Memorandum

To: Senior Management

CC: Mike Cuomo & Tyler Pelton

From: Rob Schmid & John Acevedo

Date: 02/19/2009

Re: Inverter Topologies

In considering the inverter tradeoffs, we looked at 3 major components; the location of the transformer, the types of switches (Mosfets v. IGBTs), and the PWM scheme.

Two topologies with different transformer locations are shown below. The first is the more conventional approach where the transformer is located in between the load and the H-Bridge. In this topology, the transformer runs at 60Hz and isolates the load from the rest of the circuit. One disadvantage to the topology is that a transformer at 60 Hz supplying 2KVA is large in size and expensive. A transformer for 2KVA at a higher frequency is smaller and cheaper. A low frequency transformer at 2KVA has been found from Sola/Hevi-Duty (HS1F2AS) for $300.

The cost of a 2KVA transformer at 60 Hz drove us to investigate a topology with a transformer at a higher frequency. The second topology shows this layout. There is one stage of H-Bridge fed into a high frequency transformer followed by a second stage of H-Bridge to reduce the frequency at the output. A disadvantage that comes from this design is that the load is not completely isolated from the circuit.

For instance, the filter circuitry which is done after the second stage of H-Bridge may be influence by the load. If a significantly capacitive load was connected to the output, it would alter the effectiveness of the filtering. Due to the complexity of adding a second H-Bridge and the complications caused by the load not being isolated from the filter circuitry in the high frequency transformer approach we recommend that a 60 Hz transformer be purchased and used as described in the first topology.

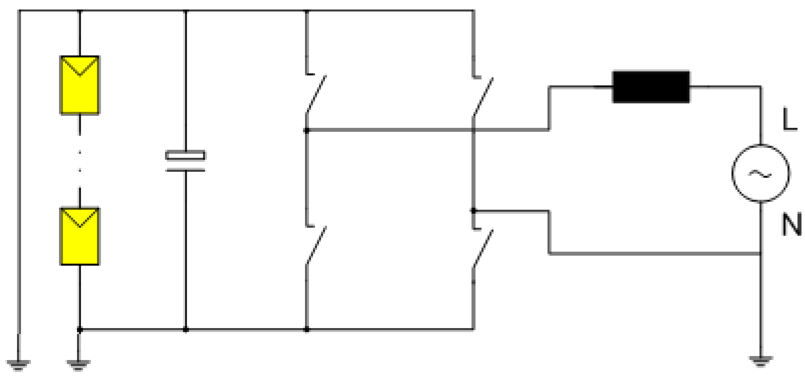


Figure 1. Low Frequency transformer topology

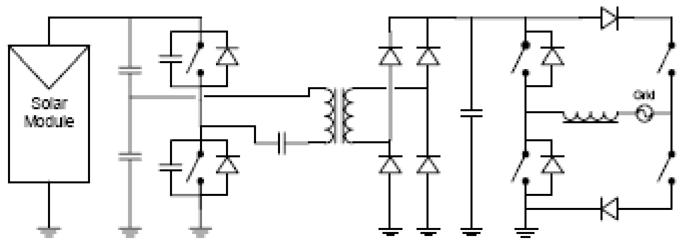


Figure 2. High frequency transformer topology

The selection of proper switches for the parts in the H-bridge is also a key component to the inverter. Our research found that IGBTs are used in high voltage applications and are more robust than Mosfets, but they are more limited in frequency and have greater loss. Mosfets can also be found at the voltage we require, but they are less robust. Mosfets offer great frequency capabilities and have less loss.

The PWM scheme used in the H-Bridge is important to converting the DC voltage to an AC signal. Three schemes were considered. The first is a simple square wave. The second is the result of comparing a reference sinusoid at 60 Hz to a saw tooth waveform. The final scheme is a signal, which is created by comparing saw tooth waveform to two sinusoids, 180 degrees out of phase of one another.

The final waveform results in a 3 level signal. The details of each PWM scheme and the harmonics caused by distortion are included in the filter memo. Each PWM scheme was modeled in Simulink and the scheme with the least harmonic and easiest to filter is the 3-level PWM scheme.

