HARMONICS REDUCTION IN THREE PHASE UNINTERRUPTIBLE POWER SUPPLY USING PASSIVE FILTER

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ABSTRACT

The presence of harmonics in the UPS system increases the losses, output voltage distortion can disturb the operation of loads, it may damage the equipment and the value of Total Harmonic Distortion (THD) is high. The conventional LC filter is very large and costlier. To rectify this problem passive filter is proposed in this paper. The most common practice for harmonic reduction is the installation of passive harmonic filters. Passive filters exhibit the best relationship among all other improvement techniques when dealing with low and medium voltage rectifier system. Compared to LC filter, the passive filter reduces the THD value. The simulation result of a 3-KW UPS with the passive filter has been developed and verified.

Keywords—Passive filter, uninterruptible power supply (UPS), Electromagnetic Force (EMF), Total Harmonic Distortion (THD), TransZ-source inverter.

I. INTRODUCTION

There is a normal growth of harmonics in the electrical loads of a modern facility as it uses advanced electronic applications such as communications, computers and servers. This equipment works on internal DC power supplies derived from the AC mains input. All these loads take non-linear currents from the supply and generate harmonics in the supply. UPS systems are normally used for continuity of communications, and holding on to programs and data. There are three types of UPS systems available today—offline, line interactive, and online. In offline and line interactive UPS systems, AC mains when available, is directly linked with no frequency or harmonic correction. Hence, the harmonics present in the mains are passed on to the loads. Likewise, the load harmonic currents are passed on to the incoming line without any filtering. This paper discuss about online UPS systems, which effectively act as a buffer for harmonics between the load and the power supply. Apart from provide uninterrupted power, they are favored for all critical electronics applications as they can receive this buffering action. UPS systems are associated with harmonic problems as well as solutions. The UPS rectifier uses filters and has battery as back EMF. This is similar to a DC drive situation. In most cases, the rectifier operates in alternating current mode, takes peak currents and has harmonics ranging from 15 to 40 per cent. The problem of harmonics is mainly serious in India since the input voltage variation is very wide along with high input impedance and wide frequency fluctuation [5], [10], [12], [14], [15]. Because of these problems, making a 6-pulse rectifier with harmonic trap to keep 5 per cent input current harmonics is a technocommercial challenge. In order to manage these harmonic currents in the input, trap filters of 5th and 7th harmonics are used. There are many practical problems in the system. First, under light load conditions, the overall power factor of the UPS gives rise to boost the voltage. Second, it creates more excitation problems in generators.

Harmonic currents generated by certain equipment’s such as static converters, discharge lamps, arc furnaces etc. The static converters draw energy from an alternating current through rectifiers. These rectifiers fitted with thyristors are generators of harmonics. It can adversely affect the function of other equipment connected to the same network. The adverse effects of harmonic currents:

- They cause excess heating especially in line conductors, transformers and condensers,
- They induce vibrations and noise in electromagnetic equipment,
- They can cause interference with communication and low current protection/signaling circuits.

Therefore, while using trap filters, extraordinary care has to be taken to carry out a stability analysis of the installation. The option of using other filters is also available.

II. TRANSZ SOURCE INVERTER

To overcome the problems in the traditional method the proposed method is implemented using Trans Z source inverter [13], [11]. It employs a unique impedance network to combine the converter main circuit to the inverter, load. The Trans Z source inverter consist of an inductor L1 and L2 and capacitor C1 connected in T-shape is employed to couple the circuit with the inverter. In case of power outage the battery bank supplies power to the inverter. The inverter consist of Trans Z source symmetrical network (L1 = L2 and C1) and inverter (S1 – S6). When the shootthrough vectors are taken the load is shorted by upper and lower switches on the same leg of the inverter. The proposed UPS can boost the voltage by using shootthrough vectors shown in Fig.1.

Fig. 1. Proposed UPS with Trans Z Source inverter
The inductor (L1 and L2) have the same inductance, the Trans Z source network becomes symmetrical. From the symmetrical and equivalent circuit in Fig.5 (a) the voltage equation can be derived as

\[VL_1 = VL_2 = VL\]  \hspace{1cm} (1)

The voltage equation of the non-shoot through states are derived as,

\[Vdc = Vc + VL\] \hspace{1cm} (2)

\[Vin = Vc - VL\] \hspace{1cm} (3)

Substituting (2) into (3) yields

\[Vin = 2Vc - Vdc\] \hspace{1cm} (4)

When the Z-source inverter is working in shoot-through states shown in Fig.5 (b) during time interval \(T_0\), where \(T_0 = T_s - T_1\), and \(T_s\) is the switching period, the inverter can be considered as a short circuit.

