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Improving Power Quality by using Hybrid Filter in Three Phase Inverter with CPPM

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Abstract: Switched-Mode power supplies are more and more widely used in industrial equipment's. But this switched mode will bring many negative effects. In the motor systems driven by sinusoidal pulse width modulation (SPWM) three-phase inverters, the peaks of common-mode (CM) voltage are so high that it will cause many negative effects. In this paper, a hybrid filter is presented to reduce the CM voltage (CMV) and the differential-mode (DM) harmonics in a three-phase inverter with carrier peak position modulation (CPPM). Because the use of CPPM strategy in the inverter can ensure that the output CMV will be only two levels in any condition, the simple active CM filter (composed of a half-bridge circuit) in the hybrid filter can effectively suppress the output CMV and CM current. The passive filter in the hybrid filter consists of an added single tuned filter and the original DM low-pass filter. The single tuned filter is designed to lower the DM harmonics, which are aggravated by the CPPM strategy in the carrier frequency band. Through the experiments, the validity of CMV and DM harmonics suppression by the hybrid filter in the three-phase inverter is verified and the calculation-control active CM filter is proved to be the best in the optional schemes.

Keywords: Carrier Peak Position Modulation (CPPM), Common-Mode Voltage (CMV), Differential-Mode (DM) Harmonics, Hybrid Filter, Sinusoidal Pulse Width Modulation (SPWM).

I. INTRODUCTION

The CM voltage (CMV) will produce a huge pulsating CM current (CMC) through the distributed capacitance of the system. The CMC could interfere with the adjacent devices along the ground wire and even will result in the wrong operation of the devices. In addition, the CMV will cause the high shaft voltage through the parasitic capacitors between the stator and the rotor. The high shaft voltage could lead to momentary electromagnetic discharge phenomena (viz. the bearing current) and will therefore damage the motor bearing. The active power filter composed of switching circuits is not affected by the limit of voltage class. In the conventional SPWM or SVM three-phase inverter, the CMV is a four-level pulse. So the active filter is implemented by using a multi-level inverter and the four-level voltage is yielded to counteract the CMV. The structure of this multi-level active filter is too complex to be used in the low cost cases. In the above active filters, all the compensative voltages are cascaded into the inverter's output through a CM transformer. The CM transformer is complex in design and manufacture, big in size, and not easy to be installed because of the cascade mode, which is especially not propitious for the revamping of the established inverter. In the inverter with CPS, the CMV is suppressed by using three phase four-leg topology. Because the modulation index under the CPS strategy is limited, the application of this filter is restricted. This paper describes the design of a hybrid filter in the three-phase inverter with CPPM. Under the CPPM strategy, the output CMV of the inverter will be only two levels in all cases. So the active CM filter in the hybrid filter is designed to be a simple half-bridge structure, which can be used to counteract almost all the CMV. The counteract voltage is paralleled into the inverter's output, which is convenient for the installation of the filter. When the carrier frequency fc is relatively low in the three-phase inverter with CPPM, the differential-mode (DM) harmonics in the carrier frequency band will be substandard. To solve this problem, a single tuned filter is added in the hybrid filter. The single tuned filter and the existing low-pass filter form a passive DM filter.

II. POWER QUALITY PROBLEMS

The electric power network has undergone several modifications from the time of its invention. The modern electric power network has many challenges that should be met in order to deliver qualitative power in a reliable manner. There are many factors both internal and external that affect the quality and quantity of power that is being delivered. This chapter discusses the different power quality problems, their causes and consequences.

A. Interruptions

It is the failure in the continuity of supply for a period of time. Here the supply signal (voltage or current) may be close to zero. This is defined by IEC (International Electro technical Committee) as "lower than 1% of the declared value" and by the IEEE (IEEE Std. 1159:1995) as "lower than 10%". Based on the time period of the interruption, these are classified into two types. They are,

- **Short Interruption:** If the duration for which the interruption occurs is of few mille seconds then it is called as short interruption.

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- **Long Interruptions:** If the duration for which the interruption occur is large ranging from few mille seconds to several seconds then it is noticed as long interruption. The voltage signal during this type of interruption is shown in Fig.1.

