AN IMPROVED VOLTAGE BALANCING METHOD FOR GRID CONNECTED PV SYSTEM BASED ON MMC

ABSTRACT

High Power Multilevel Converters, 2 level VSI and three level NPC converters are traditional converters, Modular Multilevel converters are emerging High power converters (KW, 100’s of KW to GW power level). MMC are used in Industry for applications in motor drives, HVDC, FACTS for power quality improvements etc. Modular Multilevel Converter (MMC) is considered as one of the most promising topologies for renewable energy application. The MMC has attractive features such as modular realization, scalability, and transformer less operation which makes it a suitable converter especially for PV system. For the satisfactory operation of MMC, it is important to maintain balanced voltage across each sub modules (SMs). This paper proposes an improved balancing approach based on Space Vector Pulse Width Modulation (SVPWM) for three-phase multi-string PV system based on MMC. The proposed method along with the control strategy uses only one SVPWM, which not only reduce the calculation but also balance the SM capacitor voltage, realize the independent MPPT of each PV string and reduce the circulating current.

Keywords: MMC; Space vector PWM; PV system; voltage balance; circulating current

I. INTRODUCTION

If we want to send power from source to load Fig: 1 and to control the power flow from source to load a variable resistor acts as voltage divider is used, which is not an efficient system because when we transfer the power through variable resistor huge amount of power loss occur (I2R) occur and the efficiency of the system go down. In all the High power converters efficiency is a very important factor. If the efficiency in the system is not high, losses in the system are very high, which appears as heat in the system, we need large size heat sink to dissipate heat, and heat sink is made of aluminum. Heat sinks constitute a major component in all power converters because it occupies a substantial volume and weight of the converter. Important Thumb Rule followed in industry is according to the Arrhenius principle for every 10o C raise in temperature of the power device will reduce its life time by Half. If we are operating the power device at elevated temperature for prolonged duration of time we are reducing the life time of the converter. Keeping the temperature in control in power devices is very important and there are lot of techniques to do that.

The solution to control the power flow from source to load by increasing the efficiency of the converter is replacing the variable resistor with fully controlled switch as shown in fig:2 by ON & OFF.

If the switch is On voltage is impressed across the load and when the switch is turned off no voltage is appeared across the load. Voltage across the load is series of pulses which is shown in fig:2b.

During $T_{on}$ $V_L = V$
The arrangement of source, switch and load with resistor works well, unfortunately all the loads in nature are Inductive loads, the power converters feed to loads such as Motor Transformer are inductive in nature. If load become in inductive in nature we face a challenge because of property of inductive loads. Inductive loads are represented as current source in circuit Fig:3. Now the current source

Now current source put into circuit along with a switch then we face a challenge. What is the challenge?

The challenge comes from the property of the current source. Current source and voltage source are dual in nature in terms of their property.

Current sources can be shortcircuited but they can not be opend.

Voltgae sources can be open circuited but can not be shorted.

By open circuiting the battery we can move from one place to other place and we can handle in our hands but if we short circuited the terminals of the battery, then a very large current flows through the wire which is shorting the battery. So we cannot short- circuit voltage source because the current will be enormously high and we don’t know exactly what is the magnitude of current only limited by the internal impedance of the voltage source. Similarly for a current source we can readily short circuit but we cannot open it because if we open a current source we don’t know what is the voltage across the current source.
In order to satisfy the properties of both voltage source and current source we need 2 switches S1 & S2 shown in Fig:4. Using these two switches we are transferring the power from source to load.

We have achieved the first criteria of voltage source and current sources. Note that these two switches can not be operated together. If they operated properly the sources will not satisfy. Both the switches are operated in complimentary fashion.

Realization of Switches: switches like thyristors in the past decade’s thyristors have been quite popular but they are semi controlled switches. Switch S1 is replaced with IGBT for Medium Voltage Levels and MOSFET for low voltage levels and S2 is replaced with Diode.

Rating of Switches S1 & S2
Voltage & Current rating of IGBT & diode are source voltage and load current
Similarity to Buck converter

This circuit is very similar to the traditional Buck converter.

We can also draw the circuit in a slightly different fashion.

Reverse current

- Suppose the current direction is reversed from the previous circuit.

- One way to realize the circuit is shown.

Similarity to boost converter

This is like boost converter looking from right to left.

We can redraw the converter as shown.

Half bridge converter

- We can combine both the buck and boost converters.
- This converter is a half bridge converter.
- It can produce unidirectional voltage on the load.
- It can support bidirectional current through the load.
- All four switches are useful.
By following a specific pattern switch S1 & S2 are switched. The specific pattern is developed by comparing the triangular wave with modulated wave. If the modulated wave is greater than the triangular wave pulses are generated. By changing the position of the modulating waveform average output voltage can be controlled.
The switching frequency of the triangular waveform must be typically high (10-15 times) compared to modulating waveform.

