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HARMONICS ANALYSIS AND SUPRESSION OF LEAKAGE CURRENT IN DIODE CLAMPED MULTILEVEL INVERTER BASED FUEL CELL SYSTEM

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Abstract-In this paper, the leakage current paths in Fuel Cell five level diode-clamped multilevel inverter are analyzed and supressed and also harmonics are eliminated.This simplified leakage current can be verified by using Matlab/Simulink model.

I.INTRODUCTION

Renewable energy is generated from natural resources such as water, sunlight ,wind, rain, tides geothermal sources and biomass sources such as energy crops. Renewable energy sources are continually and naturally replenished in a short period of time. In contrast ,fuels such as coal, oil and natural gas are non-renewable. Once a deposit of these fuels is depleted it cannot be replenished. Both energy sources are used to generate electricity. The widely used renewable sources are: Solar, Wind, Geothermal, Water, Biomass and Hydrogen. A Fuel Cell is a device that uses hydrogen as a fuel to produce electrons, protons, heat and water. Fuel Cell technology is based upon the simple combustion reaction given in equation,

$$H2(g) + \frac{1}{2}O2\ (g) \rightarrow H2O$$

A Fuel Cell will produce electricity as long as fuel is constantly supplied. The basic design of a Fuel Cell involves two electrodes on either side of an electrolyte. Hydrogen and oxygen pass over each of the electrodes and through means of a chemical reaction, electricity, heat and water are produced. Hydrogen fuel is supplied to the anode (negative terminal) of the fuel cell while Oxygen is supplied to the cathode (positive terminal) of the fuel cell. Through a chemical reaction, the hydrogen is split into an electron and a proton. Each takes a different path to the cathode. The electrons are capable of taking a path other than through the electrolyte, which when harnessed correctly can produce electricity for a given load. The proton passes through the electrolyte and both are reunited at the cathode. The electron, proton, and oxygen combine to form the harmless by product of water. The major disadvantage of the fuel cell is that it is currently more expensive then other forms of power conversion. But this is a barrier that is soon to be broken. To address this cost barrier the government has awarded $350 million in research grants to several companies to lower the initial cost of the cell to the necessary price range. The government is working in this area though a branch organization of the Department of Energy, called the Solid State Energy Conversion Alliance (SECA). The SECA has distributed money and provided help to four major companies in an effort to break the cost barrier by the year 2010. Once this barrier is broken it is widely speculated that fuel cells will become a dominant source of energy conversion. The reason for their desirability is that they are extremely efficient, simple, have virtually no emissions, and they run silent.Current fuel cells, when operated alone have efficiencies of about 40%-55%, and when they are used with CHP they can reach efficiencies of 80%. This is a dramatic improvement over a current internal combustion engine which is limited to an efficiently of about 30%.

II.FUEL CELL

A cell capable of generating an electricity by converting the chemical energy of a fuel directly into electrical energy.The Fuel Cell is similar to other cells in the respect that it consists of positive and negative electrode with an electrolyte between them.Fuel in a suitable form is supplied to the negative electrode and oxygen from the positive electrode. When the cell operates the fuel is oxidised and the chemical reaction provides the energy that is converted into electricity. Fuel Cells differ from conventional electric cells in the respect that the active material (*i.e* . fuel and oxygen) are not contained within the cell but are supplied from outside. Main uses of fuel cell are in power production, automobile vehicles and in military use.

As per the fuel used the main types of Fuel Cells are:

i. Hydrogen(H_2) Fuel Cell
ii. Hydrazine(N_2H_4) Fuel Cell
iii. Hydrocarbon Fuel Cell
iv. Alcohol Fuel Cell

Of these the Hydrogen-Oxygen Fuel Cell is widely used.

Components Of Fuel Cell System

Cells based on fossil fuels have three main components:

- The fuel processor which converts the fossil fuel into a hydrogen rich gas
- The power section consisting of the actual fuel cell
- The inverter for charging the direct current generated by the fuel cell into alternating current to the transmitted to user.