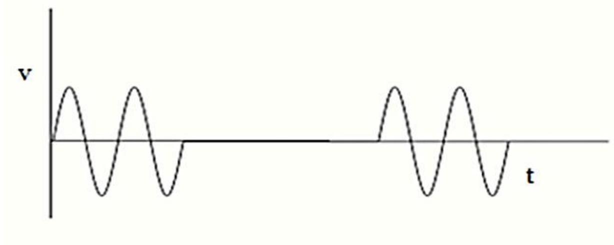

Fig.1. Voltage Signal with Long Interruption.

B. Waveform Distortion

The power system network tries to generate and transmit sinusoidal voltage and current signals. But the sinusoidal nature is not maintained and distortions occur in the signal.

C. Frequency Variations

The electric power network is designed to operate at a specified value (50 Hz) of frequency. The frequency of the framework is identified with the rotational rate of the generators in the system. The frequency variations are caused if there is any imbalance in the supply and demand. Large variations in the frequency are caused due to the failure of a generator or sudden switching of loads.

D. Transients

The transients are the momentary changes in voltage and current signals in the power system over a short period of time. These transients are categorized into two types impulsive, oscillatory. The impulsive transients are unidirectional whereas the oscillatory transients have swings with rapid change of polarity.

E. Voltage Sag

The voltage sag is defined as the dip in the voltage level by 10% to 90% for a period of half cycle or more. The voltage sag as shown in Fig. 2.

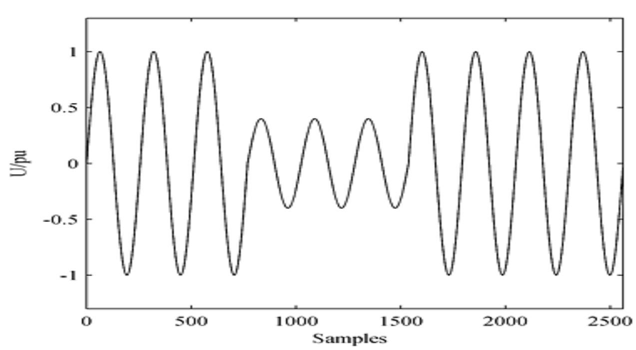

Fig.2 Voltage Sag.

F. Voltage Swell

Voltage swell is defined as the rise in the voltage beyond the normal value by 10% to 80% for a period of half cycle or more. The voltage swell as shown in Fig.3.

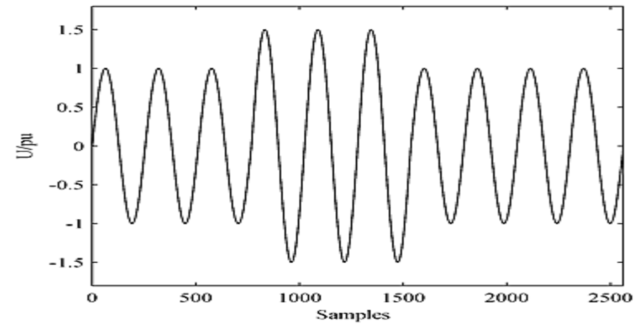

Fig.3. Voltage Swell.

G. Voltage Unbalance

The unbalance in the voltage is defined as the situation where the magnitudes and phase angles between the voltage signals of different phases are not equal as shown in Fig.4. In case of a ground faults the second reason for bonding and grounding is to give a low impedance path for the flow of fault current, so that the protective device from the power source, could isolate the faulted circuit. The third reason for the grounding is for sensitive electrical equipment is to create a ground reference plane. This is known as the Signal Reference Ground (SRG).The SRG The configuration may vary from facility to facility and from user to user. The SRG cannot be an isolated entity. To create a total ground system it should be bonded to the safety ground of the facility. Electro Magnetic interference (EMI) refers to the interaction between magnetic fields and electric fields and sensitive electronic devices and circuits. EMI is a high frequency phenomenon. The process of connecting EMI to sensitive devices is different from that of power frequency electrical transients and disturbances. The reduction in the effects of EMI requires special techniques, as will be seen later.