Vd/2 is because we have taken the reference point of the pole voltage as the lower side or negative pole of the DC bus. If we take the reference point for calculating the pole voltage as the midpoint or the imaginary midpoint of the DC bus then Vd/2 cancel out and the AC output is Vd(msinwt)/2 only.

If m varies between 0-1 it is called linear modulation, m>1 it is called overmodulation

The output voltage (Vao) varies linearly

If m>1 output voltage generates lower order harmonics (3rd, 5th, 7th) are generated from the converter which is generally avoided. If we go on increasing the M further the square wave operation of the converter is reached.
What is square wave operation?

If we do the Fourier analysis of this waveform and ignoring the DC part then the fundamental peak is $4/\pi \times \frac{V_d}{2} = 1.27$ times the obtained sine PWM.

In sine PWM the maximum fundamental output is $V_d/2$ where as in square PWM the maximum fundamental is 1.27 times $V_d/2$.

I full bridge we are having 2 legs which are fully independent on each other. The voltage of phase B is 180 degree from phase A.
In Sine PWM the peak voltage we get is \( mVd/2 \) and with square wave mode of operation we can get 1.27 times \( Vd/2 \). We are getting output between \( mVd/2 \) and 1.27m\( Vd/2 \), between 1 and 1.27 is over modulation range why we won’t go there means primarily because this over modulation or square wave mode of operation generate a lot of unwanted low frequency harmonics. So we want to avoid going into over modulation region.

**Can we get more voltage out of the converter? Yes** we can get by adding third harmonics and we can get up to 1-1.5 time than the sine PWM.

How we will get is we will study: the height of triangular wave is varying from -1 to +1. If \( M=0 \) sinewave is having 0 amplitude if \( M=1 \) sine wave is having maximum amplitude the peak of the sine wave is appear at \( \Phi=90 \) and 270 at this angles we reached the end of the linear modulation range if further increase the modulation it comes into over modulation range which insert unwanted lower order harmonics, only \( \Phi=90 \) and 270 we touch the upper and lower barriers and the we stop increasing the sine wave further, the alternating solution is if push wave down at \( \Phi=90 \) and up at 270. If we push
Some way Up and down we are still in linear modulation region. We can do that by adding another wave from to the original sinusoidal modulating wave from, the wave from is third harmonic that we are going to add. Why third harmonic why no other harmonic?

Below fig shows by adding third harmonics to sine wave we can reduce the peaks.

What is the exact magnitude of the third order harmonic we can add?
Imagine there is a potential difference between O & n.

In this converter the star point is isolated the sum of the currents coming to the star point must be equal to zero. Z is the impedance of load per phase. So if we sum the left hand side and right hand side we can see that sum on the right hand side is equal to zero. Van, Vbn.Vcn, are arm phase voltages. We see that between O&n instantaneous potential difference is exist that’s why we can’t short the point O & n. If we short them due to voltage difference dead short circuit happened. Von is called common mode. The common mode exist in converters Vao, Vbo, Vco is not equal to zero this is unlike the case if there were sinusoidal voltage sources suppose if synchronous machine connected to voltage sources. Synchronous machine produce sinusoidal voltages. If it is a perfectly balanced sinusoidal voltage the instantaneous sum is always equal to zero. But in this converter if instantaneous sum of pole voltage is not equal to zero and therefore common voltage exist between point O & n. The common mode has many implications for example high switching frequency inverters common mode causes bearing currents in motor drives also we will see that this common voltage is something which can be utilized in order to increase the linear modulation range. The instantaneous phase voltages (Van) across the load is expressed as combination of three pole voltages (Vao).

By changing the value of m
Third harmonic addition in Sine PWM: The objective of adding third harmonic into Sine triangular PWM is to increase DC bus utilization of the converter. With the help of a third harmonic addition in the modulating wave from we can get more AC voltage across the load from the same DC Bus.

Multi-level converters are used for high power and medium voltage applications. There are 2 types of multi-level converters cascaded and NPC. More recently another multilevel converter has become very popular Multi Level Converter (MMC). MMC are mainly used in Medium voltage, High voltage, and High power applications. NPC & cascaded both are used at Medium voltage level, cascaded is also used at High voltage Levels for Ex in stateom and transmission systems MMC are used for HVDC Applications but they are introduced in the market for motor drives applications at lower voltages also.

Why we use MMC is it produce highly sinusoidal voltage at medium or at High voltage range and do that by using large number of low voltage reliable power devices by using low voltages device and many of them working together we produce multilevel converter. Much expertise is achieved using low voltage devices using this low voltage devices High voltage MMC is developed by connecting in series or in parallel combination.

Primary reason for getting Multilevel Converters popular is additionally the size of the filters can be drastically reduced or in some cases completely eliminated.

