

Design and Simulation of Dc-Dc Converter for Fuel Cell Operated Vehicle with Single Reference Six Pulse Modulation

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Abstract: Even though electrical vehicle concept is introduced in early 1800's, it gained importance in past couple of decades due to growing conscience on environmental aspects. Different types of electrical vehicles are manufactured in the past centuries and now onboard generation is seems to be promising by fulfilling the needs of a vehicle. Fuel cells or fuel cell stack produces typically 32-68V of EMF, which has to be conditioned before it fed to motor. The conditioning involves two stages DC-DC conversion and then to DC-AC conversion .DC-AC conversion is done through inverter. For DC-DC to conversion various topologies are proposed such as fly back, forward, buck-boost are proposed. This paper deals with the front end DC-DC converter and inverter switching. A hybrid modulation scheme is used to produce pulses to switch the source end full bridge rectifier and inverter at load end. In this modulation scheme high frequency pulses given to full bridge rectifier and 33% modulation scheme based pulses are produced for inverter switching.

Keywords: Electrical vehicle, Fuel cell vehicle, DC-DC converter.

I. INTRODUCTION

The concept of a fuel cell had effectively been demonstrated in the early nineteenth century by Humphrey Davy. This was followed by pioneering work on what were to become fuel cells (Gas based) by the scientist Christian Friedrich Schönbein in 1838. In 1839 Sir William Groves experimented with reversing the action of an electrolyzer, and creating electricity with oxygen and hydrogen as the input fuel. Grove conducted a series of experiments with what he termed a gas voltaic battery, which ultimately proved that electric current could be produced from an electrochemical reaction between hydrogen and oxygen over a platinum catalyst. The term fuel cell was first used in 1889 by Charles Langer and Ludwig Mond, who researched fuel cells using coal gas as a fuel. The first commercial use of fuel cells came more than a century later in NASA space programs to generate power for probes, satellites and space capsules. Since then, fuel cells have been used in many other applications. Fuel cells are used for primary and backup power for commercial, industrial and residential buildings and in remote or inaccessible areas. They are also used to power fuel-cell vehicles, including forklifts, automobiles, buses, boats, motorcycles and submarines.

The primary goal in the automotive industry is to find a suitable alternative to internal combustion engine vehicles (ICEVs) to satisfy the increased needs and demands of consumers worldwide. The main criterion of this critical search

is that the selected option must be more efficient and cleaner compared to the ICE and must be less expensive to manufacture and operate. As a reference, reports from the U.S. Environmental Protection Agency (EPA) state that vehicles in the U.S. still account for about 75% carbon monoxide (CO) emissions, about 45% nitrous oxide (NOx) emissions, and amount for nearly 40% volatile organic compounds emissions[8].

Based on research results of the recent past, there exists high possibility of reducing harmful toxic gas emissions by better control of emissions from vehicles, use of cleaner fuels, and use of clean transportation alternatives, such as mass transit and public transportation. Basically, HEVs (Hybrid Electric vehicles) and FCVs (Fuel cell vehicles) aim at reducing emissions by implementing at least a couple of points mentioned above. Although FCVs and HEVs offer positive prospects for low vehicle emissions, a complete analysis of the vehicle-to-wheel emissions needs to be done in order to confirm the environmental advantages that they may offer. Even though FCVs have lower emissions than HEVs, HEVs are more widespread due to customer acceptance of economy.

Fuel cell vehicles are facing challenges due the limitations of fuel cell (slow in response as it deals with chemicals and cannot take ripple currents due to sluggish reverse characteristics). So power electronics interference is required to operate them properly. In chapter 2 different types of power conditioning systems were discussed and thus provide an efficient circuit which is added advantages of the discussed circuits. In chapter 3, the circuit derived is simulated using MATLAB/Simulink.

II. CONVERTER SCHEMES

Voltage fed Full-bridge converter:

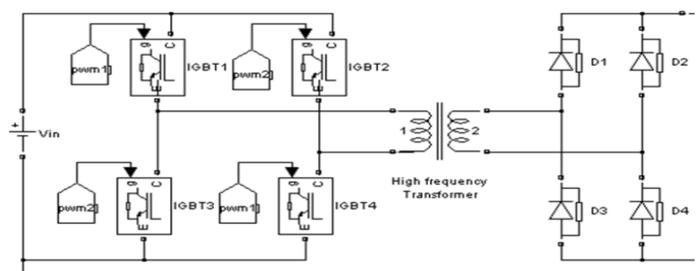


Fig.1.Isolated DC – DC full-bridge converter for fuel cell power conditioning.