Operation Of Hydrogen-Oxygen Fuel Cell:

The Hydrogen-Oxygen fuel cell consists of two electrodes, the anode and the cathode, separated by an electrolyte. Thin layer of platinum of or other metals, depending on the type of the fuel cell, is coated on each electrode to activate the reaction between oxygen and hydrogen when they pass through the electrodes. The electrolyte is usually an aqueous solution of an alkali or acid. The electrolyte is retained in a porous membrane. The electro-chemical reaction occur at the electrodes of Hydrogen-Oxygen fuel cell. At the negative electrode H_2 is converted into hydrogen ions(H^+).At this electrode hydrogen is diffused through the permeable nickel in which is embedded a catalyst. The catalyst enables the hydrogen molecules to be absorbed on the electrode surface as hydrogen atoms which react with the hydroxyl ions(OH^+) in the electrolyte to form water The overall reaction is shown by the equation below:

$$H2(g) + ½O2\ (g) \rightarrow H2O$$

III-DC-DC CONVERTER

A chopper is a static power electronic device that converts fixed dc input voltage to a variable dc output voltage. A Chopper may be considered as dc equivalent of an ac transformer since they behave in an identical manner. As chopper involves one stage conversion, these are more efficient .Choppers are now being used all over the world for rapid transit systems. These are also used in trolley cars, marine hoist, forklift trucks and mine haulers. The future electric automobiles are likely to use choppers for their speed control and braking. Chopper systems offer smooth control, high efficiency, faster response and regeneration facility .The power semiconductor devices used for a chopper circuit can be force commutated thyristor, power BJT, MOSFET and IGBT.GTO based chopper are also used. These devices are generally represented by a switch. When the switch is off, no current can flow. Current flows through the load when switch is "on". The power semiconductor devices have on-state voltage drop of 0.5V to 2.5V across them. For the sake of simplicity, this voltage drop across these devices is generally neglected. As mentioned above, a chopper is dc equivalent to an ac transformer, have continuously variable turn's ratio. Like a transformer, a chopper can be used to step down or step up the fixed dc input voltage.

Operation

A chopper is a high speed "on" or "off" semiconductor switch. It connects source to load and load and disconnect the load from source at a fast speed. In this manner, a chopped load voltage as shown in Fig. is obtained from a constant dc supply of magnitude Vs. For the sake of highlighting the principle of chopper operation, the circuitry used for controlling the on, off periods is not shown. During the period Ton, chopper is on and load voltage is equal to source voltage Vs. During the period Toff, chopper is off, load voltage is zero. In this manner, a chopped dc voltage is produced at the load terminals.

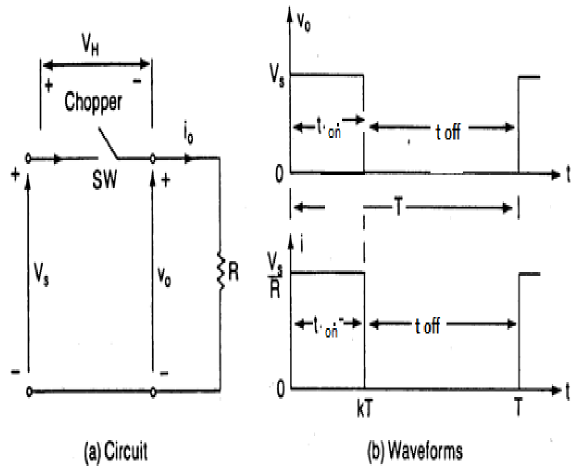

Figure 1:Chopper Circuit and Voltage and Current Waveform.

SAZZ CONVERTER (Snubber Assisted Zero Voltage and Zero Current Transient)

The SAZZ converter is made specially for fuel sources. Snubber is required to suppress the rate of rise forward voltage across the power semi conductor devices(dv/dt).The snubber circuit is basically a series connected resistor and capacitor across the thyristor. Zero Voltage and Zero Current transient is associated with resonant circuits. Resonant power converters contain resonant L-C networks whose voltage and current waveforms vary sinusoidally during one or more subintervals of each switching period. These sinusoidal variations are large in magnitude, and the small ripple approximation does not apply.The SAZZ converter normally has two switches when compared to other converters. It boost up the output DC voltage. This converter finds its application in electric vehicle.

