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Fuzzy Control of Multicell Converter

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Abstract : *Recently, industry requires the use of static power converters for high voltages and high currents applications. So, it is necessary to use an inverter. Today inverters use high power switching transistors called IGBT's and MOSFETS. These inverters have problems in high power applications. A Stacked Multi-cell Converter (SMC) represents a new solution to the problem. A SMC is an inverter (DC-AC converter) for high voltage applications. Here the analysis of SMC at different levels which decreases the THD with increase in levels is discussed and shown. This topology called SMC (Stacked Multi-cell Converter) consists of a hybrid association of commutation cell making possible to share the voltage and current constraint on several switches and this converter is made up of by p cells and n stacks. This configuration allows to share the total voltage and current stresses among the switches and also to improve the output waveforms of the converter in terms of number of levels and switching frequency. PWM technique is used to control the rms voltage at the output. Then, it is possible to use conventional semiconductors to handle high output power. A closed loop control is proposed using MATLAB Fuzzy Logic Toolbox, to control the RMS voltage at the output.The application area for a SMC can be found in applications such as UPS, Switching Power Supplies, and motor drivers*
Keywords: *Stacked multi-cell converter, Fuzzy Logic, MATLAB, PWM*

I. Introduction

A power electronic dc to ac converter, in generic form, accepts electric power in dc form and converts it to ac waveform of different amplitude, frequency, and phase. They may be single-or three-phase types depending on their power ratings. A three-phase inverter is a combination of three single-phase inverters along with synchronization so that the three phase voltages are separated by 120 degrees. The development of static converter for high power applications are made possible by the use of flying capacitor.

A Stacked Multi cell Converter is voltage source inverter and it is a new topology based on series association of commutation cells and allows a significant reduction of the volume of the capacitors.An SMC synthesizes an AC waveform from several DC levels. The output voltage levels and the switching frequency in the output waveform can be increased. A sinusoidal pulse width modulation technique along with the fuzzy logic controller is used to control the RMS voltage value of the output waveform. With increase in the voltage steps in the output waveform the Total harmonic distortion value in the output waveform can be decreased.

II. Stacked Multicell Converter

A Stacked Multi cell converter (SMC) is a voltage source inverter (VSI) and it is classified as multilevel converter. A SMC is based on a series association of commutation cells, based on two commutation devices. A commutation cell is shown in figure 1.1. The basic switching cells have complementary states. It means that only one switch is conducting at a given time.

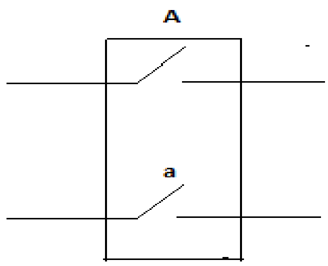

Fig 1: Commutation cell

A single commutation cell consists of two switches A and a. at a time only one switching will be in conduction i.e. Either A or a.The topology of this converter is made up of by p cells and n stacks. The cells can be increased up to p cells depending on the blocking voltage. This configuration allows sharingofthe total voltage and current stresses among the switches. Then, it is possible to use conventional semiconductors to handle high output power.

Natural balancing of a flying capacitor multilevel converter is a technique which maintains the steady state stability of the capacitor voltages by using equal duty cycles for every pair of complementary switches. This can be done by using a special pulse width modulation (PWM) scheme. In this scheme, every pair of switches has a carrier signal which has a 90 degrees phase change, a so called phase shift carrier PWM (PSCPWM). When a reference signal, normally the desired output voltage, is compared with the carriers, the switch state of the corresponding switch pair is defined. When the reference signal is above the carrier, the upper switch is on and when below, the lower switch is on.

Basic Circuit Of A Stacked Multicell Converter

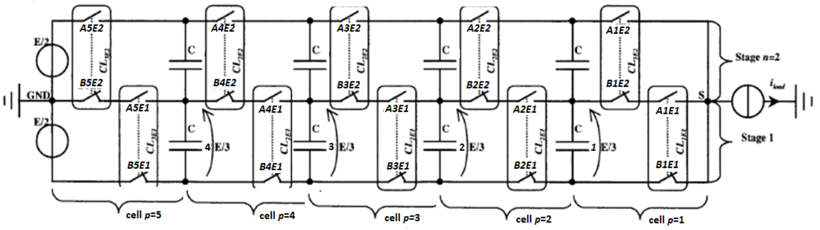

Fig 2: Basic circuit of SMC

The basic circuit of SMC is shown in fig 2.The SMC is based on hybrid association of elementary commutation cell. The commutation cells are functional only if the floating voltage sources do not provide average power.