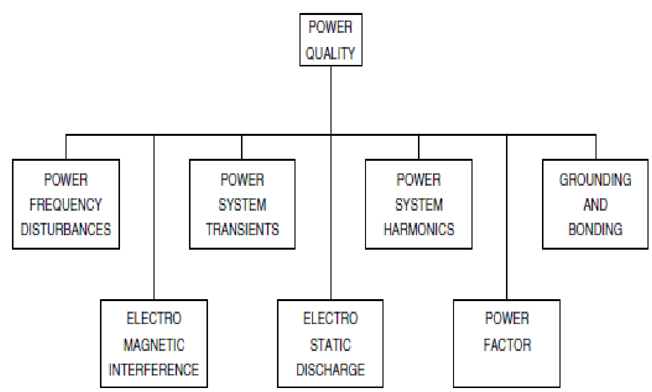

Fig.4. Power quality issue.

III. SYSTEM MODELING

In the three phase inverter as shown in Fig5. Most passive filters are realized with two common ways: a CM choke or CM transformer cascading into the main circuit; a resistor-capacitor (RC) or resistor inductor capacitor (RLC) attenuation network paralleling into the main circuit. The drawbacks of passive CM filters are as follows: its bulky size, high power loss, etc.

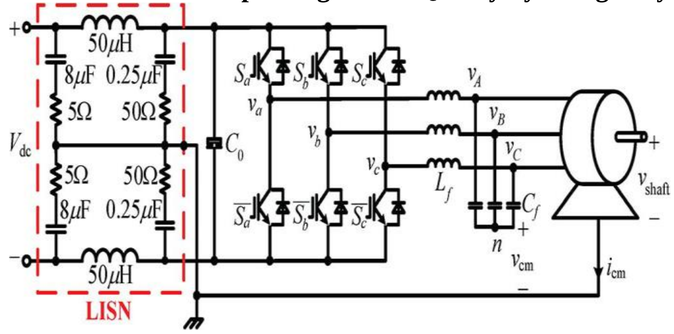

Fig. 5. Three-phase inverter.

Fig. 6(a) shows the CMV in the three-phase inverter with the conventional SPWM strategy. When va, vb, and vc are of high (or low) level, which is called the zero state, the peaks of the output CMV are maximal (about Vdc/2). The zero state is the major cause of the huge CMV. If the peaks of three carriers are mutually staggered Tc/3 (Tc is the carrier cycle) in the inverter, the probability for the occurrence of the zero state will be the lowest. This is the key idea of the CPS strategy. As shown in Fig. 6(b), the occurrence frequency and the duration time of Vdc/2 in CMV are reduced greatly. In order to avoid the zero state in all cases, the variant oblique triangular carrier is used to modulate the reference sinusoidal voltage instead of the usual symmetric triangular carrier in the inverter with the CPPM strategy. Fig. 6(c) shows that the peaks of the output CMV with CPPM are reduced to Vdc/6. The problem of the switching dead-time has been considered in the calculation of carrier peak positions. Thus, using the CPPM strategy can ensure that the output CMV of the inverter will appear only two-level voltage (Vcd/6) in any case.

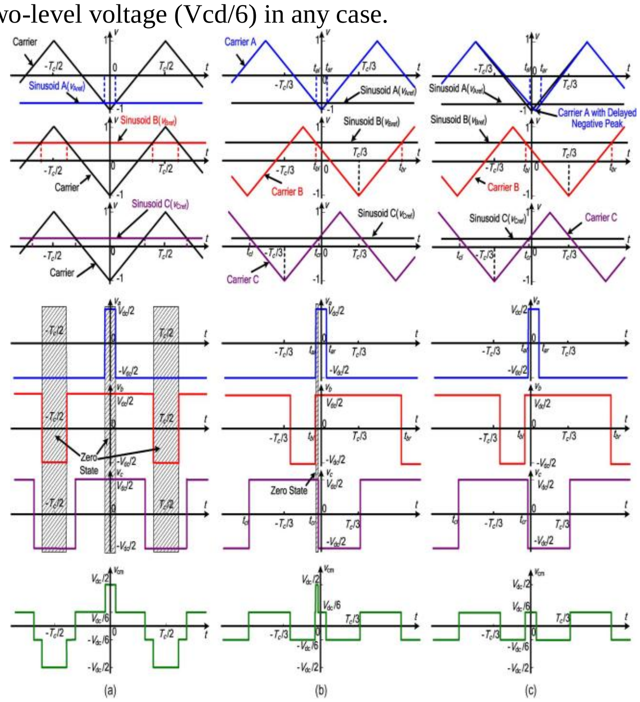

Fig. 6. Modulation of three-phase reference voltages with different carriers (top), three-phase output pulses (middle) and output CMVs (bottom) in the three-phase inverter under (a) the conventional SPWM strategy, (b) the CPS strategy, and (c) the CPPM strategy.

