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Effective Hybrid Power Conditioning System For Residential Application

S.Dhamodharan[1], M.Narayanan[2], J.Saravana Kumar[3], K.Saveetha[4]

[1,2]Assistant professor, Department of EEE, INFO Institute of Engineering,
Coimbatore, Tamilnadu 641107, India

[2,3]UG Scholar, Department of EEE, INFO Institute of Engineering,
Coimbatore, Tamilnadu 641107, India

Abstract
A worldwide demand exists for the renewable energy systems especially in solar PV systems. In domestic applications in order to supply power to the load hybrid systems are proven one. In such systems transformerless technology is an emerging technology. This paper deals with the design of hybrid power conditioning circuit which eliminates the use of a transformer in a system used for domestic applications. Here the system eliminates the transformer by increasing the number of batteries .It also evaluates the losses produced by the transformer. The proposed system proves to be an efficient system in domestic applications since losses are reduced.

Keyword:*PV/wind system, transformerless system, PWM inverters*

1. Introduction

Due to the recent worldwide demand in the renewable energy systems, the solar photovoltaic market saw a considerable amount of advances in the construction and operation of these systems. Especially in the hybrid systems which is a combination of two or more RES (Renewable energy systems) like solar PV /wind, there are significant developments as it overcomes the limitations of both the systemsso that the power production has become easier when compared to single source systems (solar or wind alone).Now a new technology in the hybrid system is that the power generation system without the use of the transformer. In domestic applications the size and reduction in cost are becoming an important issue which leads to the researchers to focus on the elimination of transformers.The design of an efficient system requires knowledgeof the converter and transformer (parameters like core, windingetc.)In order to get an optimized output the evaluation of losses inpower electronic transformers(PETs) or medium frequency transformer is taken into account. The main aim is to reduce the material size, weight in highly complex applications like wind power.

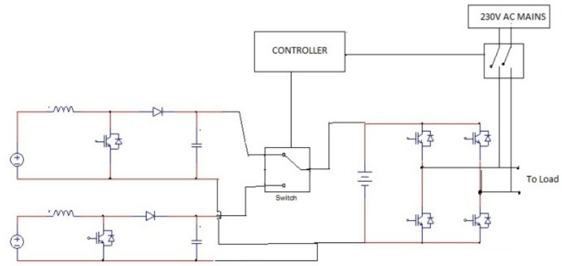
The analysis of losses includes both core loss and copper loss thus expands the study to global transformer losses. Analysis of various losses using different techniques is given and their advantages are pointed out. The transformer losses for non sinusoidal waveforms are more difficult to calculate specifically the magnetic loss or core loss with the frequency and peak flux density are of same value.The paper focuses on the study of an isolated dc to dc converter with a transformer as a conversion system for study. Fed by a non sinusoidal waveform. Copper losses depend on the shape of the coil, frequency of supply. In the experimental verification the input to the transformer is a distorted sinusoidal waveform. Even a small change in the modulation technique increases the copper loss. Core losses increases 1.2 to 1.3 times higher due to square waveform [1]This paper presents the cost of power which is required to supply the losses in transformer who bear their own generation facilities. The existing loss evaluation techniques are analysed.ABB has designed a total ownership cost calculator. The transformer users who keep their own systems should follow some strict procedures. The paper also insists that the installation and running costs should also be included in calculating cost for losses. Themain approach of the paper is to determine any operating costs associated with the losses. It is also important to forecast about the increasing power related costs rather than life cycle cost of the transformer. The proposed method uses statistical and economical methods for forecasting. Here the losses are seen as a load to the system, in which the system's capacity is sufficient to account for the peak demand and the losses. The capacity of the system is calculated by the peak demand and its losses...The losses occur in the system during peak loads is significant in the future.Here the total cost of losses consists of a demand component and an energy component.The energy component includes costs of varing costs of the generating additional energy when with respect to the life cycle.Both of these components are calculated.The fixed cost should be included in the demand component of the cost of losses and the running cost is associated with energy and demand component.The initial cost include new peak demand and the perkilowatt installation of the transmission system. The increase in losses of the transmission level would have an effect on the additional losses.[2]