The SMC of figure 2 is built up by p=5 columns or stages and n=2 rows or stacks. This converter uses *pxn=10* switching cells and *(p-1) x n = 8* flying capacitors. A SMC use capacitors like intermediate voltage sources. This is due to the fact that switching cells only work if they are being powered by flying voltage sources without average power.

Voltage across each capacitor is equal to

$$V= I *E/ n$$

Where E is the input voltage of the converter

The maximum number of output voltage levels is given by

$$N= p*n+1$$

1.5 Conduction Table

Switch / Time	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
T=2 ms	ON							ON	ON	ON	ON	ON
T=4 ms	ON	ON							ON	ON	ON	ON
T=6 ms	ON	ON	ON							ON	ON	ON
T=8 ms	ON	ON	ON	ON							ON	ON
T=10ms	ON	ON	ON	ON	ON							ON
T=12ms	ON	ON	ON	ON	ON	ON						
T=14ms		ON	ON	ON	ON	ON	ON					
T=16ms			ON	ON	ON	ON	ON	ON				
T=18ms				ON	ON	ON	ON	ON	ON			
T=20ms					ON	ON	ON	ON	ON	ON		
T=22ms						ON	ON	ON	ON	ON	ON	
T=24ms							ON	ON	ON	ON	ON	ON

Table 1: Conduction table of MOSFET

OUTPUT WAVEFORM

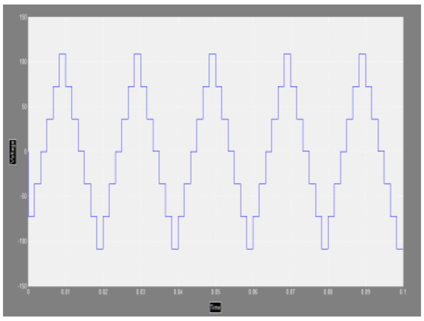

Fig 3: Output waveform of 6*2 SMC

ADVANTAGES

- Increase input voltage
- Lower power components
- Stacked multicell converter allows to share the voltage and current stresses among the devices thereby enabling the use of low power devices in high power application.
- Lower voltage switches have lower conduction losses and can switch at a higher frequency .

Applications OfMulticell Converter

- Medium voltage drives
- Input chopper for locomotives
- Multilevel rectifiers
- DC/DC converters

III. Various Pwm Strategies

PWM techniques are characterized by constant amplitude pulses. The width of these pulses is, however, modulated to obtain output voltage control and to reduce its harmonic content. Different PWM techniques are,

1. Single pulse modulation
2. Multiple pulse modulations
3. Sinusoidal pulse width modulation (SPWM)

SINUSOIDAL PWM TECHNIQUE

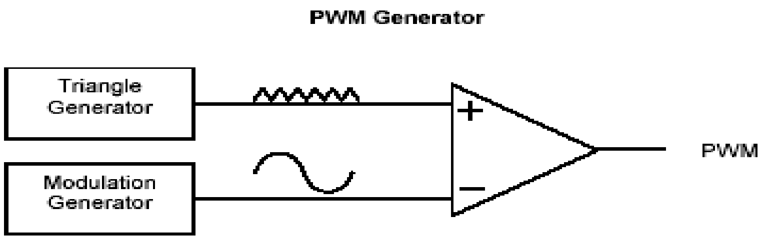

Fig 4: Sinusoidal PWM technique

The Sinusoidal Pulse Width Modulation (SPWM) is a well known wave shaping technique in power electronics as shown in Fig 1.16. For realization, a high frequency triangular carrier signal ($V_{c)}$ is compared with a sinusoidal reference signal (V_r) of the desired frequency. The crossover points are used to determine the switching instants. The magnitude ratio of the reference signal (V_i) to that of the triangular signal ($V_{c)}$) is known as the modulation index (m_i).

The magnitude of fundamental component of output voltage is proportional to mi. The amplitude (V_r) of the triangular signal is generally kept constant. By varying the modulation index, the output voltage could be controlled.