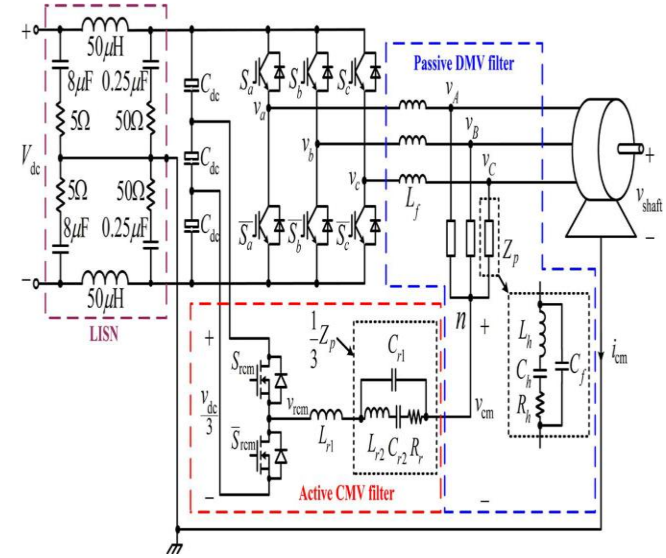

Fig. 7. Three-phase inverter with the hybrid filter.

Because a capacitor Cf in the original low-pass filter is in parallel with a branch circuit of the single tuned filter, they can be merged into the impedance Zp (as shown in Fig7). The passive DM filter is composed of the inductors Lf in the original low-pass filter and the impedances Zp. In theory, the THD of the output DMV can also be reduced by simply increasing the Cf of the original low-pass filter. But the previous studies show that a single tuned filter with a parallel capacitor has higher cost performance than a single capacitor in the harmonic suppression. It will form an organic whole to connect the above designed active CM filter with the passive DM filter through the neutral point n. That is the hybrid filter in the design plan (see Fig. 7). In Fig. 7, the proportional coefficient k, which is mentioned in Part A of Section IV, is set 1/3. From Fig. 7, it can be seen that the mid-point of the inverter dc input is equipotential with the ground in essence because of the Line Impedance Stabilization Network (LISN). Then the voltage at any point is equal to the potential difference from the point to the midpoint of the dc input. Because the output CMVs of the inverter with the CPPM strategy are Vdc/6, the dc input voltage levels of the active CM filter must also be Vdc/6 when k = 1/3. So the dc voltage of the active filter can be taken from the divided voltage of the inverter dc voltage through the middle capacitor which is one of the series capacitors on the inverter dc-side. The potentials of the middle capacitor's two ends are just Vdc/6.

IV. SIMULATION RESULTS

A. Common Mode Voltage (CMV)

Fig. 8(a) shows that the peaks of CMV (above 350 V and below −350 V) will appear in every carrier cycle under the conventional SPWM strategy. Under the CPPM strategy, the CMV wave is generally between −117 V and +117 V. Even if the overshoot of the jump edges is taken into consideration, the CMV peaks are not outside the range of 240 V Fig.8(b).

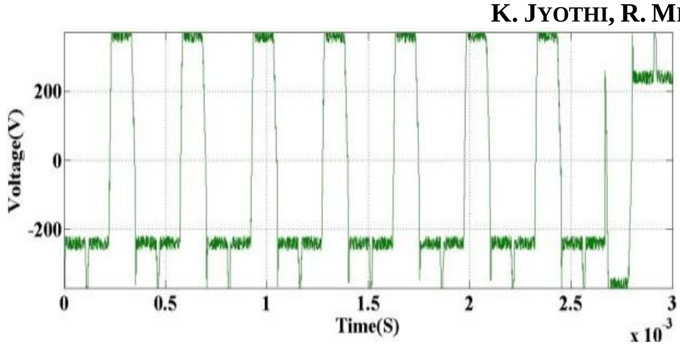

Fig.8 (a). CMV in three-phase inverter under the SPWM strategy without Hybrid filter.

