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An Advanced Active Common-Mode Filter for Grid-Connected PV Inverters

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Abstract:

At the present time most of the photovoltaic (PV) applications require to be integrated to the electrical grid. Thereare mainly two types of PV systems: with galvanic isolation(transformer) and transformerless. PV systems with lowfrequency transformer provide galvanic isolation from the grid.For PV system MPPT and boost converter is proposed in simulation. However, this transformer decreases the losses, size and cost. Onthe other side, when the transformer is included, the system can generate strong ground currents which are a function of thestray elements (capacitances). In this sense reducing the CommonMode Voltage (CMV), is an important issue in the design of powerelectronics converters for transformer PV applications. In thispaper a three-phase transformerPV inverter with reducecommon mode voltage is introduced. CMV is analyzed underdifferent modulation schemes and an analysis of losses using a real model of the IGBT´s is included

Index Terms:

Active filters, leakage current, photovoltaic systems, MPPT, boost converter, pulsewidth modulation inverters.

I.INTRODUCTION:

The Photo Voltaic (PV) power supplied to the utility grid is gaining more and more development, while the world's power demand is increasing. Not many PV systems have so far been placed into the grid due to the relatively high cost,compared with more traditional energy sources such as oil, gas, coal, nuclear, hydro, and wind[2]-[4].

In several situations, the PV inverters are used to feed the DC power into the utility grid. It is necessary for the PV inverter to be ofhigh efficiency, because of the relatively higher price of the solar PV panels [5]. Small size of inverter with reduced cost and the three phase system is now gaining advantage especially when the inverters are installed indoor and used for low power applications. In the early days utilizing traditional grid-connected PV inverters, either a line frequency or a highfrequency transformer is utilized, which provides a galvanic isolation between the grid and the PV panels.

This results in decrease in efficiency, increase in size, weight and cost because of the use of the isolation transformer. Removing the usage of the isolation transformer can be an effective solution to increase the efficiency and reduce the size and cost.

However, when the transformer is omitted, the Common Mode (CM)ground leakage current may appear on the parasiticcapacitor between the PV panels and the ground [7], [8].Usually the ground leakage current is imposed on the line.current; which results in higher harmonic in inverters without the transformer. In the transformer less grid-connectedcircuit which includes the capacitance between PV and the ground, the L-C filters, the MCSI inverter, and the impedance(Z) of the required utility grid.

The voltage magnitude of the capacitance depends on given dc PV source and the surrounding environmental conditions. Here the solar PV panels ground capacitance is very high ranging from nanofarads (nF) up to microfarads (μF) [9], [10]. This is because PV panel structure resembles a huge capacitor, in which one electrode is the PV cells and the other one is the ground frame (see Fig. 1).

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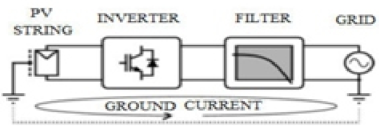

Fig.1.Path of the ground leakage current in Transformerless PV inverter connected to grid.

II.PROPOSED SYSTEM: ACTIVE COMMON-MODE FILTER:

The full-bridge topology driven by a three-level (unipolar)PWM is the most popular solution for single-phase powerconverters due to its simplicity and effectiveness. However, thistopology cannot be used in transformerless PV systems becauseof large variations of the output common-mode voltage.Fig. 6 shows the full-bridge driving signals in case of unipolar.

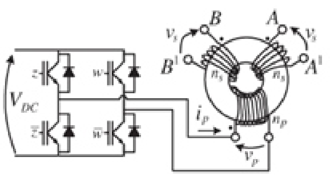

Fig. 2. Active common-mode filter topology.