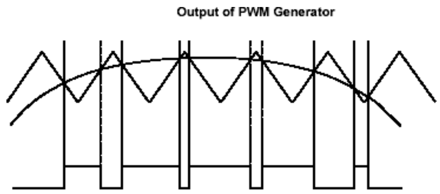

Fig 5: Output of PWM Generator

PWM is a very efficient way of providing intermediate amounts of electrical power between fully on and fully off. A simple power switch with a typical power source provides full power only, when switched on. PWM is comparatively recent technique, made practical by modern electronic power switches.

The simplest way to generate a PWM signal is the intersective method, which requires only a sawtooth or a triangle waveform (easily generated using a simple oscillator) and a comparator. When the value of the reference signal (the green sine wave i) is more than the modulation waveform (blue), the PWM signal (magenta) is in the high state, otherwise it is in the low state. PWM is also used in efficient voltage regulators. By switching voltage to the load with the appropriate duty cycle, the output will approximate a voltage at the desired level. The switching noise is usually filtered with an inductor and a capacitor.

PWM can be used to reduce the total amount of power delivered to a load without losses normally incurred when a power source is limited by resistive means. This is because the average power delivered is proportional to the modulation duty cycle. With a sufficiently high modulation rate, passive electronic filters can be used to smooth the pulse train and recover an average analog waveform.

Harmonic Analysis

The wide spread use of power electronics devices in power networks is due to the multiple function compensation, protection and interface for generators. Adapting and transforming the electrical energy they make possible the insertion in the power network in the independent generators and the renewable sources of energy however because of the switching components power electronics converters generate current and voltage harmonics which may cause measurements stability and control problems. Fig 1.19 shows the FFT analysis for a 6*2 multicellconverter the window also fig1.19 shows the THD value for a 6*2 multicell converter. The total Harmonic Distortion has further decreased to 21.30%

Since by increasing the Number Of Levels the total value of the THD (Total Harmonic distortion) can be reduced and the output voltage can be in the form of sine wave. In this paper it has been tried up to 30*2 and the harmonics are reduced and output voltage is getting closer to sine wave with increase in level.