Circuit Diagram

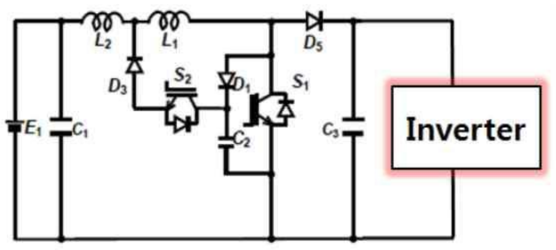

Figure 2:Circuit Diagram Of SAZZ Converter

Operation

The main parts of the SAZZ Converter are: two switches (S1 and S2), three diodes (D1,D3 and D5) and a capacitor C2. This configuration retains the desirable properties of the low turn on loss and low turn off loss by so called "soft switching". When the switch S1 turns on, the current rise through the switch is limited by the additional inductor (SL1). On the other hand, when switch S1 is turned off, the voltage rise across the switch is limited by the snubber capacitor C2.Thus, the converter uses a loss less snubber and high efficiency operation can be achieved**.** The main function of this converter is to reduce switching losses of the devices by operating them either in zero voltage or in zero current switching mode.Hence the current or voltage waveform becomes quasi-sinusoidal instead of square-wave in the DC-DC PWM converters.

Advantages

- Zero-voltage switching also reduces converter-generated EMI.
- Zero-current switching can be used to commutate SCRs.
- It can be operated at high switching frequency.
- High efficiency as switching loss is reduced.

IV-MULTILEVEL INVERTER

The inverters are DC to AC converters .The DC source is normally a battery or a output of controlled rectifier. Inverters finds its application in induction motor drives, UPS, induction heating etc. The output voltage waveform of the inverter can be square wave, quasi square wave or low distorted sine wave. The output voltage can be controlled with the help of drives of the switches. The PWM techniques are most commonly used to control the output voltage of the inverter .The output voltage of the inverter contains harmonics whenever it is non-sinusoidal. These harmonics can be reduced by using proper control schemes.The multi-level inverter is to synthesize a near sinusoidal voltage from several levels of dc voltages. As number of levels increases, the synthesized output waveform has more steps, which provides a staircase wave that approaches a desired waveform . Also, as steps are added to waveform, the harmonic distortion of the output wave decreases, approaching zero as the number of voltage levels increases.

Types Of Mutilevel Inverters

The Multi-level inverters can be classified into three types.

- Diode –clamped Multi-level inverter
- Flying –capacitor Multi-level inverter
- Cascade Multi-level inverter

Diode –Clamped Multilevel Inverter

Circuit Diagram

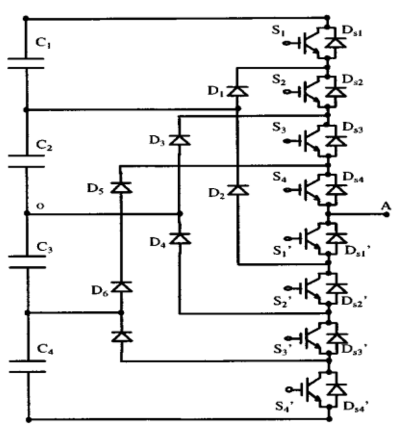

Figure 3: Five Level Diode Clamp Multilevel Inverter

CONSTRUCTION

The first practical multilevel topology is the neutral-point-clamped (NPC) PWM topology. The diode-clamped inverter provides multiple voltage levels through connection of the phases to a series bank of capacitors. The concept can be extended to any number of levels by increasing the number of capacitors. . Although the three-level NPC topology works well with high power factor loads, NPC topologies with more than three levels are mostly used for static var compensation circuits. A M -level inverter leg requires(M-1)storage capacitors, 2(M-1)switches and(M-1)(M-2) clamping diodes. For the five-level case, a total of eight switches and twelve diodes of equal voltage rating are used, which are the same with the conventional diode clamping inverter with diodes in series.

