Harmonics Reduction in Three-Phase Inverter using H-Infinity Technique

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Abstract— The three phase pulse width modulation inverter is used to generate Three-phase Alternating Current from a Direct Current voltage source. Due to nonlinear load connected to the inverter, Harmonics will be injected in the output. If no Harmonic Reduction is done in the output the equipment connected to the inverter will be damaged. To generate a robust output, h-infinity controller is used along with the three phase pulse width modulation inverter. This converter helps in reducing the harmonics that will be generated by the non-linear loads that are connected to the inverter.

Key words: H-Infinity Technique, Exergy Analysis of Pumps

I. INTRODUCTION

Now a day the usage of electrical appliances has greatly increased. So, three phase power supply is widely used in domestic purpose, abruptly the usage of three phase inverter will increase. It is necessary for the inverter to maintain the perfect sinusoidal waveform in the output. The output should not vary if any variation in the load or other disturbances like nonlinear switching, link DC voltage change or filter elements. The non-linear characteristics of many commercial and industrial loads such as power converters, computers, fluorescent lamps, variable speed motor drives (VSDs) and light dimmers, used in conjunction with fans, industrial pumps, compressors and air-conditioning equipment have commonly made the harmonic distortion to occur in electrical networks.

There are several harmonics reduction methods used to reduce the harmonics in the output of the inverter. Most probably open loop harmonics controllers are used to reduce the harmonics in the AC output from the three phase inverter. In these methods, the R.M.S. output feedback will be slow that can regulate only the output voltage amplitude to a small variation which will not used for controlling the output waveform. There are many different methods available to control the output voltage instantaneously, which is faster in response, having low Total Harmonic Distortion. There are some controllers which are used to reduce the harmonic content in the output AC supply.[3]

1) Series line reactor use an inductance in each phase which is used to reduce the harmonics.
2) Tuned harmonic filter involves parallel or series connection of high-pass filter and tuned LC.
3) Parallel and Series connected resonant filter are used to reduce low-frequency harmonics and high-frequency harmonic respectively.
4) Neutral current filter is connected to the neutral conductor the site transformer and the three-phase load.
5) Zigzag grounding filter used to protect the transformer neutral conductor from triple harmonics.

These controllers use inductance and capacitor to reduce the harmonics. But this will increase the size and weight of the controller. And the control is less robust.

The objective is to increase the efficiency of the three phase inverter by reduction of harmonic content in the output of the inverter and controlling the output voltage and also to increase the robustness of the inverter.

II. MODELING OF SINUSOIDAL INVERTER

The general three phase inverter is shown in the fig.1. The Three phase inverter consists of three legs in which each leg consist of two power electronic switches. First step is to design a switching pattern, for which the following assumptions are made.

- The switches are ideal.
- No two switches from the same leg conduct at any given instant.
- The output voltage is exactly equal to that of the input voltage applied for a bridge.

Consider the load connected to the inverter RL and there is a presence of LC filter to reduce the harmonics. However the lower order harmonics can't be eliminate by this filter. V_{dc} is the DC supply connected to the inverter and V_{as}, V_{bs}, V_{cs} are the output voltage in each phase respectively.

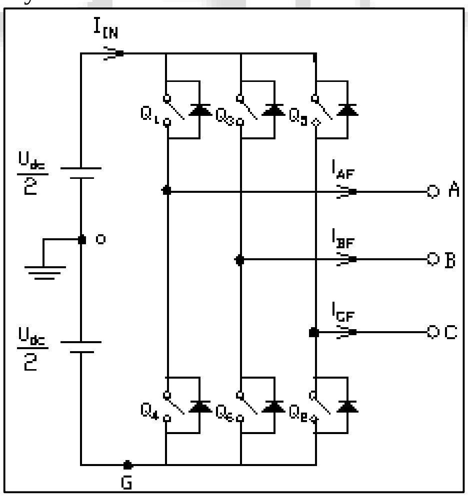

Fig. 1: Basic three-phase voltage source inverter.

