On the Issue of Fly-Back Spikes in PWM Operated Single-Phase Transformer-Less Grid-Tied Inverter

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Abstract

This paper gives in simulation details the effect of switching sequence generation (PWM) on the ultimate wave-shape of the sinusoidal output produced from a constant voltage assumed to be from solar generation. The circuit, consisting of inductive elements, is associated with the issue of fly-back spikes generation when the circuit is switching circuit. The issue of spike generation is explained through giving theoretical details while it is shown that spikes could be detrimental to having adverse effects on the final wave shape. Then are suggested techniques how spikes are controlled by the use of free-wheeling diodes whereby the spikes are reduced from 500V to 10V. The results of this work could find application in studying the stability of systems used for energy harvesting through distributed generation from solar.

Keywords: Grid-tied, Inverters, Fly-back, spikes mitigation

1. Introduction

The increase in number of modern electrical appliances, advancement in technology and necessity of comfortable house hold items and with the increase in life style requirement, the cost and consumption of electrical energy is on the rise. The high cost coupled with factors of environmental concerns and operation of a vast complex traditional AC generation and distribution system are the factors for an increased interest in renewable energy-based Distributed Generation (DG) systems connected to an AC grid supply [1-4]. The solar panel-to-grid makes a chain of equipment items such as DC-DC converter, conditioner, inverter, and shaper circuit. The last component in the series is transformer in a transformer-based topology of inverter while it is a low-pass filter along with some coils in the case of transformer-less inverters. Either it is transformer-based or transformer-less, a DC-to-AC inverter makes the core component in the chain, which becomes more significant in the case of grid connectivity. To use such renewable system as a stand-alone supply system, or share oad with the grid, there are many factors to be carefully considered as important, such as the stable supply of DC energy from renewable sources in different environmental conditions, synchronization of phase and frequency with the grid's phase and frequency, amplitude matching, square to sinusoidal wave conversion, and issues related to on load power adjustment and harmonics containment [5]. However, the most focused area in today's research is that of solar energy in distributed grid systems fashion as it is with very low generation, distribution and maintenance cost, while being environmentally friendly with long life-span of the equipment used E [6]

Whether standalone generation system or Distributed generation (grid-tied) system, in such solar energy generation practices are employed DC to DC and DC to AC converters along with normal power electronic interfacing devices [7]. Currently, the majority of photovoltaic systems are used to feed generated electrical energy into the utility grid. A block diagram of a grid-connected DG system using PV cells, DC/DC conversion and DC/AC inverter is illustrated as shown in Figure 1.

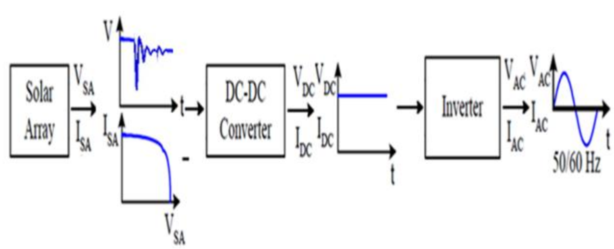

Figure 1: Conventional DC-AC Inverters

In most of the conventional grid-tied inverters, connected in cascade are DC/DC converters in

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series with DC-to-AC by turning ON and OFF in sequential manner Insulated Gate Bipolar Transistor (IGBT) as switching devices. A suitably Pulse Width Modulation generated sequence may lead to generating sinusoidal AC output sinusoidal enough for connection in synchronization with the grid frequency and voltage levels [8]. The perfect the synchronization is, the more efficient and reliable will be the energy transfer between the solar panel side onto that of the grid side, assuming an acceptable level of prior phase and amplitude matching.

Transformer-less inverters are getting more accepted due to their reduced cost and minimized weight, and such inverters are investigated for its high efficiency power transformer mechanism and easy fault tracking and hazel free installations. The PWM strategy is suitably implemented in digital controllers [9, 10] that can present robustness and improved stability in term of sine wave conversion, phase and amplitude synchronization can be also implemented [11].