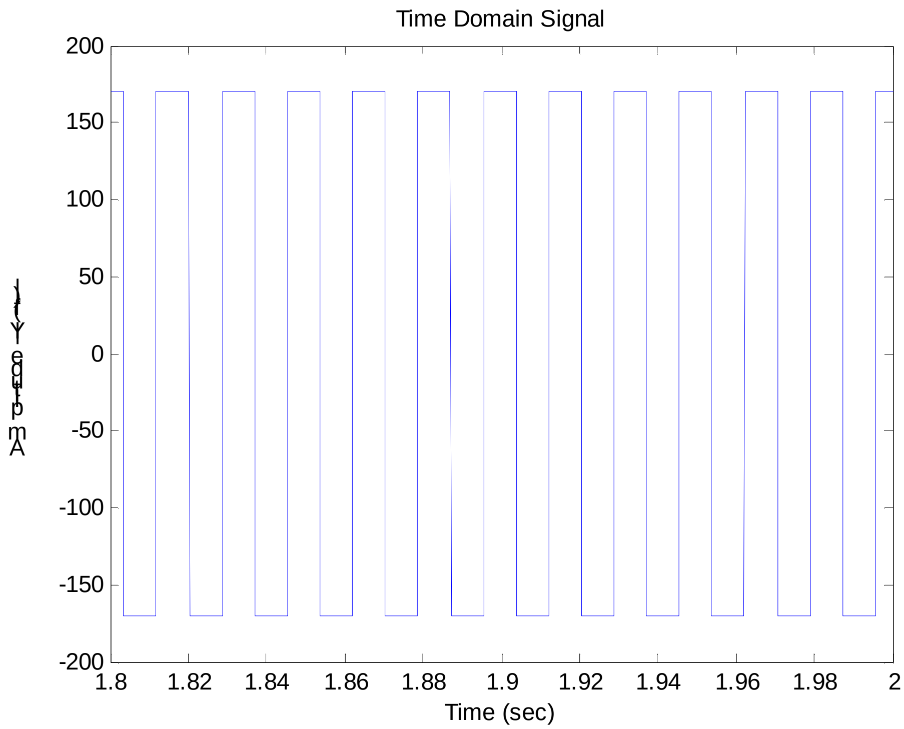


Figure 3. Simple square wave PWM

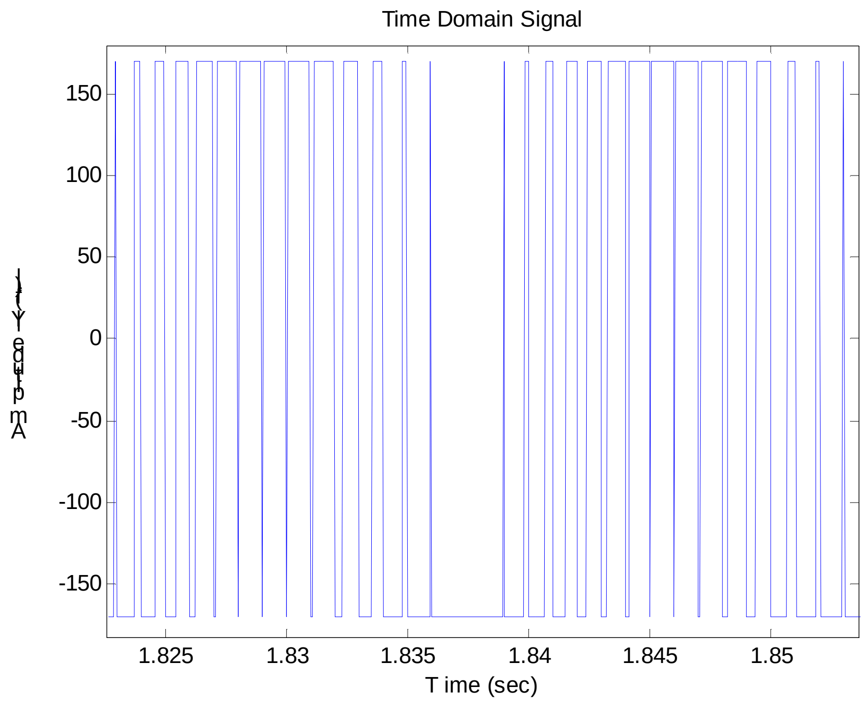


Figure 4. Wave produced by comparing a 60Hz reference sine wave to a saw tooth waveform