Mode	V_{qs}	V_{ds}	V_{os}
A	0	0	$\frac{v_{dc}}{2}$
B	$\frac{v_{dc}}{3}$	$-\frac{v_{dc}}{\sqrt{3}}$	$\frac{v_{dc}}{6}$
C	$\frac{v_{dc}}{2}$	$\frac{v_{dc}}{\sqrt{3}}$	$\frac{v_{dc}}{6}$
D	$\frac{v_{dc}}{2}$	0	$-\frac{v_{dc}}{6}$
E	$\frac{v_{dc}}{2}$	0	$-\frac{v_{dc}}{6}$

F	$-\frac{v_{dc}}{3}$	$-\frac{v_{dc}}{\sqrt{3}}$	$-\frac{v_{dc}}{6}$
G	$-\frac{v_{dc}}{3}$	$\frac{v_{dc}}{\sqrt{3}}$	$-\frac{v_{dc}}{6}$
H	0	0	$-\frac{v_{dc}}{2}$

Table 1: Reference frame dq voltage

The inverter input current (I_{in}) can be calculated as:

$$I_{in}=S_a I_{af} + S_b I_{bf} + S_c I_{cf}$$

Fig. 3 shows the block diagram detailed description for inverter phase and line voltages based on the transfer functions. The switching functions can be mathematically represented as follows

$$\begin{cases} S_a(\omega t) = \left| \sum_{k=1,3,...}^{\infty} A_k \sin k\omega t, \right. \\ S_b(\omega t) = \sum_{k=1,3,...}^{\infty} A_k \sin k(\omega t - \frac{2\pi}{3}), \\ S_c(\omega t) = \sum_{k=1,3,...}^{\infty} A_k \sin k(\omega t - \frac{4\pi}{3}). \end{cases}$$

III. DESIGN OF CONTROLLER USING H-INFINITY TECHNIQUE

To improve the stability of the inverter H-infinity technique is used to control the three phase inverter. H∞ (i.e. "H-infinity") methods are used in control theory to synthesize controllers achieving stabilization with guaranteed performance. To use H∞ methods, a control designer expresses the control problem as a mathematical optimization problem and then finds the controller that solves this optimization.

The phrase H∞ control comes from the name of the mathematical space over which the optimization takes place: H∞ is the space of matrix-valued functions that are analytic and bounded in the open right-half of the complex plane defined by Re(s) > 0; the H∞ norm is the maximum singular value of the function over that space.

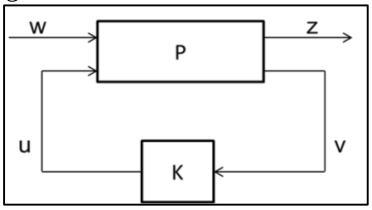

Fig. 2: Block Diagram of H-infinity Controller.

The P has two inputs, the exogenous input w, that includes reference signal and disturbances, and the manipulated variables u. There are two outputs, the error signals z that we want to minimize, and the measured variables v, that we use to control the system. W is used in K to calculate the manipulated variable u. Notice that all these are generally vectors, whereas P and K are matrices.

The generalized plant P(s) is given as,

$$\begin{bmatrix} z_1 \\ z_2 \\ z_3 \\ e \end{bmatrix} = \begin{bmatrix} W_s & -W_s G \\ 0 & W_{ks} \\ 0 & W_t G \\ I & -G \end{bmatrix} \begin{bmatrix} w \\ u \end{bmatrix} \quad (1)$$

Considering the following state space realizations

$$G \stackrel{s}{=} \left[\begin{array}{c|c} A & B \\ \hline C & D \end{array}\right], \quad W_s \stackrel{s}{=} \left[\begin{array}{c|c} A_s & B_s \\ \hline C_s & D_s \end{array}\right],$$
$$W_{ks} \stackrel{s}{=} \left[\begin{array}{c|c} A_{ks} & B_{ks} \\ \hline C_{ks} & D_{ks} \end{array}\right], \quad W_t \stackrel{s}{=} \left[\begin{array}{c|c} A_t & B_t \\ \hline C_t & D_t \end{array}\right], \quad (2)$$

A possible state space realization for P(s) can be written as

$$P = \begin{bmatrix} W_S & -W_S G \\ 0 & W_{KS} \\ 0 & W_T G \\ I & -G \end{bmatrix} = \begin{bmatrix} A & B_1 & B_1 \\ C_1 & D_{11} & D_{12} \\ C_2 & D_{21} & D_{22} \end{bmatrix} \quad (3)$$

From (2) and (3) we can write a mixed sensitivity problem as

$$P = \begin{bmatrix} W_s S \\ W_{ks} KS \\ W_t T \end{bmatrix}$$

In case of mixed sensitivity problem our objective is to find a rational function controller K(s) and to make the closed loop system stable satisfying the following expression

$$\min \|P\| = \min \begin{bmatrix} W_s S \\ W_{ks} KS \\ W_t T \end{bmatrix} = \gamma$$