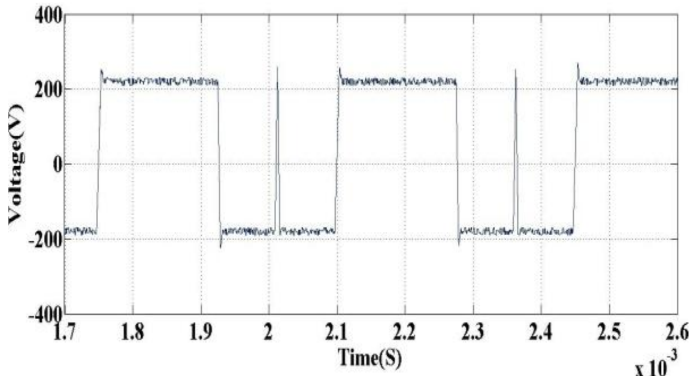

Fig.8 (b). CMV in three-phase inverter under the CPPM strategy without Hybrid filter.

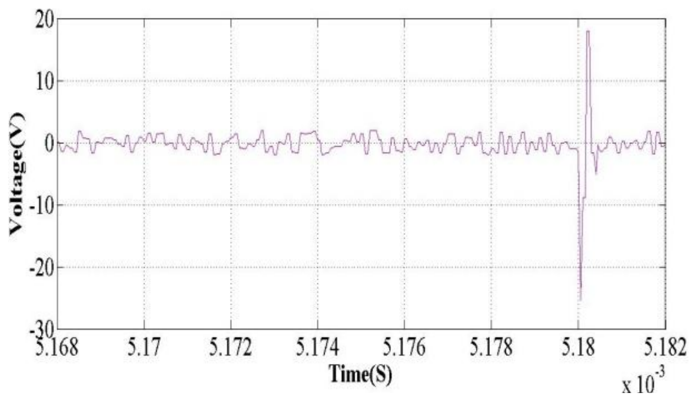

Fig.8 (c). CMV in three-phase inverter under the CPPM strategy with Hybrid filter.

Under the conventional SPWM strategy, the maximal peak of the CMV in the frequency domain is up to 44 dBV, whereas it is only about 36 dBV under the CPPM strategy. Under the CPPM strategy, the output CMVs of the inverter with the hybrid filter are shown in Fig.8(b) and 8(c). In 3-phase inverter we are using SPWM and CPPM strategies. In this CMV is high because of not using Hybrid filter. The CMV problem under SPWM and CPPM strategies with Hybrid filter and without Hybrid filter are listed below.

B. Common Mode Current

Under the conventional SPWM strategy, each jump step of the CMV is greater than 233 V and forms high CMC peak 0.5A as shown in Fig. 9(a). The simulation result of its CMC as shows in Fig.9(b). In that the maximal peak in the frequency domain is about −24 dBA. The simulation FFT result of its CMC shows that the maximal peak in the frequency domain is about −24 dBA as shown in Fig.9(c). After the hybrid filter is added in the three-phase inverter, the CMC peaks are decreased obviously. Under the CPPM, the spikes of the CMC are less than 300 mA as shown in Fig.9(c). Fig. 9(a) and 9(c) shows the output CMCs of the inverter under different conditions. The peaks of CMC are derived from dv/dt of the CMV jump edges. The CMC in three-phase inverter under SPWM and CPPM strategies without Hybrid filter and CMC in three-phase inverter under CPPM with Hybrid filter. The CMC in SPWM and CPPM with Hybrid filter.

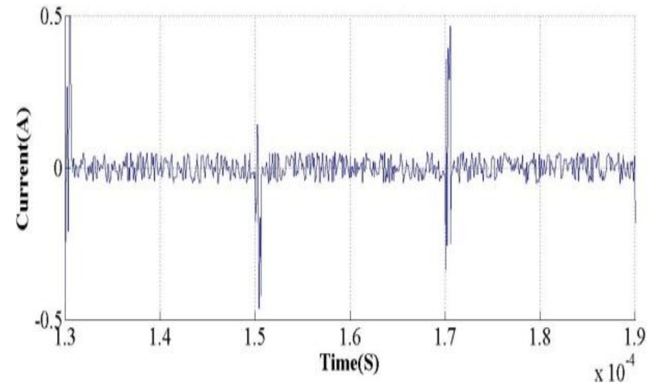

Fig.9(a). CMC in the three-phase inverter under SPWM strategy without Hybrid filter.