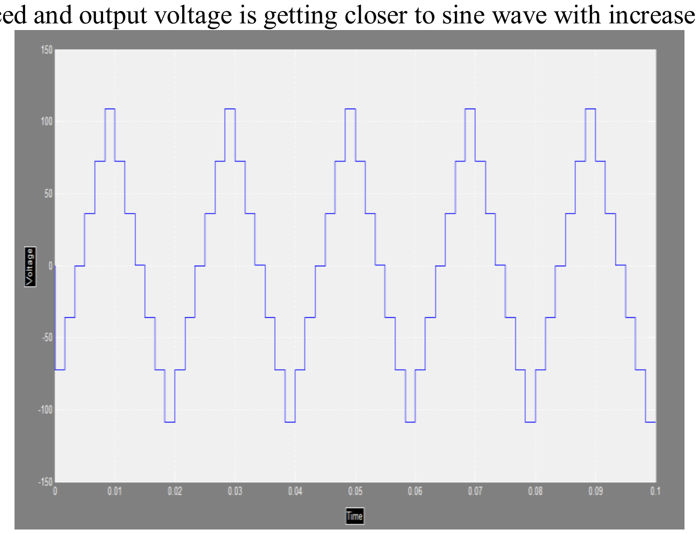

Fig 6: Output voltage - 6*2 multi-cell converter

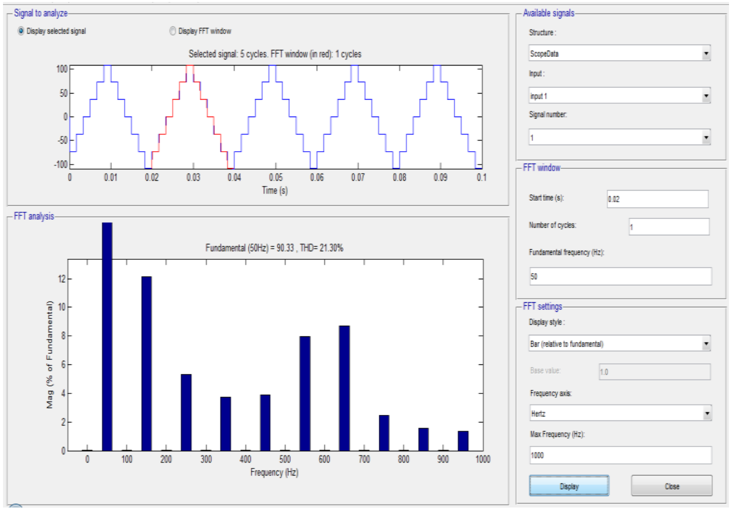

Fig 7: THD For6*2 SMC

Further the number of levels can be increased in the similar way to reduce the Total Harmonic Distortion in the output waveform. The outputs for different stages has been obtained and it has been found through MatLab simulation that with increase in levels the harmonics is reduced considerably and the output of last level upto which we have tried is shown in the forth coming figure.

Output voltage - 30*2 multicell converter

Fig 8: Output voltage - 30*2 multicell converter

Fig 8 shows the output load voltage for 30X2 multicell converter and Fig 1.21 shows the harmonic analysis window for 30X2 multicellconverter from which it can be inferred that the THD decreases with increase in level the THD for 30X2 multicellconverter is 12.49%.

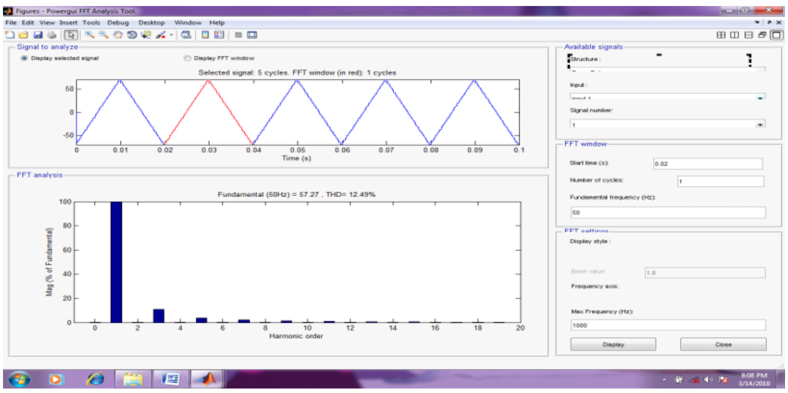

Fig 9: THD For 30*2 SMC

IV. Fuzzy Logic

Soft computing includes fuzzy logic, neural networks, probabilisticreasoning, andgeneticalgorithms.Today,techniquesoracombinationoftechniquesfromalltheseareasareusedto designanintelligencesystem.Neuralnetworksprovidealgorithmsforlearning,classification, andoptimization,whereasfuzzylogicdealswithissuessuchasformingimpressionsandreasoningonasemantic orlinguisticlevel. Probabilisticreasoningdealswithuncertainty. Althoughtherearesubstantialareasofoverlapbetweenneuralnetworks,FL,andprobabilisticreasoning ingeneraltheyarecomplementaryratherthancompetitive.Recently,manyintelligentsystems calledneurofuzzysystemshavebeenused.Therearemanywaystocombineneuralnetworks andFLtechniques.Beforedoingso,however,itisnecessarytounderstandbasicideasinthe designofFLtechniques.Inthischapter,wewillintroduceFLconceptssuchasfuzzysetsand theirproperties,FLoperators,hedges,fuzzypropositionandrule-basedsystems,fuzzymaps and inference engine, defuzzification methods, and the designofanFLdecisionsystem.

Logicscomeinmanyguises.Classicallogic,totakethemostobviousexample,maybe presentedsemanticallyusingtruthtablesorBooleanalgebrastodefinethemeaningof connectiveslike"and" or"implies",orsyntacticallyviaproofmethodssuchasaxiomatizations,Gentzensystems,orTableaux.Otherlogicsmayt akeoneguiseasprimary; substructurallogicsareoftendefinedusingGentzen systems, whilemodal logics originateviaclasses of Kripke frames. Wemay think ofsuchguisesasframeworks, within whichlogicsarisenaturallyasaresultofvarious"designchoices".Forexample,se-manticallywemightselectcertainpropertiesthatwewantfromourlogic,principles like the law of excluded middle "every proposition is either true or false" that we think should hold or not hold. From a syntactic point of view we might choose certain axioms or rules over others. Such choices might be made on philosophical grounds, or on a more practical level, based on mathematical or computational considerations.