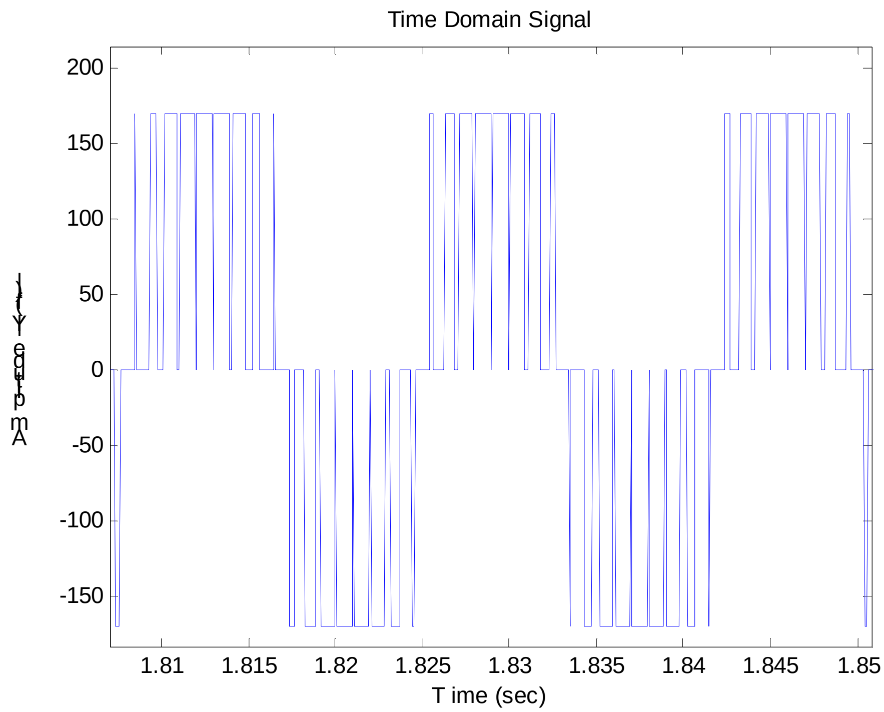
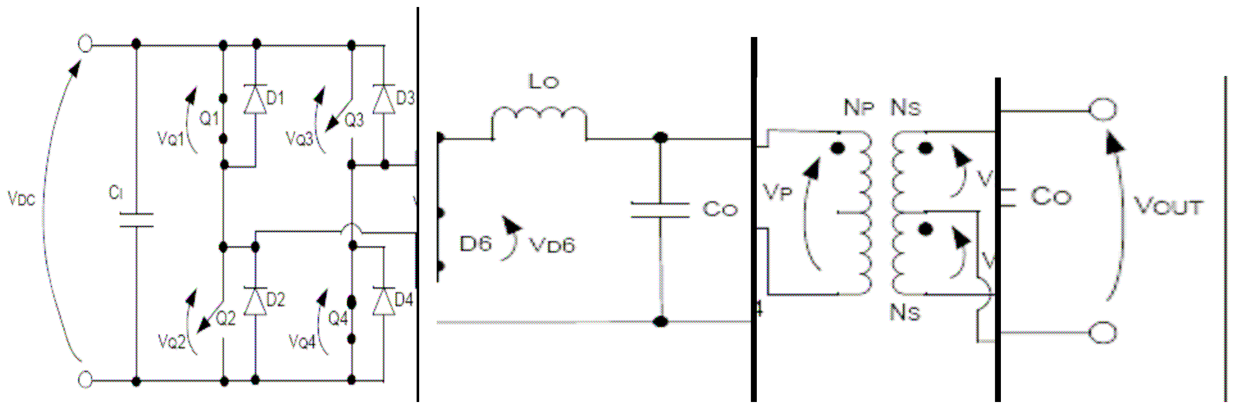


Figure 5. The 3-level PWM signal created from 2 reference sinusoids

Design Considerations for the application

Various switching topologies were analyzed based on the two inverter topologies presented and the PWM scheme. Following is a brief description of these topologies, their pros & cons.