OPERATION

MODE 1

In this ,switches S2,S3.S4 are always ON, while S1 and S1' work alternatively connecting the inverter output to$V_{dc/2}$ and $V_{dc/4}$ respectively.

MODE 2

In this, switches S3,S4,S1'are always ON, while S2 and S2' work alternatively connecting the inverter output to $V_{dc/4}$ and 0 respectively.

MODE 3

In this S4,S1',S2'are always ON, while S3and S3' work alternatively connecting the inverter output to 0 and $-V_{dc/2}$ respectively.

MODE 4

In this,S1',S2',S3'are always ON, while S4 and S4' work alternatively connecting the inverter output to $-V_{dc/4}$ to $-V_{dc/2}$ respectively

The following rules govern the switching operation of a M-level diode clamping inverter:

- At any moment, there must be M-1 neighbouring switches that are ON.
- For each two neighbouring switches, the outer switch can only be turned on when the inner switch is ON.
- For each two neighbouring switches, the inner switch can only be turned off when the outer switch is OFF

Advantages

- Voltages across the switches are only half of the dc-link voltage.
- The first group of voltage harmonics is centered on twice the switching frequency.

V-PWM TECHNIQUES

The output voltage of the inverter needs to be varied as per load requirement. Whenever the input DC varies the output voltage can change. Hence these variations need to be compensated. In case of motor drives the ratio of voltage to frequency is maintained constant. The output voltage and frequency of the inverter is adjusted to keep V/F constant. These all the reasons which indicate that the output voltage of the inverter is to be controlled. This technique are mainly used for voltage control. This is the most efficient method and they control the drives of the switching devices. The following are the types of PWM Techniques

- Single Pulse Width Modulation Techniques
- Multiple Pulse Width Modulation Techniques
- Sinsoidal Pulse Width Modulation Techniques
- Modified Pulse Width Modulation Techniques
- Phase Displacement Control

These techniques differ from each other in the harmonic content in their respective output voltage.Thus the choice of PWM technique depends on permissible harmonic content in the inverter output voltage.

Single Pulse Width Modualtion

There is only one pulse per half cycle and the width of the pulse is varied to control the inverter output voltage.

- Reference Wave: Rectangular Wave
- Carrier Wave:Triangular Wave

Frequency of reference signal determines the fundamental frequency of the output voltage

Multiple Pulse Width Modulation

The harmonic content can be reduced by using several pulses in each half cycle of the output voltage. The width of all pulse is same.

- Reference Wave: DC control voltage
- Carrier Wave: Triangular Wave

The carrier frequency determines the number of pulses per half cycle.

Sinsoidal Pulse Width Modulation

The Sinsoidal Pulse Width Modulation is most widely used method of voltage control in inverters. The width of each pulse is weighted by the amplitude of sine wave at that instant.

- Reference Wave: Sine Wave
- Carrier Wave:Triangular Wave

The width of pulses depend upon the amplitude of the sine wave.If amplitude is increased ,width increase. The rms value of output voltage of the inverter depends upon width of the pulses. These width depend on modulation index which controls the output voltage of the inverter.

Modified Pulse Width Modulation

The widths of the pulses near the peak of the sine wave do not change much when modulation index is changed. Hence carrier is suppressed at ± 30º in the neighbourhood of peak of sine wave. Here the triangular wave is presented for the period of first 60º and last 60º of the half cycle of sine wave. The middle 60º of the sine wave do not have the triangular wave. Hence the generated

PWM have less number of pulses. The rms value is more for the modulation index. The harmonic content is also reduced. This control scheme also reduces switching losses. The implementation of this scheme is relatively complex than sine PWM.

Advantages

- Output voltage can be controlled without any additional components.
- Lower order harmonics can be eliminated or minimised along with its output voltage control.
- As higher order harmonics can be filtered easily the filtering requirements are minimised.