Fuzzy logics, the subject matter of this course, are characterized as "logics based on the real numbers". That is, logics where the truth degrees are taken from the real line R, and connectives are interpreted as functions on R. With FL, we can specify mapping rules in terms of words rather than numbers. Computing with the words explores imprecision and tolerance. Another basic concept in FL is the fuzzy if–then rule. Although rule-based systems have a long history of use in artificial intelligence, what is missing in such systems is machinery for dealing with fuzzy consequents or fuzzy antecedents. In most applications, an FL solution is a translation of a human solution. Thirdly, FL can model nonlinear functions of arbitrary complexity to a desired degree of accuracy. FL is a convenient way to map an input space to an output space.

Fuzzy logics provide the basis for logical systems dealing with vagueness, e.g. for formalising common natural language predicates such as "tall" or "fast". Design choices in this framework are made as to which real numbers to take as truth values, and which properties connectives should have. In fact logics based on real numbers occur in a number of areas in logic.

Membership Function

In our project a triangular membership function is used. Because they are easier to represent and implement, as a result the complexity of the problem is reduced. The fuzzy set definition is more important than the shape of the membership function.

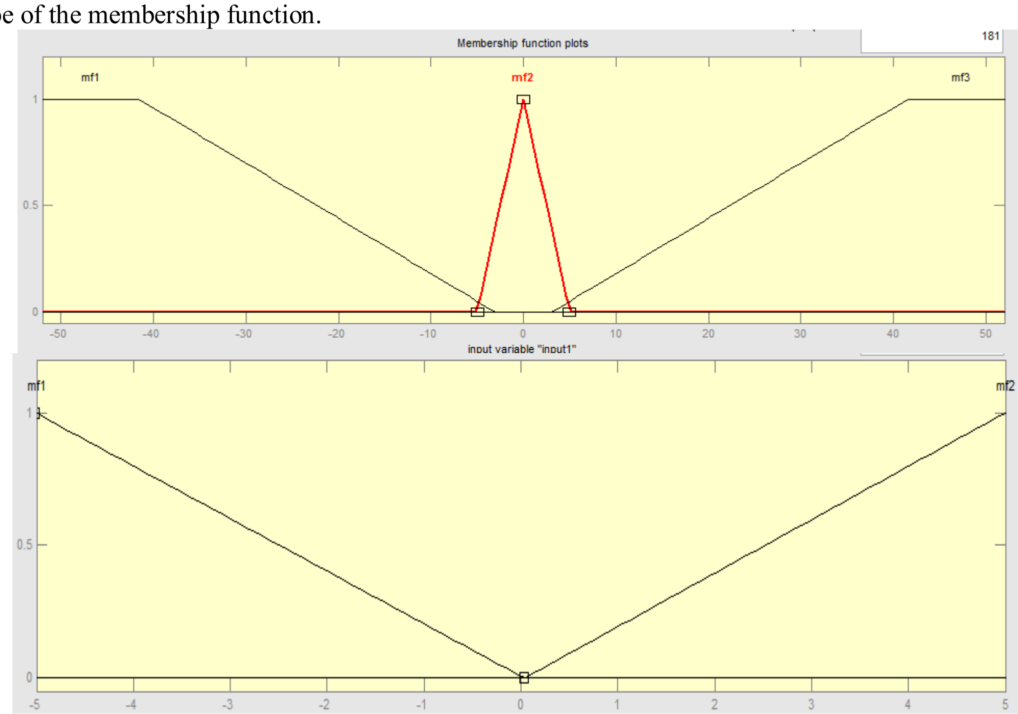

Fig 10: Membership Functions for the input.

The figure 10 is for input membership function set for the closed loop control of the PWM based 6X2 multi-cell converter. The input to the fuzzy logic controller is the error signal created by getting the difference between the reference signal that can be set by the user and the RMS voltage that has been obtained at the output, the range is fixed as 0 to 52 voltage RMS.