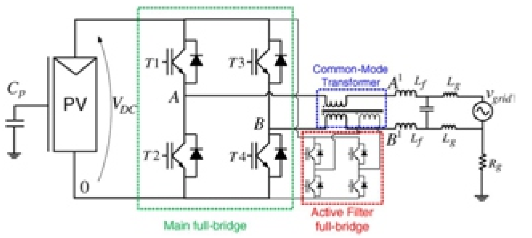

Fig. 3. Topology of the proposed solution

modulation and the resulting vcm, which presents a peak-topeakamplitude equal to the dc link voltage Vdc at switchingfrequency. The full-bridge driven by unipolar modulation canbe used in PV systems only if other devices are added to thisbasic structure. In [6], two additional power switches, suitablydriven, were added in order to eliminate common-mode voltagevariation. As stated above, instead of proposing a custom power convertertopology able to mitigate the variations of the outputcommon-mode voltage, this work proposes the use of theefficient and simple full-bridge topology driven by unipolarmodulation followed by a device able to cancel the commonmodevoltage variations at the converter output.

Obviously, thisadditional device should be characterized by low power losses,simplicity, and low cost.The additional magnetic component needed for the proposedsolution can be obtained, to a first approximation, adding a third winding to the standard common-mode inductors usedat the output of power converters in order to comply withelectromagnetic compatibility (EMC) standards.

By addinganother winding to the common-mode choke (see Fig. 7), itis possible to consider this new magnetic component as acommon-mode transformer. If a specific voltage is suppliedto its primary winding through an additional low-power fullbridge,the secondary voltages (vs) of the transformer can beused to compensate for the variation of vcm. This way, the totalcommon-mode voltage at the converter output, i.e., vcmT , can be effectively kept constant.

PHOTOVOLTAIC SYSTEMS:

A photovoltaic system, also photovoltaic power system, solar PV system, PV system or casually solar array, is a power system designed to supply usable solar power by means of photovoltaics. It consists of an arrangement of several components, including solar panels to absorb and directly convert sunlight into electricity, a solar inverter to change the electrical current from DC to AC, as well as mounting, cabling and other electrical accessories to set-up a working system..It may also use a solar tracking system to improve the system's overall performance or include an integrated battery solution, as prices for storage devices are expected to decline.
Strictly speaking, a solar array only encompasses the ensemble of solar panels, the visible part of the PV system, and does not include all the other hardware, often summarized as balance of system (BOS).

Moreover, PV systems convert light directly into electricity and shouldn't be confused with other solar technologies, such as concentrated solar power (CSP) and solar thermal , used for both , heating and cooling.We create and deliver bespoke solar energy solutions to the commercial, industrial and public sectors for new build, refurbishment projects and for existing buildings. With our leading expertise, we can provide you with an integrated PV package, from the design & consultation stage right through to installation and performance monitoring.

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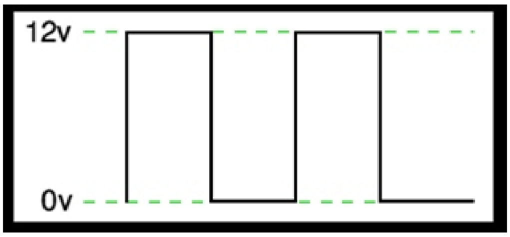
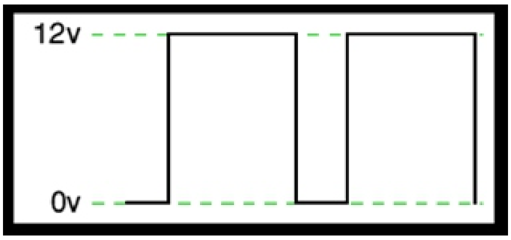
III CONTROL STRATEGY:
PULSE WIDTH MODULATION:
What is PWM?

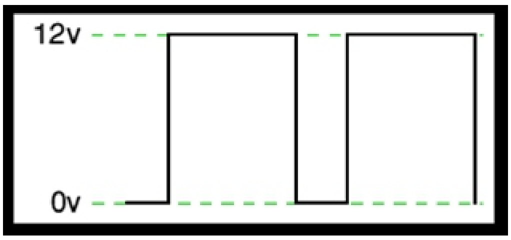
Pulse Width Modulation (PWM) is the most effective means to achieve constant voltage battery charging by switching the solar system controller's power devices. When in PWM regulation, the current from the solar array tapers according to the battery's condition and recharging needs Consider a waveform such as this: it is a voltage switching between 0v and 12v. It is fairly obvious that, since the voltage is at 12v for exactly as long as it is at 0v, then a 'suitable device' connected to its output will see the average voltage and think it is being fed 6v - exactly half of 12v. So by varying the width of the positive pulse - we can vary the 'average' voltage.