A full-bridge converter, as shown in Fig.4 provides electrical isolation. For electrical isolation and high boost ratio, forward, push- pull, half-bridge and full-bridge are the options. Nevertheless, the full-bridge converter is the best for fuel cell power conditioning, based on the following reasons:

- As transistor voltage and current stresses are not high the full-bridge converter is suitable for high-power transmission.
- The full-bridge converter has small input and output current and voltage ripples.
- The full-bridge topology is a favorite topology for zero voltage switching (ZVS) pulse width modulation (PWM) techniques.

In lateral stages several topologies are implemented based on the full bridge idea to achieve less leakage inductance and soft switching etc...

The following wave forms show the voltage and current wave forms of full bridge converter.

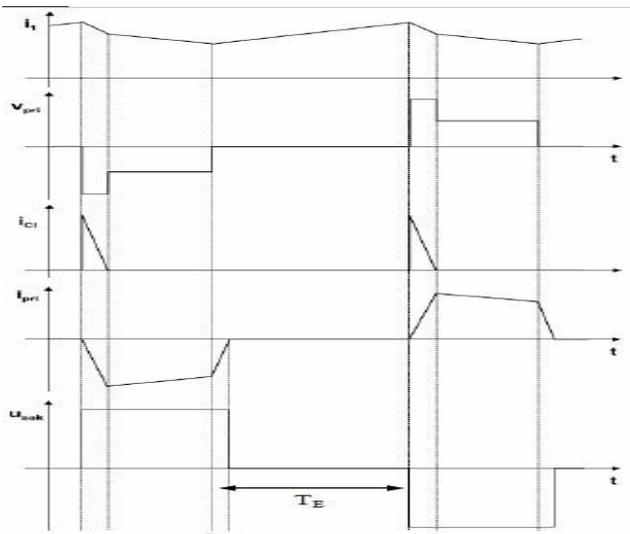


Fig.2. Waveforms of voltage fed full bridge converter.

Soft switching direct converter:

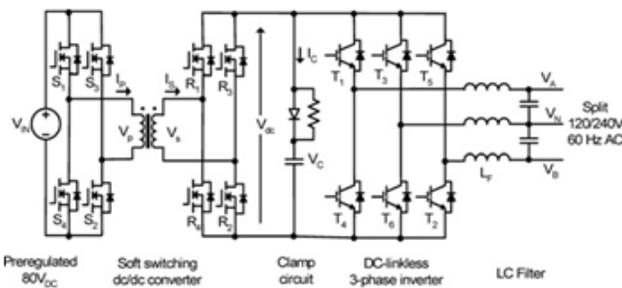


Fig 3. Soft switching full-bridge DC/DC converter.

As one can observe that in above circuit the circuit is not connected to fuel cell module. The voltage has to be pre regulated to using a boost converter and then soft switching technique is applied to the converter. This topology requires clamping circuit. The soft switching full-bridge DC/DC converter is composed of two H-bridge converters with an intermediate high-frequency transformer to boost the voltage to the appropriate level as seen in Fig.6. Capacitors placed in parallel with the MOSFET switches enable the converter to have ZVS turn-on and zero current switching (ZCS) turn-off. On the other side this circuit uses clamping circuit which causes the poor dynamic response.

Wide input range converter:

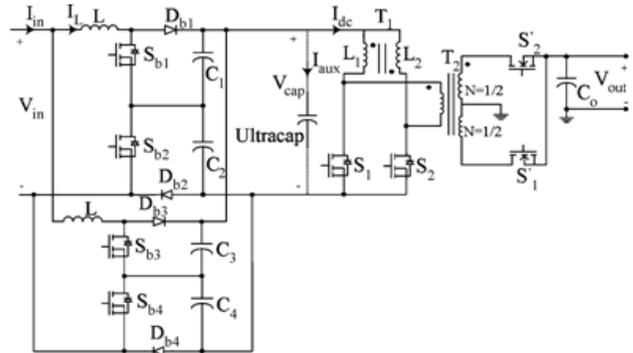


Fig.4.Wide input range converter

The above circuit uses the cascaded connection which enables the circuit to accept wide range of input power and also give lower current ratings .As the circuit has two boosting stages cascaded so it delivers a constant output voltage. The second stage is composed of an isolated two inductor boost converter and boosts the voltage to the final level. This fuel cell power conditioner is capable of achieving overall efficiencies of 90% or higher. The complexity of the system is high with two transformers and eight switches. So implementing the modulation for such system is complex.