Transformers connected to the renewable energy systems are affected by the conditions dc offset input current, variation in load, voltagefluctuations. Due to these conditions it not only increases the losses but also in some cases it leads to the failure of transformer. The researchers did not concentrate on the effect of saturation. This paper analysis the characteristics of a transformer under heavily saturated conditions. The main analysis is confined to no-load of a single phase shell type transformers..The characteristics are determinedby Newton Raphson method.[3]Many power electronic converters have been discussed which gives us the details about the shortcomings of conventional systems which are complex in terms of size number of devices .Many converters use pwm pulses to generate the gate signals. Due to the presence of high frequency harmonics in the output of such converters it also increases the magnetic losses in transformer. Understanding the core losses helps us in improving the efficiency of the system. The iron losses increase heavily in case of pwm supply is mainly due to the eddy current losses. The eddy current losses are calculated in terms of frequency, modulation index and dc link voltage. The fundamental value of voltage and harmonics contributes to more amount of eddy current losses. A term called loss ratio is used here to calculate the increment in core loss when fed by a pwm converter which is nothing but the ratio between the losses produced when fed by sinusoidal waveform to the losses produced when fed by the pwm supply. The experimental results show that loss ratio increase upto 2.46 times when a PWM supply of frequency 1Khz compared to the pure sine wave. Also the increase in switching frequency has neglible effect on the loss ratio. Also the modulation index has a considerable effect on the eddy current loss, so a high amplitude modulation index is suggested. The qualitative analysis of is based on the duty cycle versus variation of eddy current loss is calculated. Under no-load conditions the difference between the input power of the PWM supply and the pure sine wave is taken as the eddy current loss. The increase in the eddy current loss with PWM supply is due to the presence of voltage harmonics. Also the additional losses caused by the PWM supply on transformers are significant and it cannot be neglected. The evaluation of losses include only core losses which is taken under no load conditions.[3]

In low power PV system It is very convenient to remove the transformer so that it reduces the losses, cost and size. The removal of transformer between the inverter and the load increases the ground leakage current due to the parasitic capacitance of the PV panel. The unipolar PWM strategy is proposed in this paper which provides no variation in the common mode voltage variation. The power loss comparison of the converter topologies also give better results and this uniplolar PWM strategy is efficient.[4]The paper proposes a single phase transformerless inverter configuration which consists of two step down converters. The dc link current in the transformerless systems is three times higher than the system with transformers. The inverter design eliminates dc link currentproblem. Thedesign also reduces the harmonic contents, discharge currents flowing to the ground due to parasitic capacitance formedby the PV panel. The transformerless inverters are subjected to high input voltage when compared to the transformer inverters so a high blocking voltage switch is necessary. This topology reduces the cost and increase the reliability of the system. High level of efficiency is achieved with reduced number of switches.[5]

2.Proposed Power Conditioning System

All the systems currently available uses a transformer which itself contributes to 30% of losses. So this paper provides a power conditioning system which eliminates the transformer. The block diagram of the proposed system is shown in fig.1



In the proposed system the voltage sources are solar PV panel output and wind turbine output. The output of the voltage source is 12V dc.The voltage output is not sufficient to power the load. So a dc-dc converter(charge controller) which is a boost converter is used to charge the battery. The voltage is stepped up from 12V dc to 230V dc which is fed to the battery bank.In the existing system the voltage from the solar panel or wind turbine is fed to a single battery of 12V through the charge controller which is then fed to the inverter. There it is converted into ac voltage which is stepped up using a step up transformer(12V is stepped into 230V) which can be fed to the load. In our system instead of a transformer we are using a series of batteries connected in series together to form a battery bank. Here 20 number of 12V batteries are connected in series to obtain the required voltage 230V.(the actual voltage is 240V in which any fluctuations in the output voltage can be met).

The battery bank is used to feed the inverter which in turn feeds the load. The inverter ratings should be provided in such a way that it should match the load and the battery voltage that is given as input to the inverter. In the other the utilization of power from the input source is not in an appropriate manner. In our proposed design this problem is overcome by providing proper switching process. Also another advantage of our proposed system is the power supply to the load is from either wind power or solar or minimizing the dependency on the mains supply(supply from EB mains).