Being a conglomeration of switching devices coupled with transformer and coils, the output of the circuit is with the problem of fly-back voltage that develops when it drives a coil or coil-based device such as DC motor or transformer. A coil does not allow an ongoing current to ease instantaneously when it gets interrupted; rather it opposes such interruption by setting up a reverse electromotive force (EMF). Such an EMF may climb to hundreds or thousands of volts in potential and may lead to causing arc through the switching device to destroy it. This paper looks at the issue of inductive fly-back whenever a switch (i. e., IGBT) makes and breaks a current through the coil.

2. Circuit Simulation Details

The inverter circuit of Figure 2 is consisting of four MOSFET transistors connected in H-bridge configuration to be operated in a sequence for generating AC waveform. The positive half and negative half cycles of a 50Hz sinusoidal AC output, these four switches are turned ON & FF in pairs (Q1, Q3) and (Q2, Q4) by a 50Hz modulation frequency and sampling frequency ranging from 1kHz to 20kHz. For positive half cycle as shown in Figure 3 during which switches Q1 and Q3 conduct allowing the current to flow through the load in series with L1 and L2 inductor coils [4]. For the negative half cycle (as shown in Figure 4) switches Q2 and Q4 are turned ON making the current to flow in opposite direction through the load in series with L3 and L4. During both of these cycles the low pass filter by L5, C2 section is tuning the sample to as close to a sinusoidal as possible. It is obvious during each half of 50 Hz cycles the coils L1-L5 are activated de-activated a number of times equals to the sampling frequency of PWM control signal which carries the possibility of fly-back EMF generation.

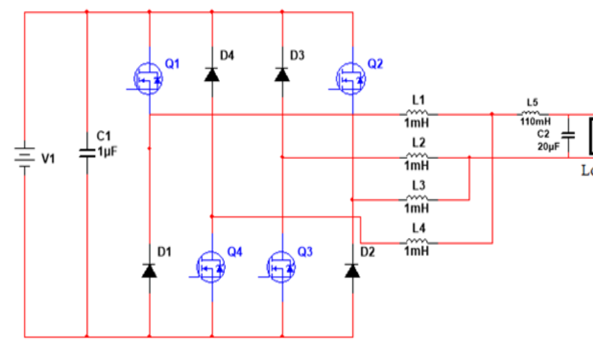

Figure 2: Inverter circuit diagram without fly-back diode

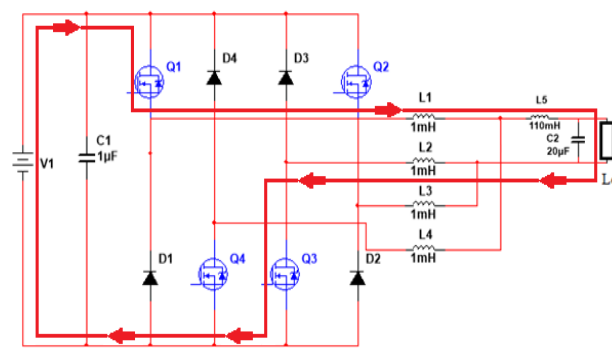

Figure 3: Positive half cycle current flow

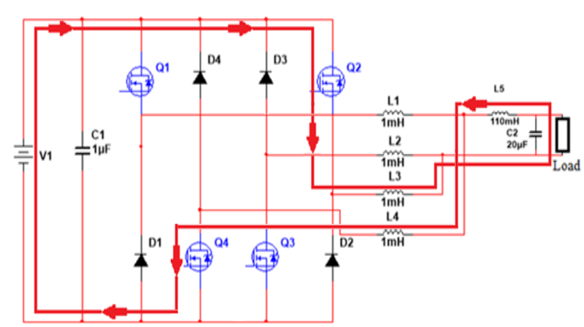

Figure 4: Negative half cycle current flow

The inverter circuit shown in, Figure 5 is made from switching devices and fly-back voltage clamped diodes in the form of two legs. Each leg