1. Single Stage H- Bridge PWM converter and low frequency transformer



There are various aspects to consider in this case:

- Switching the devices at low frequency (60 Hz) followed by a filtering stage and finally utilizing an isolation transformer directly connected to the grid. Some devices are already selected for this purpose.

  In this topology, we can take advantage of IGBTs and their drivers. The losses at low frequency are reduced, the operating voltages over 250V with a de-rating factor of 50% (close to 400V) is achieved easily.

  Filtering capacity based on PWM scheme can be easily managed as the harmonics created are related to the 60Hz fundamental. We must analyze this based on the work done by Rupesh & Ram.

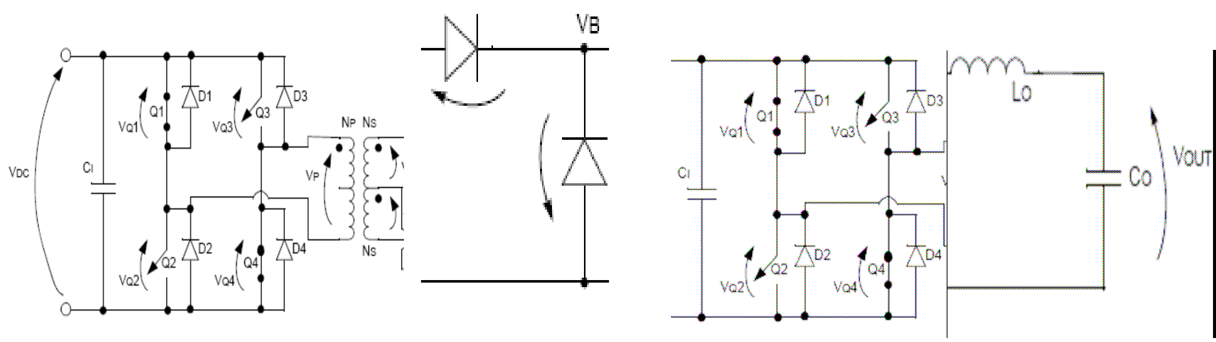
  In the last stage, the isolation transformer is bulky and expensive. As stated above, the prices can be at least $300.00. There is however the possibility to search into Ferroresonant transformers that feature a built in Square Wave filter stage. This could potentially eliminate the need for a sophisticated filtering stage after the H-Bridge.

- A second option within this topology is switching the upper IGBTs at high frequency (20KHz – 50KHz) and the lower devices at low frequency 60 Hz. In this fashion, the lower IGBTs are turned on for half the cycle (8 mS) one at a time, while its corresponding upper IGBT on the leg switches rapidly. In this manner, the inductors can be kept reasonably small and will suppress the harmonics effectively.

There may be considerations about switching IGBTs at high frequencies due to power losses and perhaps finding an appropriate driver. These considerations while valid may be pure speculations. We have searched into latest technology in IGBTs and currently, Fairchild, International rectifiers & IXYS Corporation offer a new line of IGBTs suited for high frequency application over 50Khz.

Some of the aspects in this topology under the described conditions involve filtering the harmonics created due to the high switching effect. In the work done by Rupesh & Ram, the simulation of this type of modulation apparently causes the worst THD. However we may need to investigate into a PWM technique (perhaps Unipolar PWM) to facilitate the filtering stage. In this case however the isolation transformer is still in use and its characteristics are as above.