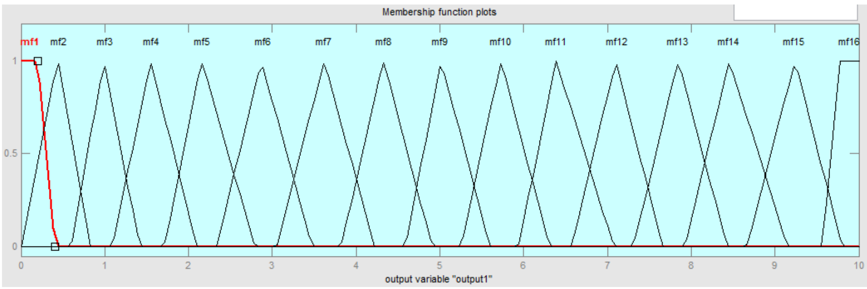

Fig 11: Membership functions for the output

The figure 11 is for output membership function set for the fuzzy controller. The output range is fixed between 0 to 10 which is the time input given to the pulse generator

RULE VIEWER

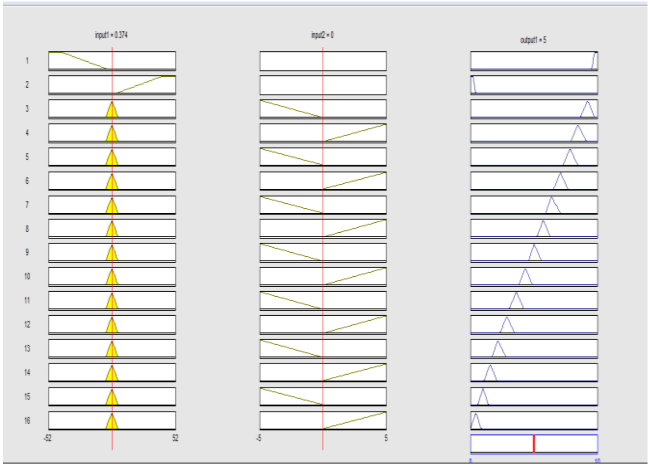

Fig 12: Fuzzy rule Viewer for 6*2 closed loop controller

V. Simulation And Analysis

1. OPEN LOOP CONTROL

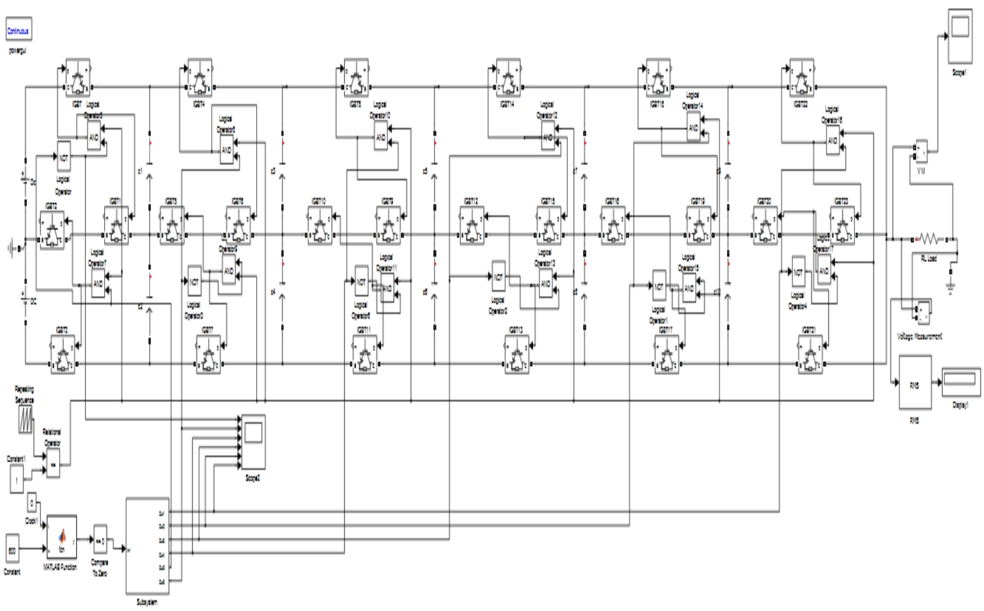

Fig 13: Open loop circuit for 6*2 Multicell Converter

Fig 13 shows the circuit for Open Loop control of 6*2 stacked multicell converter. Here we vary the gate pulses using PWM technique to get different output voltages across the load.