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contains a pair of switches, turned ON and OFF together simultaneously a number of times for selected PWM signals dependent duration. In the ON state the switch pair (Q1, Q3) provides for a path of current through the coils (L1 and L2) into the grid (load) for a return path to the negative of the PV source. Operated by many PWM signals meant to sample every half/negative of the 50 Hz ensure by switch Q5. It is in this time when the coil gets magnetized and demagnetized equal to the number of times the PWM is turning ON/OFF Q1 and Q3. A magnetized coil does not allow its current to ease down without inducing an EMF spike, one may call it surge or common-mode voltage development of opposite polarity which is guaranteed to be stabilized by switch Q5 and fly-back voltage clamped diode, D5. This voltage clamp back diode remains reverse biased except when the current through coils is interrupted by the switching transitions (activation and de-activation) of switch Q1 and Q3.

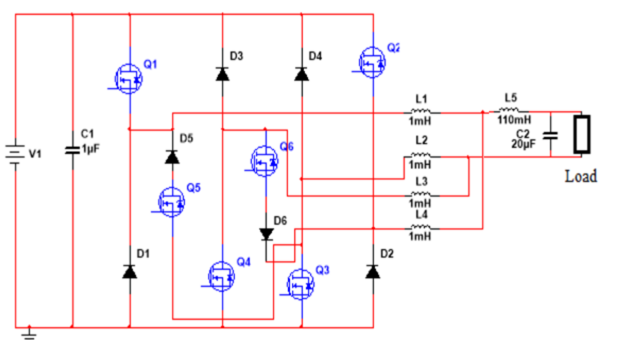

Figure 5: Inverter circuit diagram with fly-back diode

2. Theoretical Analysis of Inverter Fly-Back Voltage Generation

Current rise and fall through an inductive element is not linear, rather is follows an exponential style of increase and decrease when a coil is excited by a current source as given by equation (1). How fast or slow the current is, depends on the value of R and L both in addition to the value of current flow through the coil at the time when the source is applied (equation (2))

For current i;

$$i_L = \frac{V_s}{R}(1 - e^{\frac{-t}{\tau}}) \qquad (1)$$

where, $\tau = \frac{L}{R}$

$$i_L = \frac{V_s}{R} + (I_o - \frac{V_s}{R})e^{\frac{-t}{\tau}} \qquad (2)$$

That seems obvious that current change does not remain perfectly linear, however when switches used are operated by a high frequency gate signals, then such nonlinearity become with ignorable effects ultimately. The switching signals applied to MOSFET switches become a source of frequent break and make of current through the coil, which are surely associated with the EMF generation of opposite polarities following equation (3) giving rise to spikes generation for very short interval of times. In the case of un-magnetized coil, the above equation can be reduced to (3) as under, leading to produce spikes

$$v_L = L\frac{d}{dt}[\frac{v_s}{R}(1 - e^{\frac{-t}{\tau}})] \qquad (3)$$

Such spikes may sometimes rise to few hundreds volts, and may become hazardous for safety as well they may damage for the coils and transistor. The spikes cause transients becoming source of affecting the zero-crossing as well as may inject harmonics into the system, causing stability concerns. Also, such transients may become a reason for improper power factor conditions of the operating load.

3. Inverter Fly-Back Mitigation

A current through a coil when gets interrupted, produces a voltage of opposite polarity across the coil referred to fly-back spike. The fly-back development of voltage for the RL circuit of Figure 6 is as shown in Figure 7; in this case, one needs to get the energy dissipated before breaking the current for fly-back to get develop