Similarly, if the switches keep the voltage at 12 for 3 times as long as at 0v, the average will be 3/4 of 12v - or 9v, as shown below.



and if the output pulse of 12v lasts only 25% of the overall time, then the average is

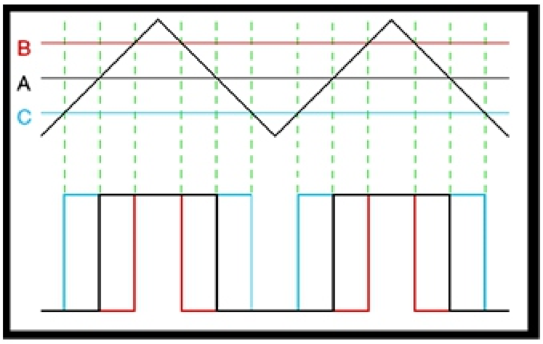


By varying - or 'modulating' - the time that the output is at 12v (i.e. the width of the positive pulse) we can alter the average voltage. So we are doing 'pulse width modulation'. I said earlier that the output had to feed 'a suitable device'.

A radio would not work from this: the radio would see 12v then 0v, and would probably not work properly. However a device such as a motor will respond to the average, so PWM is a natural for motor control.

Pulse Width modulator:

So, how do we generate a PWM waveform? It's actually very easy, there are circuits available in the TEC site. First you generate a triangle waveform as shown in the diagram below. You compare this with a d.c voltage, which you adjust to control the ratio of on to off time that you require. When the triangle is above the 'demand' voltage, the output goes high. When the triangle is below the demand voltage, the



When the demand speed it in the middle (A) you get a 50:50 output, as in black. Half the time the output is high and half the time it is low. Fortunately, there is an IC (Integrated circuit) called a comparator: these come usually 4 sections in a single package. One can be used as the oscillator to produce the triangular waveform and another to do the comparing, so a complete oscillator and modulator can be done with half an IC and maybe 7 other bits.

The triangle waveform, which has approximately equal rise and fall slopes, is one of the commonest used, but you can use a saw tooth (where the voltage falls quickly and rinses slowly). You could use other waveforms and the exact linearity (how good the rise and fall are) is not too important.

Traditional solenoid driver electronics rely on linear control, which is the application of a constant voltage across a resistance to produce an output current that is directly proportional to the voltage. Feedback can be used to achieve an output that matches exactly the control signal. However, this scheme dissipates a lot of power as heat, and it is therefore very inefficient.

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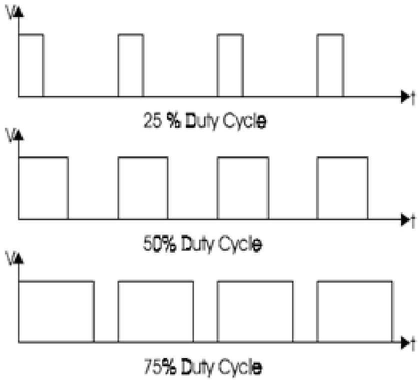
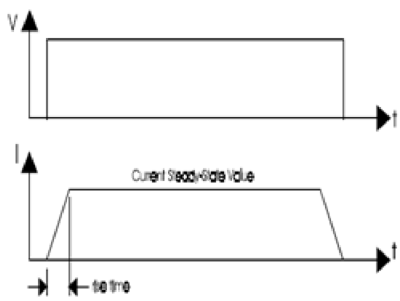
A more efficient technique employs pulse width modulation (PWM) to produce the constant current through the coil. A PWM signal is not constant. Rather, the signal is on for part of its period, and off for the rest. The duty cycle, D, refers to the percentage of the period for which the signal is on. The duty cycle can be anywhere from 0, the signal is always off, to 1, where the signal is constantly on. A 50% D results in a perfect square wave. (Figure 1).