OUTPUT WAVEFORM

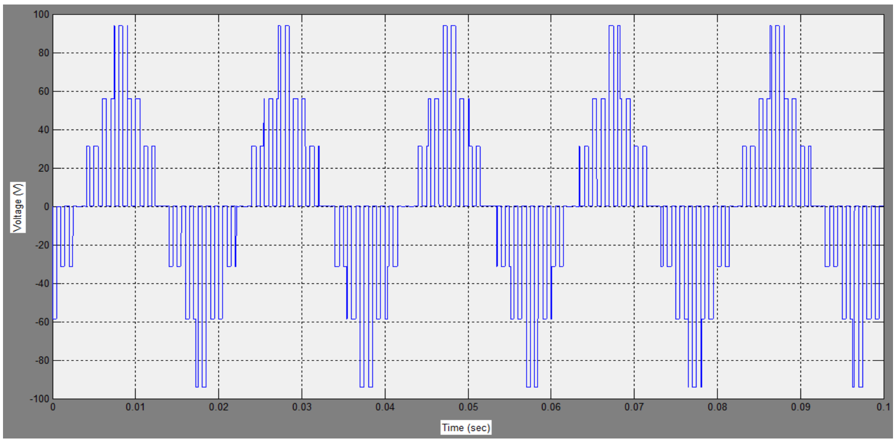

Fig 14: Output waveform for Open Loop Control of 6*2 Multicell Converter

Fig 14 shows the output waveform of 6*2 SMC using PWM technique to control the RMS value of output voltage.

JOHNSON COUNTER

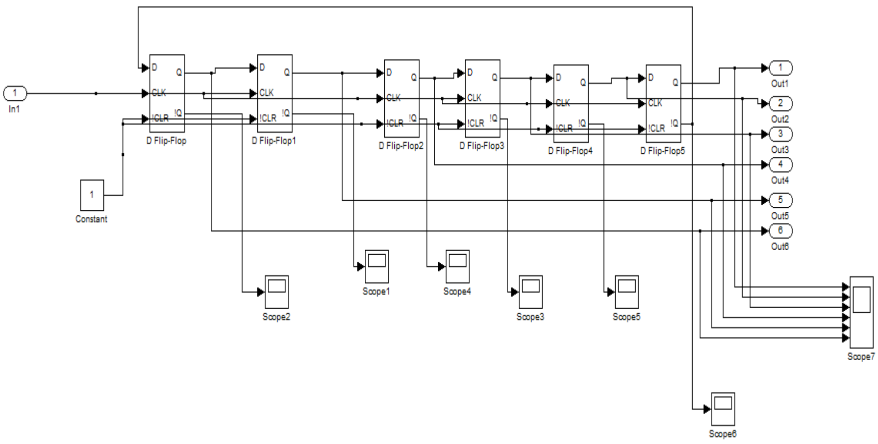

Fig 15: Johnson Counter

Fig 15 shows the circuit for Johnson counter with six D-flip flops. Johnson counter is used to trigger the gate pulses of IGBT at fixed intervals to get the desired output.