System Design

Theproposed system consists of the boost converter design, inverter design and also takes the power output from the source which is maximum and to switch over to the main supply when both sources are not available

A.Boost Converter Design

For this system the proper selection of converters is essential Different topologies of dc-dc converters are available such as buck,boost,buck-boost,cuk.For the proposed power conditioning system we are using a boost converter since the voltage from the renewable source is not sufficient to power the load The output voltage of the boost converter is always higher than the input voltage.

The main principle related to the boost converter design is the capability of the inductor to resist the change in current by creating and destroying the field. Fig 2 shows the boost converter configuration which is used between PV panel or wind turbine and battery.

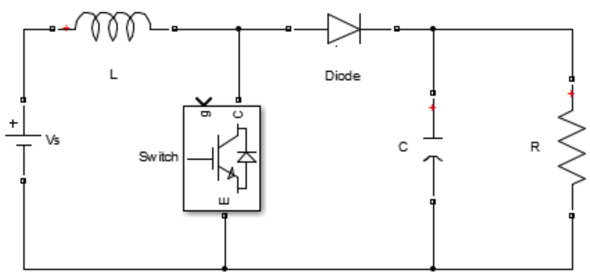


Fig 2.Circuit of Boost Converter

During the on-state, the switch is closed which makes the output voltage to appear across the inductor L.Thus the current flowing through the inductor(I_L) increase during the time period t.

$$\frac{\Delta I_L}{\Delta t} = \frac{Vs}{Vo}$$

At the end of the on time the inductor current I_L is given as

$$\Delta I_{Lon} = \frac{1}{L}\int_0^{DT} Vs\, dt$$

$$= \frac{DT}{L} Vs$$

Where D is the duty cycle. It represents the part of the commutation period when the switch is turned on.

During the off state, the switch is kept on ,so I_L flows through the load. If we consider zero voltage drop in the diode, and a capacitor large enough for its voltage to remain constant., then

$$Vs - Vo = L\frac{dI_L}{dt}$$

Therefore the variation of I_L during off period is

$$\Delta I_{Loff} = \int_{DT}^{T} \frac{(Vs - Vo)}{L} dt$$

$$= \frac{(Vs - Vo)(1 - D)T}{L}$$

As the converter operates in the steady state conditions, the amount of energy stored in the inductor is same throughout the period.

$$\Delta I_{Lon} + \Delta I_{Loff} = 0$$

$$\frac{VsDT}{L} + \frac{(Vs + Vo)(1 - D)T}{L} = 0$$

This can be written as,

$$\frac{Vo}{Vs} = \frac{1}{(1 - D)}$$

From this duty cycle for the converter is calculated as

$$D = 1 - \frac{Vs}{Vo}$$

The above equation indicates that the output voltage is always greater than the input voltage and with increase in the value of duty cycle the output voltage also increases.

The boost is operated in the continuous current mode in which the inductor current never falls to zero. So the inductor should be chosen such that maximum output voltage is obtained. The inductor value is given by,

$$L = \frac{Vs * (Vo - Vs)}{\Delta I_L * f * Vo}$$

wherefs is switching frequency and ΔI_L is the ripple current of the inductor which should be maintained between 20% to 40% of the output current and is given by

$$\Delta I_L = (0.2\ to\ 0.4) * Iomax * \frac{Vo}{Vs}$$

Here Iomax is the maximum output current thatis supplied to the load. Also the minimum value of the capacitance is maintained in order to keep the output voltage when the load value exceeds. The capacitance value is

$$Cmin = \frac{\text{Iomax} * \text{D}}{\text{fs} * \Delta\text{Vo}}$$

Here ΔVo is the desired output voltage ripples and in order to limit the voltage ripple due to the output capacitor the formula is given as,

$$\Delta Vo(ESR) = ESR * (\frac{Iomax}{(1 - D)} + \frac{\Delta I_L}{2})$$

ESR is nothing but the extra series resistance added to the capacitor to limit the current.

3.Battery

The battery is a storage device which is used to store power in the form of charge. When the power is not available from the sources it will supply power to the load .Here a lead acid battery is used to store charge. This battery is used most widely for a domestic application(in home, office etc.,) dueto. Large number of batteries connected together in series to form a battery bank..

- Low power to weight ratio
- low cost
- less maintenance

- improved storage time

Large format lead acid designs are widely used in backup power supplies in high availability settings like hospitals and stand alone power systems. Lead acid battery cell consists of two plates which are immersed in the sulfuric acid solution. The positive plate(anode) is made up of lead oxide(PbO_2) and the negative plate is made up of lead(Pb).The battery operates in two modes.