VI-SIMULATION RESULTS

MATLAB

MATLAB is an interactive system for numerical computation. Numerical analyst Clever Moler wrote the initial FORTRAN version of MATLAB in the late 1970s as a teaching aid. It become popular for both teaching and research and evolved into a commercial software package written in C. For many years now, MATLAB has been widely used in universities and industries. Matlab has several advantages over more traditional means of numerical computing.

- It allows quick and easy coding in a very high level language.
- Data structures require minimal attention arrays need not to be declared
- An interactive interface allows rapid experimentation and easy debugging.
- High quality graphics and visualisation facilities are available.
- MATLAB M-files are completely portable across a wide range of platforms.
- Toolboxes can be added to extent the system.

Furthemore, MATLAB is a modern programming language and problem solving environment.I t has sophiscated data structures contains built in editing and debugging tools and support object oriented programming.Being interpreted MATLAB inevitably suffers some loss of efficiency compared with complied languages but built –in-performance acceleration techniques reduce the in efficiencies and users have the possibility of linking to complied FORTRAN or C code using MEX files.Matlab has a in built library to build the simulation units and run them on the same.

Simulink Model

Simulink is a block library tool for modelling ,simulating and analyzing dynamic systems. It supports linear and non-linear systems, modelled in continuous time, sampled time is a hybrid of the two. Systems can also be multirate .It is developed by the Math Works and works with their flagship product, MATLAB.

It is widely used in control theory and digital signal processing for multi-domain simulation and design. Coupled with real time workshop, another product from the math works , simulink can do automatic code generation for real time implementation of systems. As the efficiency and flexibility of the code improves, this is becoming more widely adopted for production systems, in addition to being a popular tool for embedded system design work because of its flexibility and capacity for quick iteration.A number of third-party hardware and software product s are available for use with Simulink software.

Simpower Systems

Simpower systems extend Simulink with tools for modelling and simulating basic electrical circuits and detailed electrical power systems. These tools let us to model the generation, transmission, distribution and consumption of electrical power as well as its conversion into mechanical power. Simpower systems is well suited to the development of complex ,self-contained power systems, such as those in automobiles, aircraft, manufacturing plants and power utility applications.

Features

- Enables electrical circuit modelling and simulation using standard symbols.
- Provides comprehensive block libraries for building power system model

