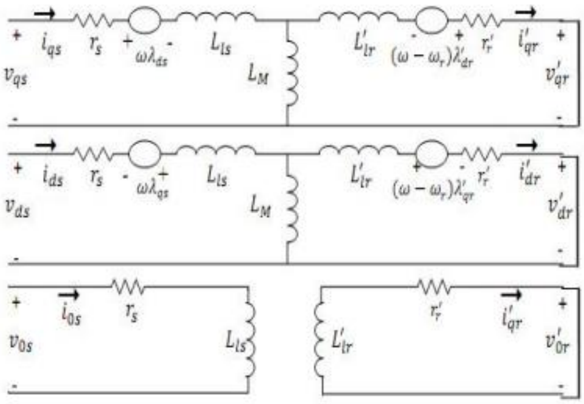

Fig.5. The dq0 equivalent circuit of an induction motor

$$\lambda_{mq} = X_{ml}\left[\frac{\lambda_{qs}}{X_{ls}} + \frac{\lambda_{qr}}{X_{lr}}\right]$$

$$\lambda_{md} = X_{ml}\left[\frac{\lambda_{ds}}{X_{ls}} + \frac{\lambda_{dr}}{X_{lr}}\right]$$

$$X_{ml} = \frac{1}{\left[\frac{1}{X_m} + \frac{1}{X_{ls}} + \frac{1}{X_{lr}}\right]}$$

$$I_{qs} = \frac{1}{X_{ls}}\left[\lambda_{qs} - \lambda_{mq}\right]$$

$$I_{ds} = \frac{1}{X_{ls}}\left[\lambda_{ds} - \lambda_{md}\right]$$

$$I_{qr} = \frac{1}{X_{lr}}\left[\lambda_{qr} - \lambda_{mq}\right]$$

$$I_{dr} = \frac{1}{X_{lr}}\left[\lambda_{dr} - \lambda_{md}\right]$$

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$$\frac{d\lambda_{qr}}{dt} = \omega_b \left[V_{qr} - \frac{(\omega_e - \omega_r)}{\omega_b}\lambda_{dr} + \frac{R_r}{X_{lr}}(\lambda_{mq} - \lambda_{qr})\right]$$
$$\frac{d\lambda_{dr}}{dt} = \omega_b \left[V_{dr} - \frac{(\omega_e - \omega_r)}{\omega_b}\lambda_{qr} + \frac{R_r}{X_{lr}}(\lambda_{mq} - \lambda_{dr})\right]$$

$$T_e = \frac{3}{2}\left(\frac{P}{2}\right)\frac{1}{\omega_b}\left[\lambda_{ds}I_{qs} + \lambda_{qs}I_{ds}\right]$$
$$\omega_r = \int \frac{P}{2J}(T_e - T_l)$$

where, p is the number of poles and J is the moment of inertia (Kg/m^2)

Battery bank

The variations of renewable energy generation do not match the time distribution of the demand. Therefore, renewable power generation systems dictate the association of battery storage facility to smooth the time distribution mismatch between the load and renewable energy generation and to account for maintenance of the systems.

The battery stacks may contain a number of batteries ranging from 0 to 500units. A battery of 6 V, 1.39 kWh has been chosen. Number of batteries per string considered is 8. The state of charge (SOC) of the battery is the cumulative sum of daily charge/discharge transfers. At any hour (t) the state of charge of the battery is related to the previous state of charge and to the energy production and consumption situation of the system during the time from t-1 to t. During the charging process, when the total output of all systems exceeds the load demand, the available battery bank capacity at hour (t) can be described by,

$$E_{Bat}\ (t) = \text{Battery Capacity (Ah)/Battery Current (A)}$$

On the other hand, when the load demand is greater than the available energy generated, the battery bank is in discharging state. Therefore, the available battery bank capacity at hour t can be expressed as

$$E_{Bat}\ (t) = E_{Bat}\ (t-1) - E_{Needed}\ (t)$$

Let d be the ratio of minimum allowable SOC voltage limit to the maximum SOC voltage across the battery terminals when it is fully charged.

So, the Depth of Discharge (DOD), $DOD = (1 - d) * 100$

DOD is a measure of how much energy has been withdrawn from a storage energy device, expressed as a percentage of full capacity

Converter

The DC-DC converter model is given below

$E_{REC-OUT}(t) = E_{REC-IN}(t) * \eta_{REC}$

$E_{REC-OUT}(t)$ = Hourly energy output from rectifier, kWh

$E_{REC-IN}(t)$ = Hourly energy input to rectifier, kWh

η_{REC} = Efficiency of rectifier

$E_{REC-IN}\ (t) = E_{SUR-AC}\ (t)$

$E_{SUR-AC}\ (t) = E_{DG}\ (t)$

$E_{SUR-AC}(t)$ = Amount of surplus energy from AC source, kWh

E_{DG} (t) = Surplus energy from diesel generator to DC power of constant voltage, when the energy generated by the hybrid energy system exceeds the load demand.

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5. SIMULATION AND RESULTS

In order to evaluate the performance of the proposed controller, simulation has been carried out for set point change, source and load variations. The circuit parameters of the chosen buck-sepic converter are listed in Table 2. The controllers were made to maintain the output voltage constant at 48V.

Components	Values
Inductors	L_1, L_2=0.0133mH
Capacitors	C_1 =0.2mF, $C_{2=}$200mf
Resistor	100Ω
Frequency	1kHz
Controller	GOA and PO controller

Table 2 .Circuit Parameters

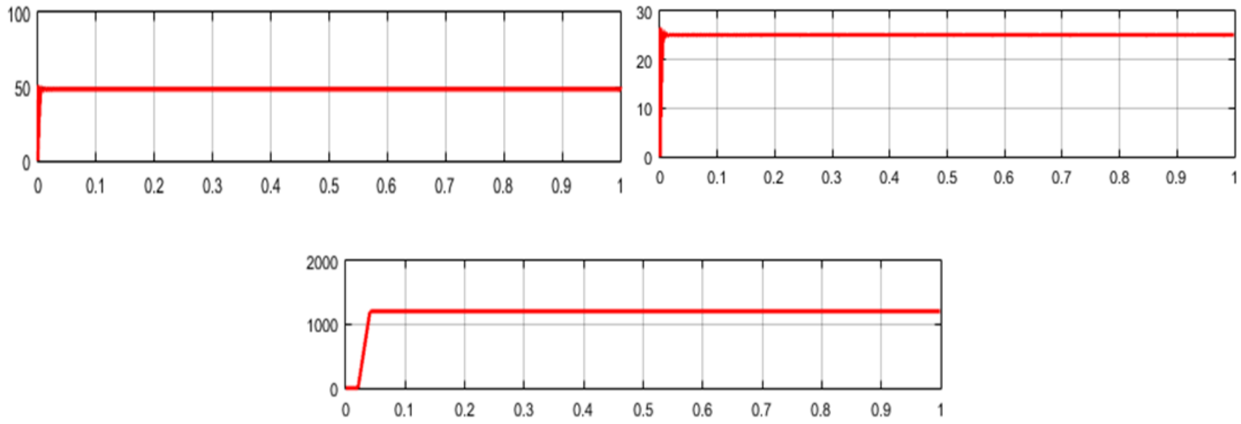

Fig. 6. Output Power

6. CONCLUSION

In this paper, the importance of electric water pumping system and the drawbacks of the existing water pumping systems that are available in the literature are explained. The water pumping system design process is presented in detail and the mathematical modelling of the various components of the fused components are explained. Detailed analysis of the system operated by the IM is analyzed.

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