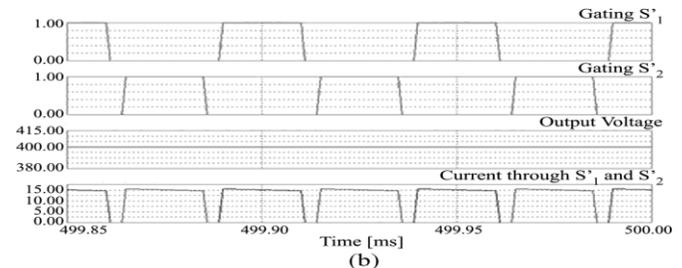
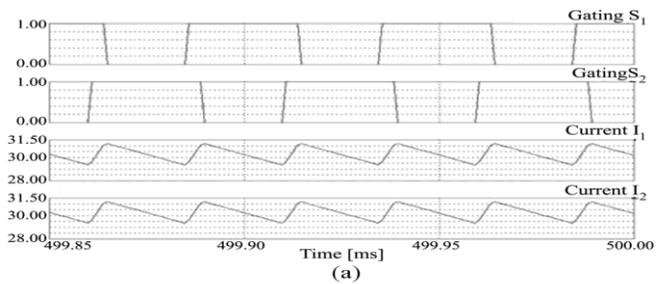


Fig.5.Simulation results for a second stage dc-dc converter: (a) at the primary side of T2, (b) at the secondary side of T2[xii].

Front-end multiphase dc/pulsating-dc converter:

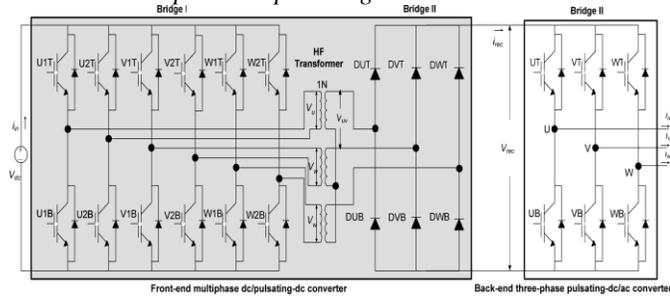


Fig. 6. Multiphase dc/pulsating-dc converter.

The above converter uses three rectifier bridges at the front end to convert the dc to dc and an inverter at back end an inverter to convert dc to ac.

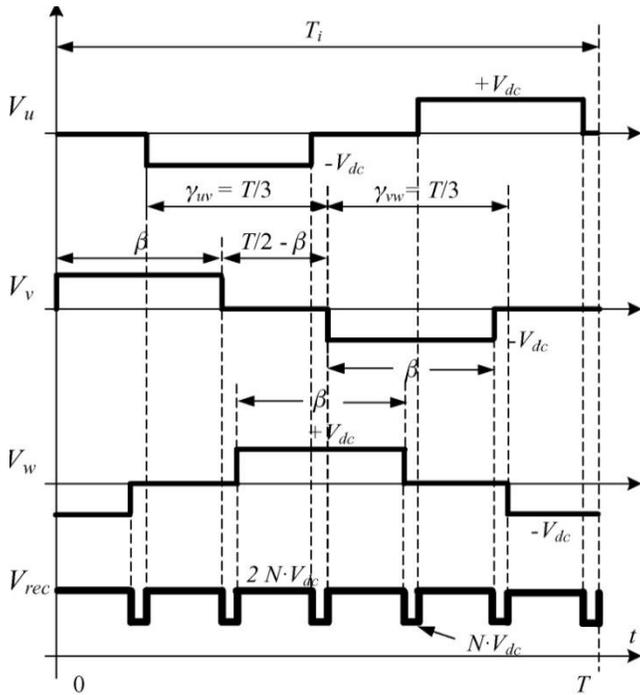


Fig.7. Proposed hybrid modulation switching scheme [xvi].