Simulation Diagram

Fuel Cell & SAZZ Converter

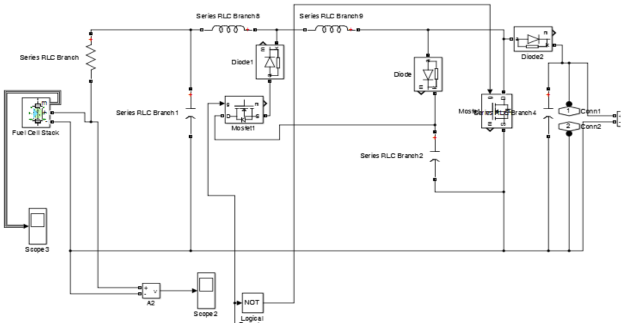

Figure 4:Simulation Diagram Of Fuel Cell And SAZZ Converter

Five Level Diode Clamp Multilevel Inverter

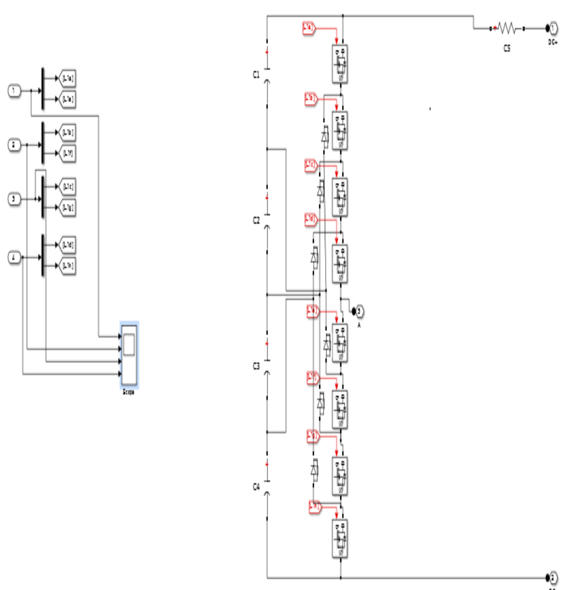

Figure 5:Simulation Diagram Of Five Level Diode Clamp Multilevel Inverter

Overall Simulation Diagram

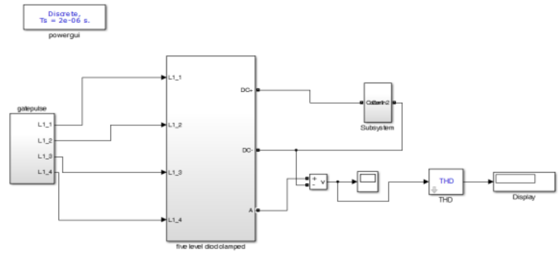

Figure 6:Overall simulation diagram

Waveform For Fuel Cell

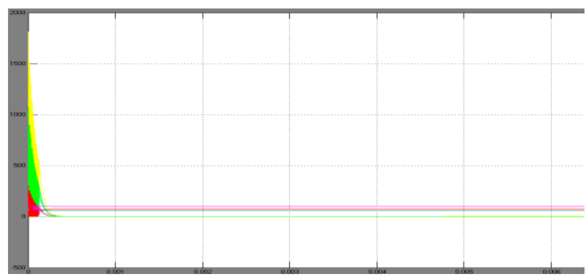

Figure7:Output Waveform Of Fuel Cell

Waveform For SAZZ Converter

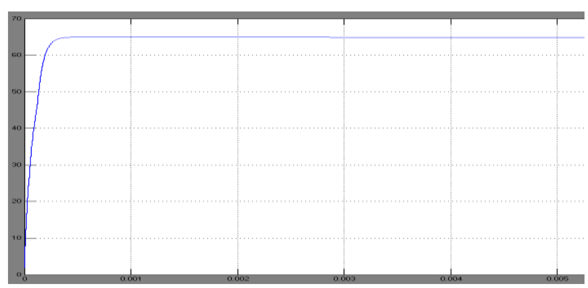

Figure 8:Output Waveform SAZZ Converter

Waveform For Multilevel Inverter

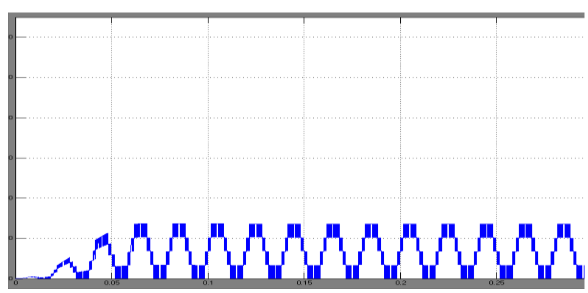

Figure 9:Output Waveform Of Five DCML

VII-CONCLUSION

The Fuel Cell used in this work converts chemical energy to electrical energy.The output of the Fuel Cell is unregulated DC voltage. The SAZZ converter which is made specially for fuel sources converts the unregulated DC voltage to a regulate DC voltage. The SAZZ converter normally has two switches when compared to other converters. This converter finds its application in electric vehicle.This SAZZ converter can be operated at high switching frequency and also it reduces switching loss. The multi-level inverter is used to synthesize a near sinusoidal voltage from several levels of dc voltages. As number of levels increases, harmonics are eliminated. The diode-clamped inverter provides multiple voltage levels through connection of the phases to a series bank of capacitors. The concept can be extended to any number of levels by increasing the number of capacitors..The boosted DC voltage from the SAZZ converter is then converted to AC voltage. Finally MATLAB/SIMULINK software is used for design and to simulate to get desired output.Using the above mentioned technique the leakage current path in DCML is suppressed and also the harmonics are eliminated.

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