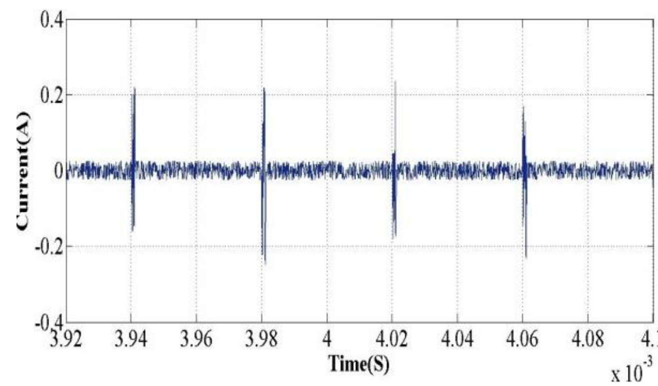

Fig.9(b). CMC in the three-phase inverter under CPPM strategy without Hybrid filter.

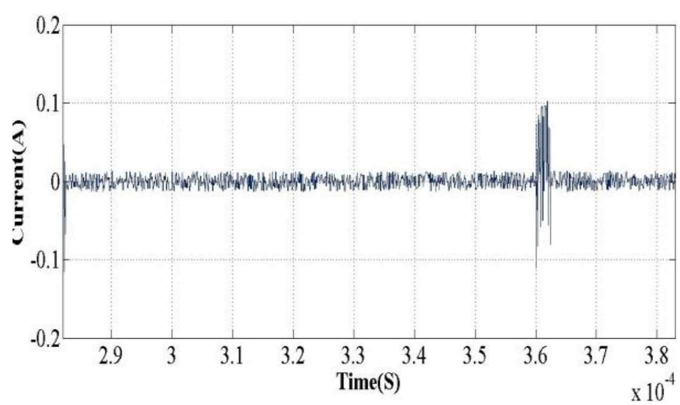

Fig.9(c). CMC in the three-phase inverter under the CPPM strategy with Hybrid filter.

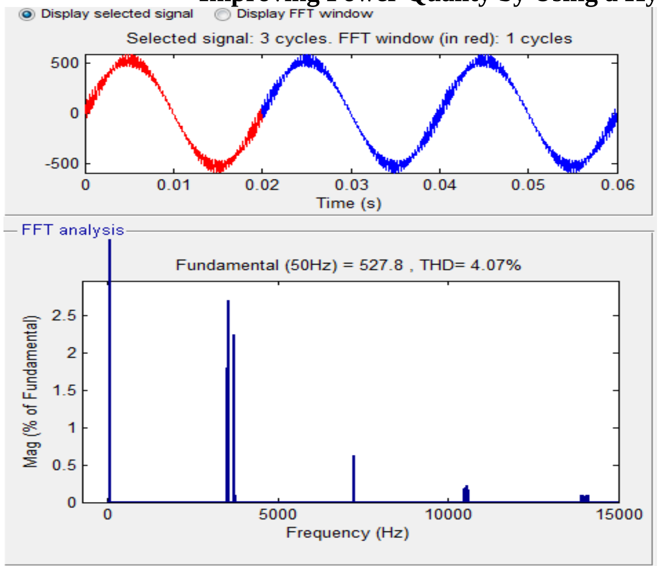

Fig.10(a). THD of DM harmonics under SPWM strategy without Hybrid filter.

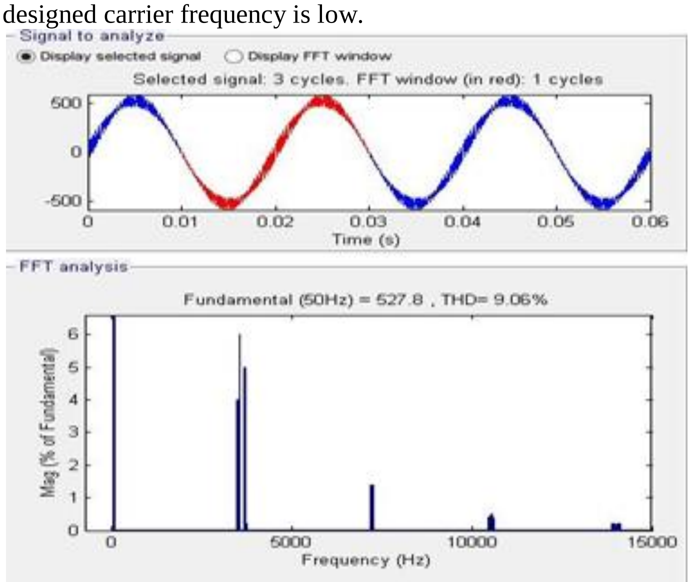

Fig.10 (b). THD of DM harmonics under CPPM strategy without Hybrid filter.