OUTPUT WAVEFORM

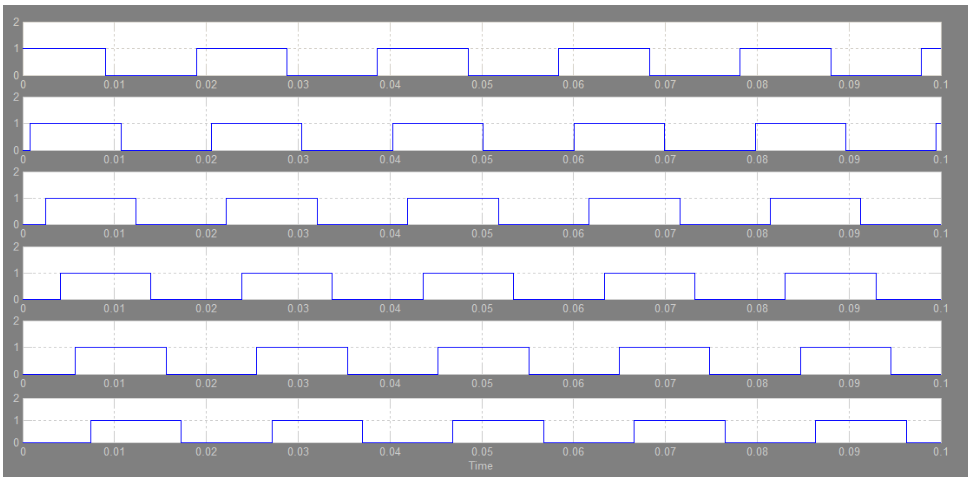

Fig 16: Pulses of 6*2 SMC

2. CLOSED LOOP CONTROL

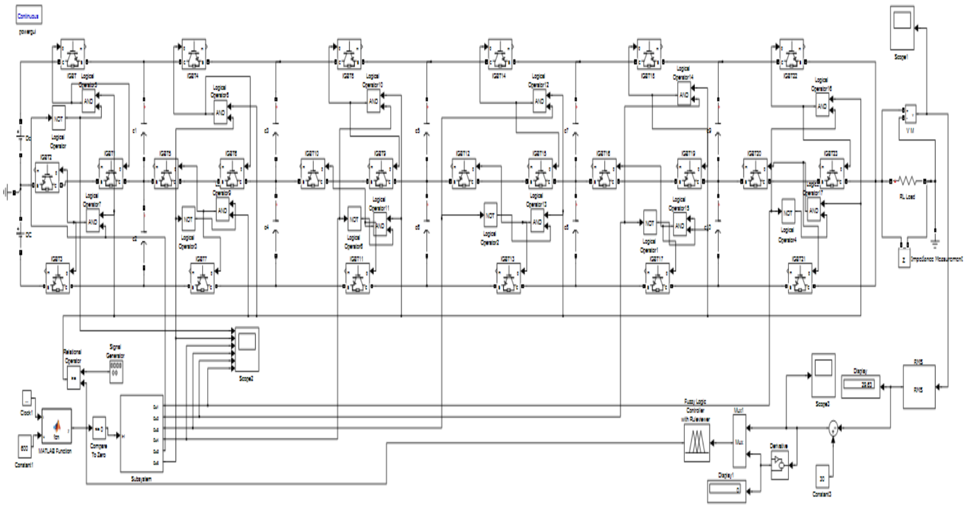

Fig 16: Closed Loop circuit for 6*2 Multicell converter

Fig 16 shows the circuit for closed loop control of 6*2 stacked multicellconverter. Here a reference voltage is fed and compared with the output voltage. The error and change in error is fed to fuzzy logic controller and the output of the fuzzy logic controller is used to control the gates pulses of IGBT to get the desired output Voltage.

OUTPUT WAVEFORM

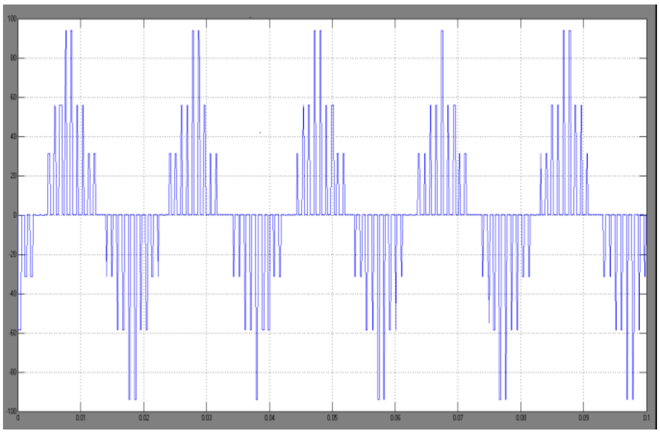

Fig 17: Output waveform for Closed Loop Control of 6*2 Multicell Converter

VI. Conclusion

This project presents a new stacked multi cell converter topology. The main advantage compared to classical multi cell converter is that it has less capacitor and these capacitors are smaller. Moreover, this new topology has the same dynamics performance as classical multi cell converters. Theoretical analysis and simulations results shows that with increase in number of levels in the output voltage of the converter, Total Harmonic Distortion value are decreased, used Pulse width modulation technique (PWM) to control the input voltage of the converter implemented FUZZY Logic controlling the RMS value of output voltage of 5*2 stacked multi cell converter circuit in MATLAB. This feature largely simplifies the complexity of control. The converter is completely free of the commutation problems associated with conventional multi cell converters and it offers the possibility of better efficiency than the conventional multi cell converter. This project can be used for some of the applications like uninterrupted power supplies, Renewable energy system, Induction motors.

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