2. **<u>Multi- Stage High Frequency Transformer H- Bridge PWM with low-frequency unfolding</u>**

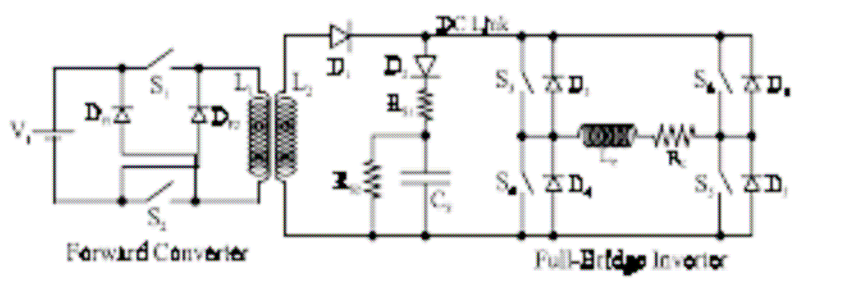


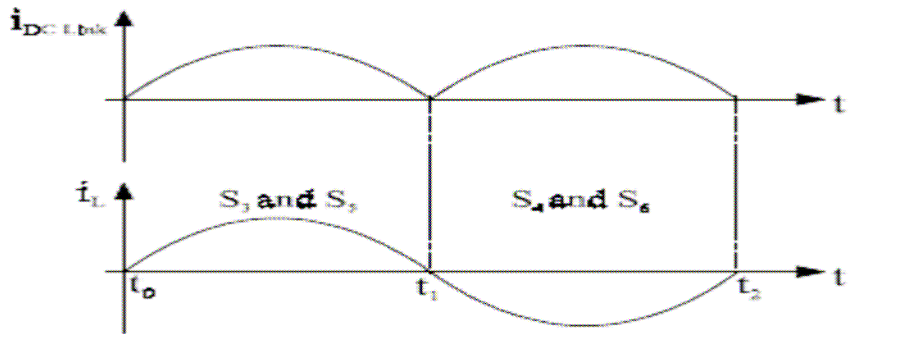
Considerations in this topology:

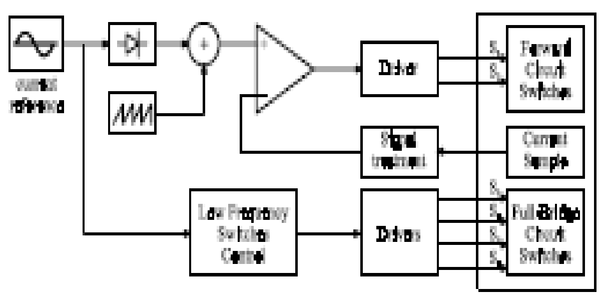
- In the H-bridge high transformer section, the isolation is generated here and allows the second stage output to operate as a conventional low frequency full bridge inverter. The high frequency section could be switched at over 50KHz utilizing power Mosfets. In the output section given the low frequency operation, standard planar IGBTs can be used.

  In this topology, the high frequency offers the opportunity of a small transformer eliminating the bulky isolation transformer at the output stage. This is one advantage in cost. However the flip side of this is that complexity of the circuit requiring much more devices. One more advantage as well is that the low switching reduces EMI levels.

An alternate method to this design is the use of a forward converter in the front end rather than an H-bridge topology. In this case the PWM is designed to define the sinusoidal current that is unfold via the H- bridge output section (current controlled Inverter).







The disadvantage of this topology mentioned is on the complexity of the designed directly linked to our time constrains. Investigations should be done and simulations but it is definitely a good alternative based on the previous work and research done with transformers and PWM schemes.

In any case, power semiconductors required for either application are rather available. The team is searching for an industrial transformer that satisfies the needs for high frequency if this option is selected. Isolation transformers represent no problem and in fact the Sola/Hevi-Duty (HS1F2AS) could be a solution. In the same token, let's keep in mind the Ferroresonant transformer that could highly eliminate the need for a special filter.

In conclusion, based on previous filtering & PWM analysis, we can recognize that the first topology is probably the more simplistic and as such easier to design. A cost analysis however is needed, as this could be key in the topology selection as the insulation transformer drives the cost in the couple of hundreds. This based on the fact the system will be grounded as commonly agreed.

Further and in depth analysis are also needed to determine the switching mode. Whether the low frequency switching on all IGBTs in alternating cycles per leg could create any issues with the IGBT performance and system efficiency or second if the switching technique of manipulating the upper IGBTs at high frequency (20Khz – 50 KHz) while commutating the lower devices at 60 Hz could be much more practical and efficient for the design based on time constraints.