A solenoid is a length of wire wound in a coil. Because of this configuration, the solenoid has, in addition to its resistance, R, a certain inductance, L. When a voltage, V, is applied across an inductive element, the current, I, produced in that element does not jump up to its constant value, but gradually rises to its maximum over a period of time called the rise time (Figure 2). Conversely, I does not disappear instantaneously, even if V is removed abruptly, but decreases back to zero in the same amount of time as the rise time.



Therefore, when a low frequency PWM voltage is applied across a solenoid, the current through it will be increasing and decreasing as V turns on and off. If D is shorter than the rise time, I will never achieve its maximum value, and will be discontinuous since it will go back to zero during V's off period (Figure 3).* In contrast, if D is larger than the rise time, I will never fall back to zero, so it will be continuous, and have a DC average value. The current will not be constant, however, but will have a ripple (Figure 4).

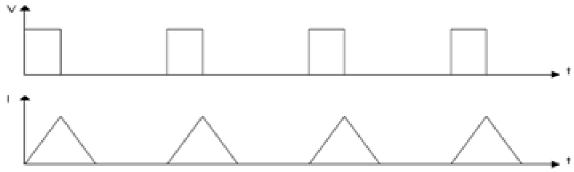
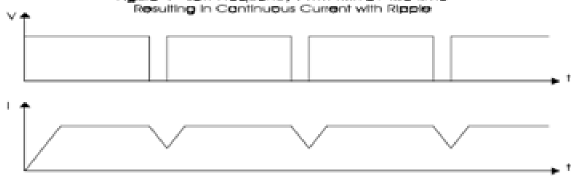
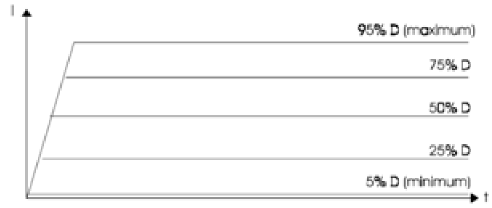


Figure 4 - Low Frequency PWM with D>rise time Resulting in Continuous Current with Ripple



At high frequencies, V turns on and off very quickly, regardless of D, such that the current does not have time to decrease very far before the voltage is turned back on. The resulting current through the solenoid is therefore considered to be constant. By adjusting the D, the amount of output current can be controlled. With a small D, the current will not have much time to rise before the high frequency PWM voltage takes effect and the current stays constant. With a large D, the current will be able to rise higher before it becomes constant. (Figure 5).



Dither:

Static friction, stiction, and hysteresis can cause the control of a hydraulic valve to be erratic and unpredictable. Stiction can prevent the valve spool from moving with small input changes, and hysteresis can cause the shift to be different for the same input signal. In order to counteract the effects of stiction and hysteresis, small vibrations about the desired position are created in the spool. This constantly breaks the static friction ensuring that it will move even with small input changes, and the effects of hysteresis are average out. Dither is a small ripple in the solenoid current that causes the desired vibration and there by increases the linearity of the valve. The amplitude and frequency of the dither must be carefully chosen. The amplitude must be large enough and the frequency slow enough that the spool will respond, yet they must also be small and fast enough not to result in a pulsating output.

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The optimum dither must be chosen such that the problems of stiction and hysteresis are overcome without new problems being created. Dither in the output current is a byproduct of low frequency PWM, as seen above. However, the frequency and amplitude of the dither will be a function of the duty cycle, which is also used to set the output current level.

This means that low frequency dither is not independent of current magnitude. The advantage of using high frequency PWM is that dither can be generated separately, and then superimposed on top of the output current. This allows the user to independently set the current magnitude (by adjusting the D), as well as the dither frequency and amplitude. The optimum dither, as set by the user, will therefore be constant at all current levels.

Why the PWM frequency is important:

The PWM is a large amplitude digital signal that swings from one voltage extreme to the other. And, this wide voltage swing takes a lot of filtering to smooth out. When the PWM frequency is close to the frequency of the waveform that you are generating, then any PWM filter will also smooth out your generated waveform and drastically reduce its amplitude. So, a good rule of thumb is to keep the PWM frequency much higher than the frequency of any waveform you generate.