As compared to the conventional SPWM hard-switching schemes, in which all switches operate at high frequency, the hybrid modulation achieves up to a 67% loss reduction on Bridge III. However, the switching loss may be still high, especially when slow switching-speed devices are used. With hybrid modulation, the switches on two legs of Bridge III commute at line-frequency with negligible switching loss, while the rest two switches on the third leg commute under hard-switching condition at high frequency. The obtained output voltage V_{rec} will be a pulsating dc with six times of switch frequency $6f_s$. In order to simplify the implementation of hybrid modulation in practice, it is preferable to switch the third leg on Bridge III in synchronism with each pulse of the link voltage V_{rec} . In other words, the switching frequency of the third leg on Bridge III under hybrid modulation should be at least $2f_s$ for the aforementioned two schemes. To further reduce the frequency of the output voltage V_{rec} , asymmetrical duty-cycle-based phase-shift control can be applied to primary side full bridges [16].The

circuit uses three bridges at the front end; it results in complex control and has major issue of circulating current among the bridges conducted by semiconductor devices. If one bridge fails, the modulation fails, i.e., the pulsating dc voltage does not contain six-pulse information anymore, and hence, the inverter is not able to produce balanced three-phase output.

III. CONVERTER TOPOLOGY

By taking the positive aspects from each of the above mentioned schemes a novel converter is proposed; It uses interleaved connection at the front to widen the input range, uses a full bridge converter in that cascaded connection and further to improve current rating at secondary or input of inverter, it uses the hybrid modulation scheme proposed in the front end multiphase dc but as we use an interleaved connection reduces the complexity of modulation scheme. In addition, the circulating current between the bridges is eliminated because of the proposed modulation scheme. The proposed circuit is shown in figure below.

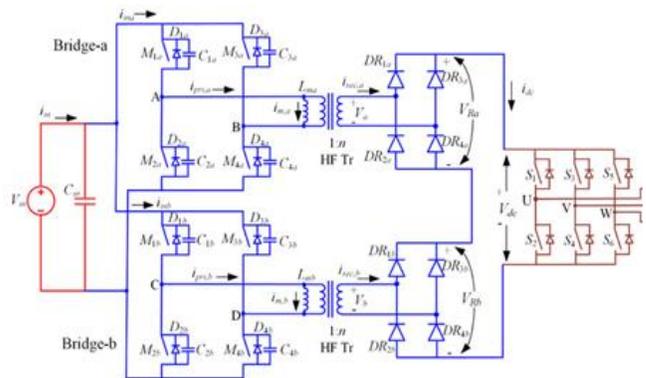


Fig.8. proposed converter schematic

The above proposed circuit is operated through an unique hybrid modulation technique with a single six pulse reference to produce pulses for front end converter as well as the inverter switches. In this modulation scheme three sinusoidal waveforms which are in a phase difference of 120° to each other are taken to produce the six pulse reference, and is produced by applying the sine waves to the MAX function. When this six pulse wave form divides the wave from produced in modulation scheme shown below produces pulses of 120° width each . The modulation scheme is shown below.

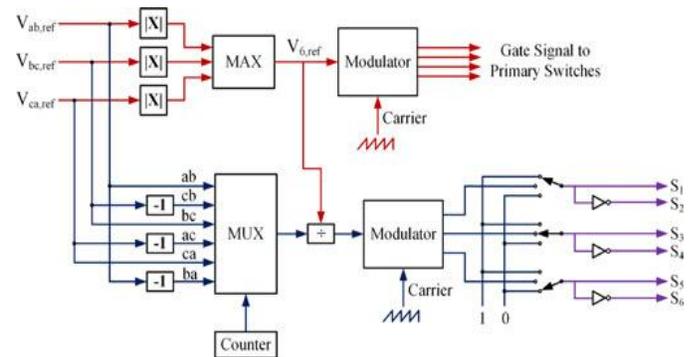


Fig.13. Modulation scheme.