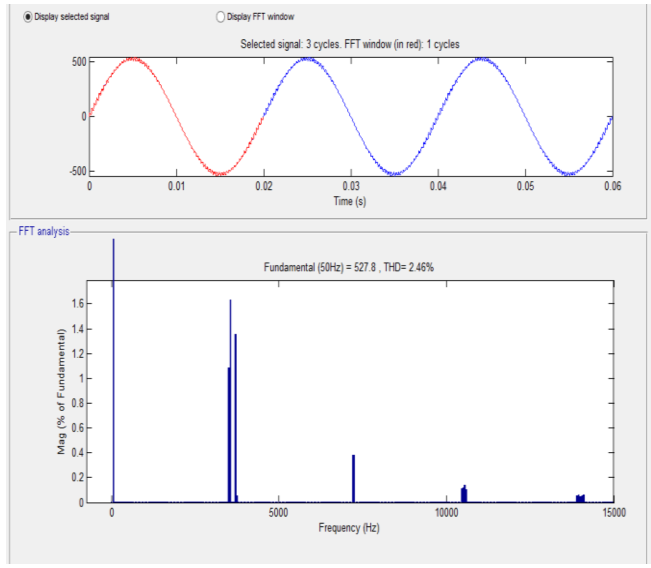

Fig.10 (c). THD of DM harmonics under CPPM with a Hybrid filter.

C. THD of DM Harmonics

Fig.10(a), 10(b) and 10(c) shows the output DMV v_{AB} in the inverter under SPWM and CPPM strategy without Hybrid filter and also CPPM strategy with Hybrid filter. The FFT results in Fig.10 confirm the previous simulation conclusion; the major harmonics of the DMV are near the carrier frequency. Under the conventional SPWM strategy and the CPPM strategy without a hybrid filter, the maximal magnitudes of the DM harmonics are 20 dBV and 30 dBV respectively. FFT results of the DMV v_{AB} under three strategies at fc = 3.6 kHz. The maximal harmonic peak of DMV usually appears at the carrier frequency. The magnitude of DMV under the CPS strategy at fc will not be zero and even will be large. Although the harmonics of the output DMV will be somewhat reduced through the low-pass filter, the total harmonic distortion (THD) of DMV would be serious and even be substandard when the designed carrier frequency is low.

In Fig.10(c), the magnitude of the DMV harmonic at f is still about 8% of the fundamental magnitude despite the fact that the low-pass filter is used. The CPPM strategy is based on the CPS strategy. The difference between them is that the carrier peak position is changed for a short time in a small range. Hence the output DMV harmonics in the inverter with CPPM will be similar to that with CPS. Compared Fig.10(a) with Fig.10(b) the harmonic magnitude in the carrier frequency band is almost the same and the THD in Fig.10(b) is slightly higher. As shown in Fig. 10 (c), the harmonic peak of the DMV in the carrier frequency band is reduced by more than 20 dBV while the hybrid filter is added. Under the condition of low fc, if the CMV is suppressed by using the CPPM strategy, an extra DM filter is needed to reduce the harmonics in the carrier frequency band. In 3-phase inverter we are using SPWM and CPPM strategies. In this CMV is high because of not using Hybrid filter. The DMV problem under SPWM and CPPM strategies with Hybrid filter and without Hybrid filter are listed below.

V. CONCLUSION

Through the analysis the effectiveness of hybrid filter is studied for two cases such as Battery operated inverter fed 3-Φ Induction motor drive and Photo Voltaic (PV) based inverter fed 3-Φ Induction motor drive. Simulation results demonstrated that the feasibility of hybrid filter for reducing the CMV and DM harmonics in an inverter fed 3-Φ Induction motor drive. It gives simple structure, easy installation, flexible in application, compatible in THD standard and also increases voltage utilization.

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