Generally starts from 3KV and goes up to 33KV beyond which it is High voltage region in power range from several MW to GW. MMC has become popular for HVDC applications where voltage level is +- several 100KV and power can go up to GW. MMC is very popular at Very High voltage level apart from they are High Redundant High Modularity and fault tolerant capacity.

Using MMC we can bypass some modules and still run the converter with reduced capacity instead of shutting down the entire converter.
By bypassing the faulty module we can still run the converter.

The basic idea of the multilevel converter can be understood using the following figure.

If output of the converter is fed to the motor, the red waveform is what I wish to produce, and the black waveform is what I produced. The instantaneous error between the red and black waveforms is less. The significance of error is that the harmonics getting produced from the converter are reduced if the instantaneous error is reduced. The harmonics produced at pole voltage for a 2-level converter are less than those of a 3-level converter.

In a multilevel converter, when we superimpose the red waveform on the black waveform, it is very close to the sine wave. The MLC converter has better harmonic performance compared to 3&2 level waveforms.

If we get the waveform close to the sine waveform, we do not need any filters, and the cable and motor inductance is sufficient to attenuate any high-frequency currents. We use a large number of low-voltage devices to produce high voltage.

Each switch is a combination of IGBT & Antiparallel diode, the DC source may be a capacitor, in some cases, it may be fed from a Rectifier in some cases, it is fed from a PV panel. These cascaded H bridge means several H bridges (Cells or Modules) connected in series, when we cascade each cell has an isolated DC link for each cell. Each cell produces three levels of voltages.

With 2 cells, the number of voltage levels is 5. If we connect N such cells, the number of levels is (2n+1). All the switches are identical in voltage and current rating. It has high degrees of repetitiveness and modular in structure, which is advantageous for producing cells in mass production, thus reducing the cost.

All the sources are fed from isolated DC sources. The neutral point of load n and N are isolated; there may exist potential between n&N. Because they are isolated from each other during fault operation it is

For lower voltages, we have more multiplicity, and for higher voltages, we have less possibilities. Why these multiplicity is useful. These are useful in various situations. For example, suppose we consider the DC buses as stiff DC sources made up of capacitors. We are connecting a capacitor in Statcom applications; we are injecting reactive power in the transmission line at some multiplicity; the capacitor is bypassed without changing the voltage at the capacitor. Depending on the operation, in the event of flow of current, the voltage at the capacitor charge can be changed. Using several multiplicity, we can redistribute the losses effectively and have an equal temperature rise. For Statcom applications, we can charge up the capacitor very quickly by selecting multiplicity, this multiplicity is used to balance the capacitor voltages. So the loss distribution is equal in all the cells using multiplicity.

**Steady state model of the converter:**

When **real power flow** through the capacitor, energy stored in the capacitor increases or decreases. If **reactive power flow** through the capacitor over cycle, we give some energy to the capacitor and get it back from the capacitor. Over a cycle, the net energy over a cycle becomes zero, and voltage and current are 90° angle. When real power
flow through the capacitor real power flow up or down unless we take some precautionary measure. When real power is flowing DC source through the capacitor through the load the arm will lose its energy or gain energy when real power is flowing from DC side to AC side so in order the energy in arm has to be at steady value the voltage at the capacitor has to be kept at fixed value if the voltage at the capacitor are going up and down we will not get output pure sine wave output. If the capacitor voltage in each arm is diverging we get non sinusoidal output waveform. The output voltage of each arm must be steady and not be discrete. It is important the capacitor voltage in arms should be within acceptable time (tolerance) at that case only we get stiff output waveform. When real power flowing through the capacitor cause the capacitor voltage to go up or down depending up on the direction of flow energy is flowing based on $1/2cv^2$.

The ac component of the current flowing must be compensated such that the voltage on the capacitor do not diverge up or down it can be compensated by circulating current (DC current). Why a DC current we will do in mathematical modelling. This circulating current ensures that the net energy taken over certain period of time is zero. The circulating current is predominantly DC current.

When single phase current is interacting with single phase voltage sources 2nd harmonic currents are produced.

Arm current expression:

To balance the voltage between capacitors we need sorting algorithm.

II. CONCLUSION

This kind of energy exchange is not taking place in other converters. We are having 6 energy sources. If these MMC type of converter is used for PV system where pv cells are connected to the arms then the generation of each pv cells are equal or may not be equal then the arm energy input are also unequal and therefore there will be circulating currents which will have several frequency components which is very interesting research problem how to manage the circulating currents and how to feed a balanced currents into the grid.

The Modular Multilevel Converter (MMC) represents an emerging topology with a scalable technology making high voltage and power capability possible. The MMC is built up by identical, but individually controllable submodules (Half-Bridge and Full Bridge), the converter can act as a controllable voltage source.

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REFERENCES