The voltage equation of the Trans Z-source inverter at shoot-through states are,

\[Vc = VL Vin = 0\] \hspace{1cm} (5)

The average voltage of inductor L1(or L2) over one switching period in steady-state operation is zero

\[\frac{(Vdc - Vc)T_1 + VcT_0}{T} = 0\] \hspace{1cm} (6)

Or

\[Vc = \frac{T_1}{T_1 - T_0} Vdc\] \hspace{1cm} (7)

Substituting (7) into (4) gives

\[Vin = \frac{T_0}{T_1 - T_0} Vdc = B Vdc\] \hspace{1cm} (8)

Where \(B = \frac{T_0}{T_1 - T_0} > 1\) \hspace{1cm} (9)

\(B\) is the boost factor. If the voltage across the inductor is ignored, the output peak voltage is

\[V_{o.m} = V_{1.m} = M \cdot Vin = M \cdot B \cdot Vdc\] \hspace{1cm} (10)

Where \(U_{1.m}\) is the peak value of fundamental voltage of the inverter and \(m\) is modulation index \((m \leq 1)\).

The selection of the boost factor and the modulation index can obtain the desired ac output voltage regardless of the battery bank voltage. The Transfer function of the Inverter is given as:

\[K = 1 - \frac{T_0}{T_0 - T_1} Vdc = \frac{(1 - d)}{(1 - 2d)} Vdc\] \hspace{1cm} (11)

Where \(T_0/T_s = d\) is the shoot through duty period. The high switching frequency \(f_s = 1/T_s\). The capacitor voltage over one switching period is constant, which is equal to average input voltage.

The inductor current \(iL\) in the inner loop and the output voltage \(V_o\) in the outer loop shown in Fig.3 is proposed in this paper [2], [3], [4], [7].

\[\text{Fig. 3. Control system of Trans Z source inverter for the proposed UPS system}\]

\[\text{A. Inner loop}\]

The current feed forward control of the inner loop has eliminated the load current disturbance shown in Fig.4.

\[ire - iL = V_s\] \hspace{1cm} (12)
Where \( i_L \) is the current across the filter. \( i_{ref} \) is the reference voltage obtained from the comparison of voltage.

![Fig. 4. Block diagram of inner loop](image)

### B. Outer Loop

The output voltage \( V_0 \) is regarded as a disturbance to the current inner loop. To smooth the output voltage, a voltage feed forward control is adopted shown in Fig. 5.

\[
V_0 - Kw . \frac{(V_{dc})}{(1 - 2d(sTs + 1))} - V_0
\]  
(13)

Where \( Kw \) is the transfer function of voltage feed forward controller

\[
Kw = \frac{(1 - 2d)}{(1 - d)V_{dc}}
\]  
(14)

The voltage across the inductor \( L_s \) can be given as,

\[
VL = V_1 - V_0 = V_s \frac{(1 - d)V_{dc}}{(1 - 2d(sTs + 1))} - V_0
\]  
(15)

![Fig. 5. Block diagram of outer loop](image)

### C. Shoot Through Zero Vector Control

The zero vectors can be controlled to boost the capacitor voltage in the Trans Z-source network, which maintain the desired level of the average input voltage of the Trans Z-source inverter. When the battery bank voltage drops, voltage across the capacitor of the Trans Z-source inverter also drops. Thus, the voltage difference between the reference and the actual capacitor voltage is sent to the PI controller which generates the shoot-through zero vectors.

The shoot through zero vectors can be calculated as,

\[
L = \frac{(H - H_1)}{H} \cdot B
\]  
(16)

where \( H \) is the height of carrier wave. \( B \) is the width of carrier wave. \( H_1 \) value is obtained by comparing the voltage across the battery and the reference value.

### IV. Passive Filter

The input filter has four main functions. One is to prevent electromagnetic interference, generated by the switching source, from the power line and affecting other equipment. The second is to prevent high-frequency voltage on the power line from passing through the power supply. Third is to improve the power factor and forth one is eliminate the harmonics. The passive filter consists of parameters like inductor, capacitor and resistor for the filtration purpose is shown in Fig. 6. [6], [8], [9]. This makes the filter configuration simple and easy to implement. The filter is connected with the and is modified to present low impedance to particular harmonics so that these harmonics are diverted from their regular path through the filter or is modified to present high impedance to particular harmonics to stop them from affecting the circuit. The modification depends on the configuration of the filter designed. The passive filter is a very good choice for constant loads and is a cost efficient solution to harmonic reduction and power factor improvement. All these advantages can be lost if the filter is not properly designed.

![Fig. 6. Equivalent circuit for Passive Filter](image)

### V. Simulation Results

The simulation model of a 3-Kw UPS with the Trans Z-source inverter has been developed. The voltage and current waveform across the load using passive filter are shown in Fig. 7 and 9. The Total Harmonic Distortion of the open loop and closed loop system are shown in Fig. 8 and 10.

\[
VL = V_1 - V_0 = V_s \frac{(1 - d)V_{dc}}{(1 - 2d(sTs + 1))} - V_0
\]

![Fig. 7. Voltage and current waveform across the load using passive filter in open loop system](image)
VI. Conclusions

The traditional LC filter is well suited only for high Total Harmonic Distortion. However, low Total Harmonic Distortion is required to obtain a more accurate output. To sort out this problem Passive Filter has been introduced. In this paper a three phase uninterruptible power supply using Trans Z source inverter with Passive Filter has been designed and simulated. A model for 3-Kw UPS with the Passive Filter has been developed in MATLAB Simulink software and the results are verified.

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References


Table I shows the comparative results of Total Harmonic Distortion using Passive filter. This results show us the increment of voltage with less size, cost, and weight.