The switching operation is similar to that of the full bridge and switching of complementary switches is delayed by DT_s ; thus the full bridge produces a voltage waveform as shown below:

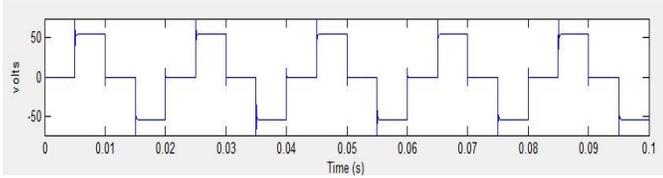


Fig.9. Full bridge output voltage(V_a).

This voltage is converted into dc by means of a diode bridge and addition of V_{Ra} and V_{Rb} will give a dc voltage which is fed to the inverter is shown below.

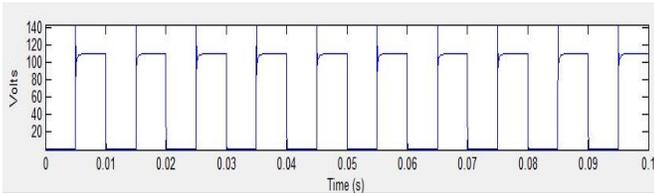


Fig.10. Dc input to the inverter

As we stated that inverter input is combination of V_{Ra} and V_{Rb} , we can see that each bridge produces similar wave from as we feed them with same pulses. Hence there will be no miscommunication between the bridges and hence produces no circulation currents. And hence we can see that this topology uses no clamping circuit as in the soft switching converter. Even in the case of bridge failure other bridge will produce the same voltage wave form and hence a balanced three phase voltage waveform will continue to exist at the load end. But the magnitude of the wave form will decrease. This leads to reduction of torque in case the load is a synchronous motor. This limitation can be overcome by a coordinated bidirectional boost topology at the source side. Inverter pulses of the modulation scheme are given below.

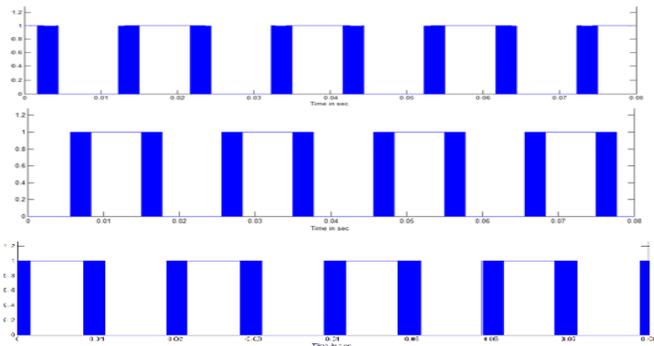


Fig.11. Inverter pulses S_1, S_3 and S_5 respectively.

IV. RESULTS AND DISCUSSIONS

When the pulses shown above are given to the inverter it produces the line to line voltages as shown in figure below.

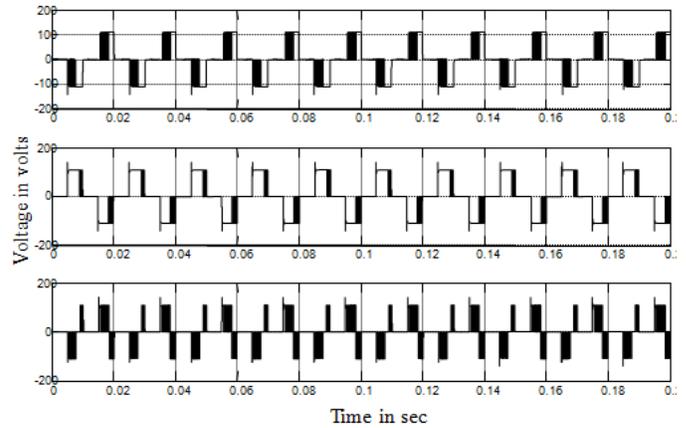


Fig.12. Line to line voltages without filter.

These voltages cannot be fed to load as they are, they need to be filtered before. By following the designing of filter pattern mentioned in [i]. And obtained LC values as $L=10\text{mH}$ and $C=10.004782e^{-5}$ farads. when they applied to the circuit the following line to line voltages waveforms were obtained.