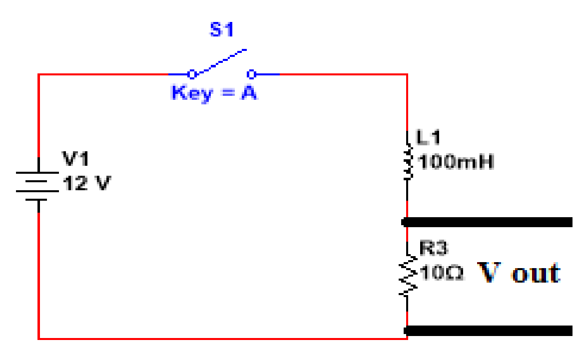

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Figure 6: Basic RL Circuit

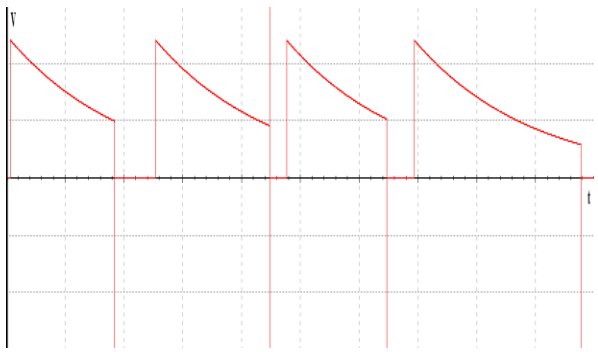


Figure 7: RL circuit output with negative spike

However, with addition of resistor of 500 Ω in parallel with the coil the fly-back voltage is reduced as shown in Figure 8. The buildup of current through the coil is not as much affected as it helps in getting the waiting time almost eliminated altogether as shown Figure 9.

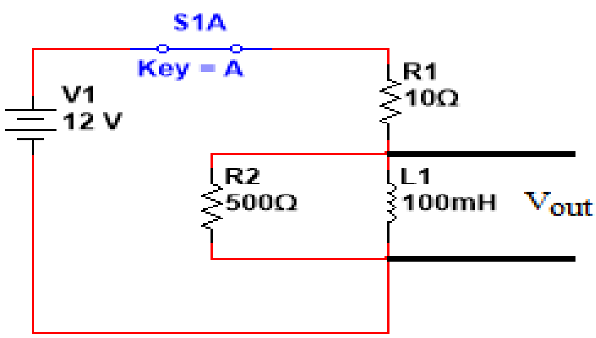


Figure 8: RL Circuit with normalized output with R in parallel

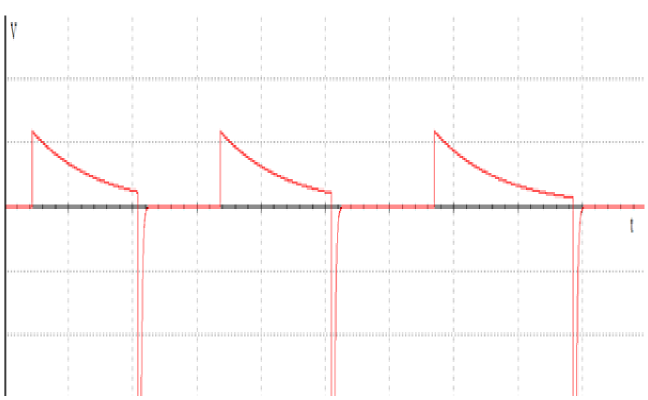
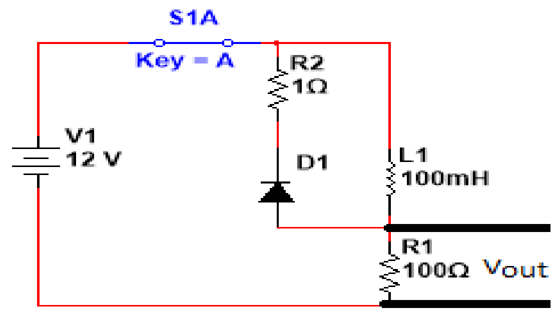


Figure 9: RL normalized output with R in parallel

The negative spike issue can be later resolved by connecting a diode in reverse direction in parallel to coil acting as a freewheeling diode or



fly-back diode as in Figure 10 and Figure 11.