Finally, filtering pulses is not just about the pulse frequency but about the duty cycle and how much energy is in the pulse. The same filter will do better on a low or high duty cycle pulse compared to a 50% duty cycle pulse. Because the wider pulse has more time to integrate to a stable filter voltage and the smaller pulse has less time to disturb it the inspiration was a request to control the speed of a large positive displacement fuel pump. The pump was sized to allow full power of a boosted engine in excess of 600 Hp.

At idle or highway cruise, this same engine needs far less fuel yet the pump still normally supplies the same amount of fuel. As a result the fuel gets recycled back to the fuel tank, unnecessarily heating the fuel. This PWM controller circuit is intended to run the pump at a low speed setting during low power and allow full pump speed when needed at high engine power levels.

IV SIMULATION RESULTS:

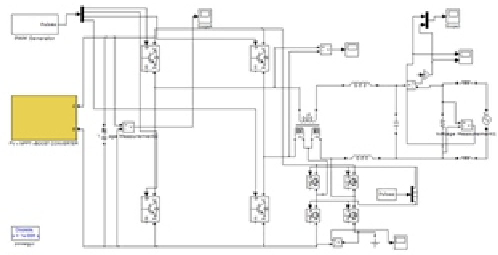

Fig 4 matlab circuit

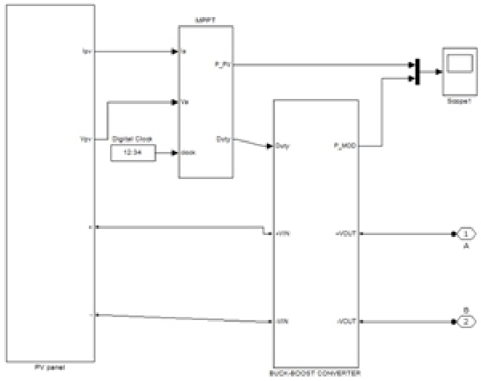

Fig 5 PV+MPPT+Buck-Boost Converter blocks

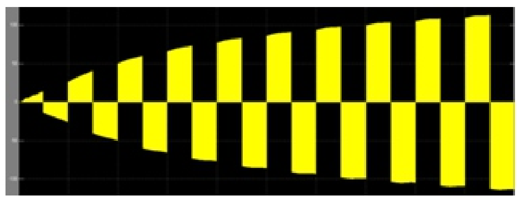

Fig 6 Three level inverter voltage

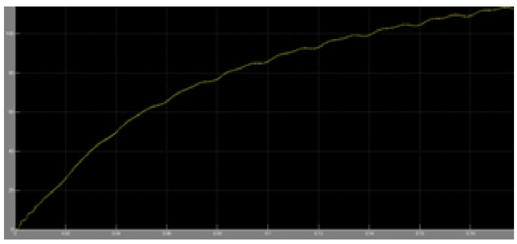

Fig 7 DC Capacitor Voltage

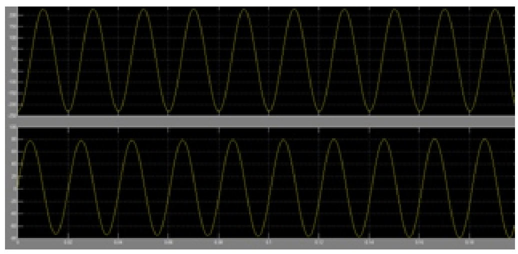

Fig 8 Grid Voltage & Current

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V CONCLUSION:

This paper contributes the analysis and simulation of a PV being supported by a P& O MPPT controller interactive withShunt Active power Filter. This system is used to eliminate ground leakage current by appropriate modulation techniqueand also to minimize the harmonics generated by a nonlinear load and reactive power compensation .The shunt active filter is used because of its adaptability to the changing load condition. As regards the control strategy, this control method is based on optimal voltage space vector current was explained in this paper; because of the accuracy in the selection of inverter's switch state is becoming much better, with reduced Switchgear Malfunction and improved switch life. The results shows that a good compensation effect with reduced THD.

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