1)Charging: In charged state, each cell contains negative plates of elemental lead(Pb) and positive plates of lead oxide(PbO_2) in an electrolyte. The charging of the battery is done by the removal of electrons from positive plates to the negative plates. The chemical reaction during charging is given by,

Positive plate:

$PbSO_4(s)+H^+(aq)+2e \rightarrow Pb(s)+HSO_4(aq)$

Negative plate:

$PbSO_4(s)+2H_2O(l) \rightarrow PbO_2+HSO^-_4(aq)+3H^+(aq)+2e^-$

b)Discharging: During discharge through the load both the positive plates become lead sulfate($PbSO_4$).the electrolyte losses sulfuric acid. The discharging is done by the conduction of electrons from the negative plate back to the positive plate.

Positive plate:

$Pb(s)+HSO^-_4(aq) \rightarrow PbSO_4(s)+H^+(aq)+2e^-$

Negative plate:

$PbO_2(s)+HSO^-_4(aq)+3H^+(aq)+2e^- \rightarrow PbSO_4(s)+2H_2O(l)$

Certain points are to be kept in mind while charging and discharging the battery. Over charging leads to the increase in sulfation and the battery will be spoiled. Over charging also causes some adverse effects. They are electrolysis of water and generation of hydrogen gas. Also the electrolysis of other compounds generates poisonous gases. The battery can bulge and deformation can occur. The following steps are taken to ensure the life of battery is maintained for long time:

- The depth of discharge should be controlled
- If the battery is fully charged and it is not utilized ,then a method called "float" is made to preventleakage current
- Pulsing to break up chunks of lead sulfate

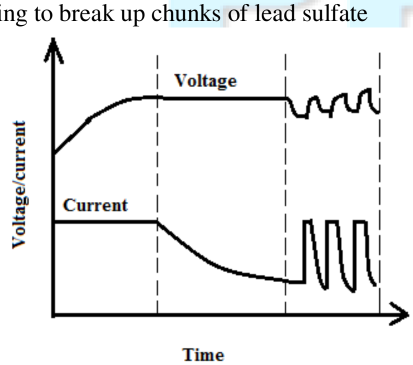


Fig 3.Battery Characteristics

The Fig 3 shows characteristics of the battery during charging. From the graph we can see terminal voltage of the battery increases and the corresponding current value decreases while charging. In order to maintain a good charge profile Terminate the charging process when the state of charge is 80%.Also the charging voltage should be maintained constant.

4. Inverter Design

The single phase inverter is used to supply the load with necessary voltage. It receives its dc supply either from the battery or rectifier or dc source from a renewable system like PV panel and wind turbine. In our system the inverter receives its power from the battery bank. The switches used here is IGBT for purpose of power flow
The circuit diagram consists of IGBTs in which they are connected to form a bridge circuit bridge circuit

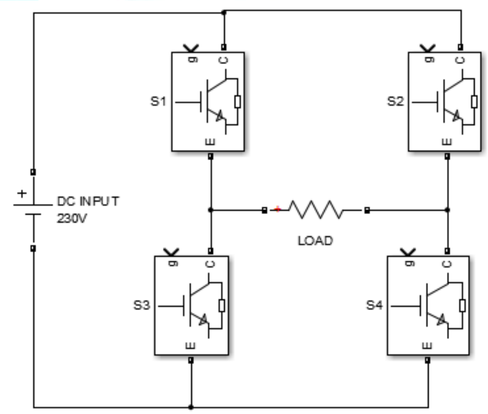


Fig 4.Inverter configuration

During the first half of the period the IGBTs S1 and S4 are turned on by giving pulses to its gate terminal. During this time the input supply is 220v DC and at the output the 220v is applied across the load. The current starts from the supply positive, S1, S2, load and to the negative of the supply. The circuit diagram of the inverter is shown in fig 4.During the next phase the switches S2 and S3 are turned on turned. Now the output voltage is equal to the input supply voltage but in the opposite direction. The current path is given V+,S2,S3, load, and V-.Thus the cycle continuesthe voltage and current applied to the load is alternating in nature thereby converting from dc to ac voltage.