Figure 10: RL circuit with Fly-back Diode

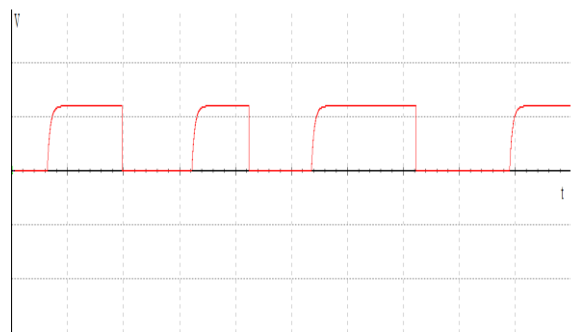


Figure 11: RL output with Fly-back Diode

4. Simulation Results

Figure 12 shows the output voltage at terminals A-B of Figure 3, 50 Hz is modulated by sampling frequency of 1 kHz.

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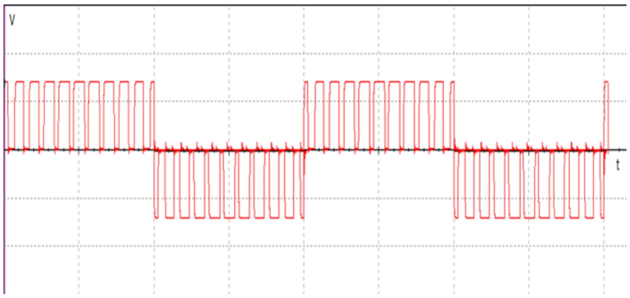

Figure 12: PWM 50 Hz output

The output at terminals A' and B' after Low pass filter at different sampling frequencies varying from 1 kHz is as shown in figure 13(a) while Figure 13(b), 13(c) and 13(d) shows the output at sampling frequencies, 5 kHz, 10 kHz and 20 kHz respectively.

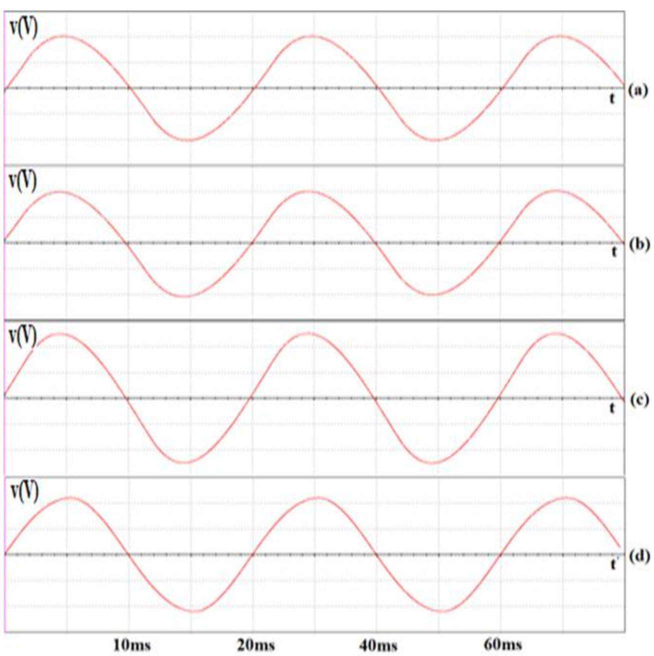

Figure 13: 50 Hz Sinusoidal wave at different frequencies (a) 1 kHz, (b) 5 kHz, (c) 10 kHz and (d) 20 kHz

5. Conclusion

In this paper the issue of negative spikes generation as applied to switching sequence applications in inverters, is addressed. The spikes generation is analyzed by a theory support, and means of mitigating such spikes are covered. The effect of PWM ranging from 1 kHz to 20 kHz for producing better wave-shape is shown. The negative spikes are shown to be better stabilized by reducing these spikes from 500V to 10V using freewheeling diode connected in parallel with the inductive elements. The effect of the free-wheeling diodes ultimately on the shape of the output AC source is studied, and it is concluded that such spikes mitigating diodes are effective in making better shapes possible. The findings of these articles are in the process of being verified experimentally; find applications in systems used as stand-alone for harvesting of solar power for residential applications.

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