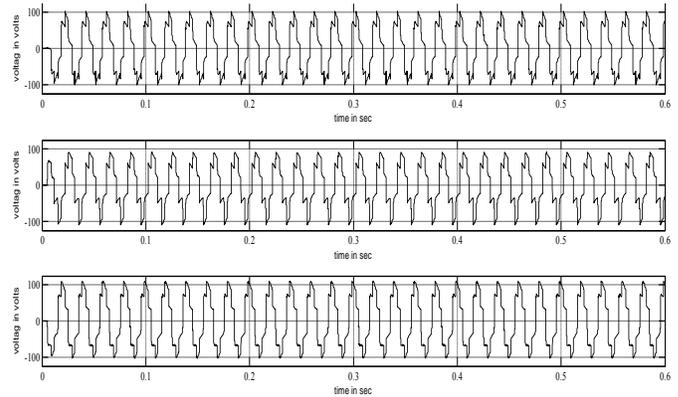


Fig.13. Line to line voltages with LC filter

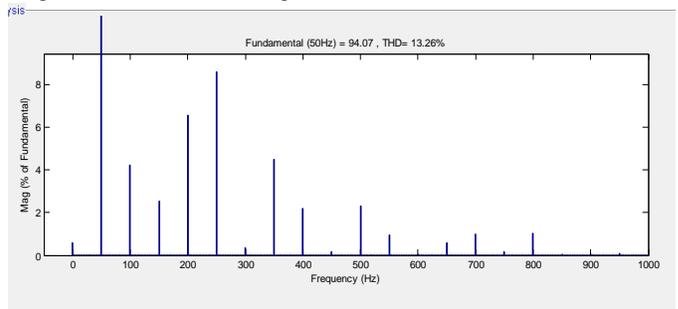


Fig.14. THD value with LC filter

Here we can see that fifth harmonic as prominent and thus a new filter RLC is designed. With the introduction of R into circuit we can maintain circuit in under damped condition by maintain the low R value. This filter values are $R=0.63, L=10\text{mh}$ (considered) and $C=10.873\mu\text{f}$ (obtained). A RL load is connected at the load end (In place of motor). The following wave forms and THD are obtained.

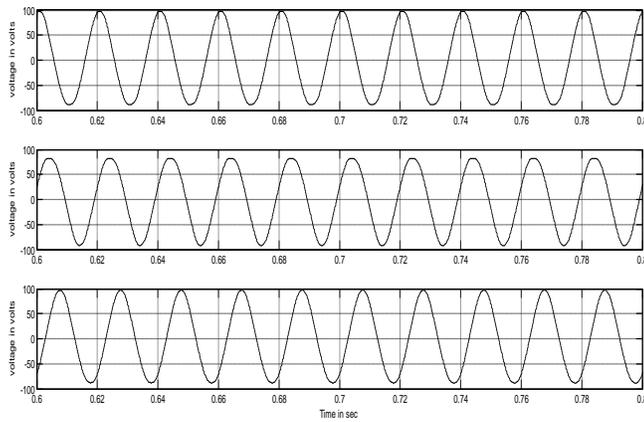


Fig.15. Line to line voltages with RLC filter.

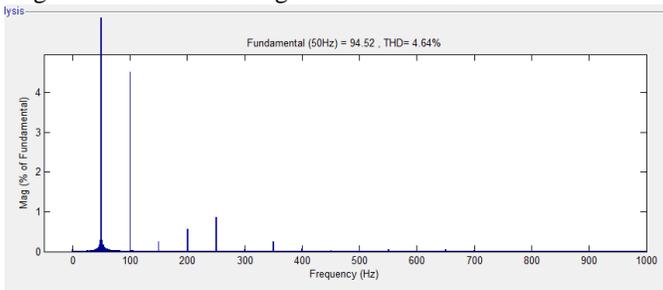


Fig.16. THD value with RLC filter.

We can observe that less harmonic distortion compared to the LC filter value. We can also observe that the harmonics occurred in the LC filter case are mainly of fifth harmonic. Here we can observe that fifth harmonic value is very less and hence harmonic distortion is also less compared that of LC filter.

V. CONCLUSION

In this paper different topologies that can be used for the conditioning of fuel cell power are discussed and by picking strengths of each configuration and switching; the topology used in [1] will be reliable is discussed. The implementation if modulation scheme is done through the MATLAB/Simulink. After the modulation scheme output voltages of inverter with different filter are compared . The RLC filter is giving much better results compared to that of the LC with lesser harmonic distortion. As a future work a better modulation schemes can be used at modulation such as SVPWM or Modified SVPWM which are better and have advantages in controlling of motor.

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