5. Simulations and Result

The simulation of the proposed power conditioning system is simulated using MATLAB and simulink is shown in fig 5. Which consists separate boost converters for renewable energy source which is represented by a dc voltage source, battery bank(20 number batteries).

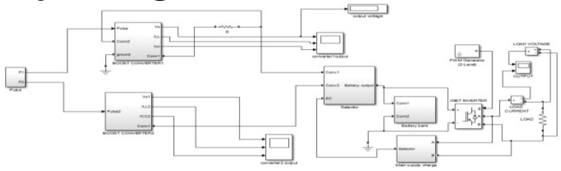


Fig 5.Complete simulation of the power conditioning system

The parameters for the boost converter are the input voltage(12V dc),output voltage 230V dc,switching frequency of about 20Khz.The inductance and capacitance value are calculated using the formula described in section III.The battery bank is represented by the string of a 20 number of batteries connected in series. The nominal voltage value, rating in ampere hours, and state of charge are specified for a typical lead acid battery. The battery bank subsystem is shown in fig 6.

In order to select the maximum output to the battery a subsystem which selects the maximum output to be used by the battery for charging. Thus we can minimize the dependency of the main ac supply.

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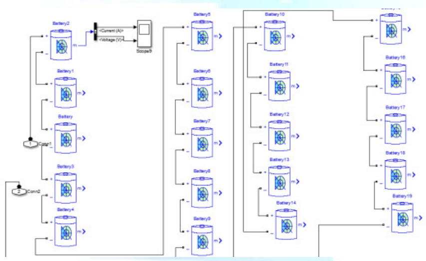

Fig 6.Battery bank in the subsystem

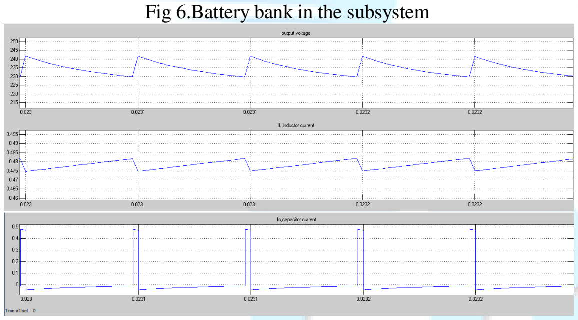

Fig 7.Converter output waveforms

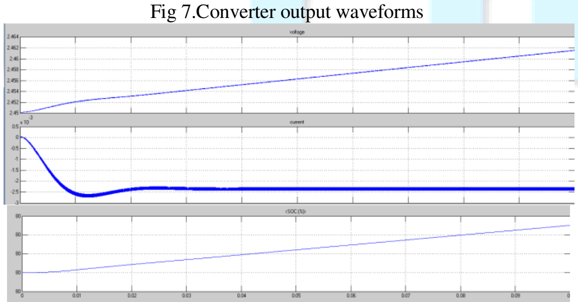

Fig 8.Battery output waveforms

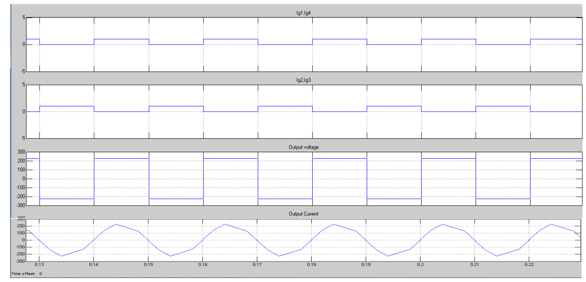

Fig 9.Inverter output waveforms

The converter used here is of special type that it acts as both converter and inverter so that when the both sources are not available so that we can charge from ac supply in which inverter acts as converter which converts ac into dc supply. The converter output waveform(Fig 7)and the battery output voltage, current and state of charge(Fig 8).Also the load output voltage waveforms are shown(Fig 9)

6. Conclusions

The proposed system provides good efficiency by eliminating the transformer .The experimental results were verified by the simulation results. This shows improved efficiency of the proposed system even though the increased number of battery strings. The losses due to the battery bank is negligible when compared to the losses contributed by the transformer .Thus this power conditioning system proves to be one of the promising solution for the future since losses are reduced considerable amount. Also the control of such systems can be carried out further. This is the future scope of the system.

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