Where, P is the transfer function from w to Z i.e

$$\|T_{ZW}\| = \gamma$$

Where, $\|T_{ZW}\|$ = P is the cost function. Applying the minimum gain theorem, we can make the norm of zw T less than unity, i.e,

$$\min \|T_{zw}\| = \min \begin{bmatrix} W_s S \\ W_{ks} KS \\ W_t T \end{bmatrix} \le 1$$

Therefore we can achieve a stabilizing controller K(s) is achieved by solving the algebraic Riccati equations, thereby, minimizing the cost function γ. As mentioned in the robust control theory the synthesis of the controller requires the selection of two weight functions. There are various methods available in literature for selection of weights. In most of these design methods the weighting functions are selected using trial and error and further the H∞ controller is synthesized by loop shaping technique. But train and error procedure may not end up in a stabilizing controller and this is the main draw back in this type of synthesis. The weights $W_s S$, $W_{ks} KS$ and$W_t T$ are the tuning parameters and it typically requires some iterations to obtain Weights which will yield a good controller. That being said, a good starting point is to choose

$$W_s = \frac{\frac{S}{M} + \omega_0}{S + \omega_0 A} \qquad W_{ks} = const$$

$$W_s = \frac{\frac{S}{\omega_0} + M}{AS + \omega_0}$$

Where A < 1 is the maximum allowed steady state offset, ω_0 is the desired bandwidth and M is the sensitivity peak (typically A = 0.01 and M = 2). For the controller synthesis, the inverse of $\omega_Z$is an upper bound on the desired sensitivity loop shape, andω_{kZ}^{-1} will effectively limit the controller output u which is symmetric to ω_Z around the line $\omega = \omega_0$. Fig shows the two weighting functions for the parameter values A = 0.01(= −40dB), M= 2(= 6dB) andω_0 = 1 rad/sec.

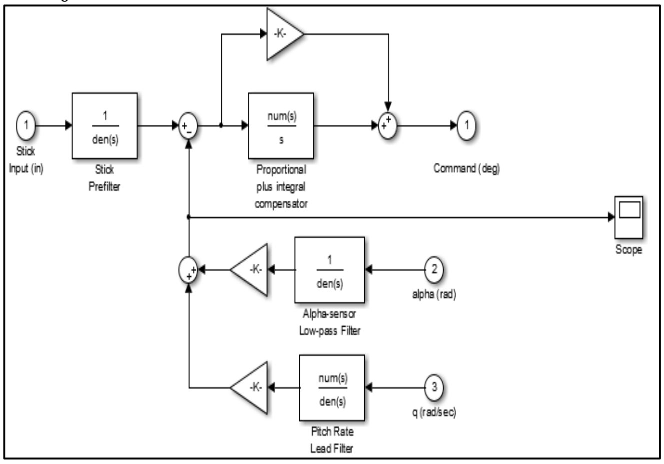

Fig. 3: MATLAB model of H-infinity controller

IV. Simulations and Result

With the help of MATLAB (simulink) the mentioned system with the designed K is simulated. Fig.4. shows the output voltage in the closed-loop case for different load variations with sinusoidal input reference as:

$$V_{in} = .8\sin(100\pi t)$$

As seen, the variations of the output signal with the load variations at the time 25 ms, are negligible, except in fig. 7.d. for which the load variation is out of the allowed range. Fig.5 shows the FFT analysis Of the proposed system

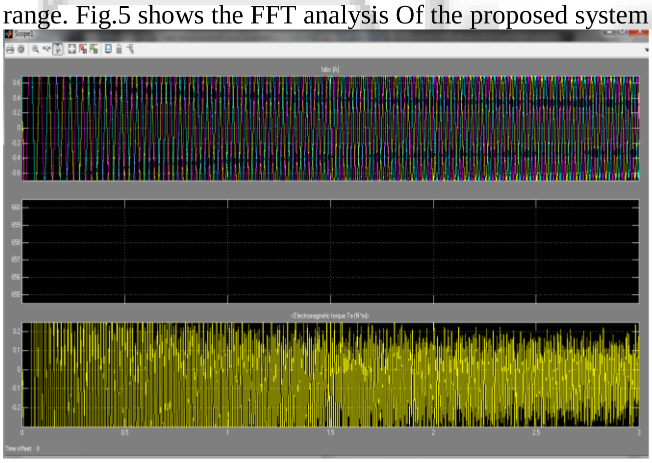

Fig. 4: Current and Torque waveform

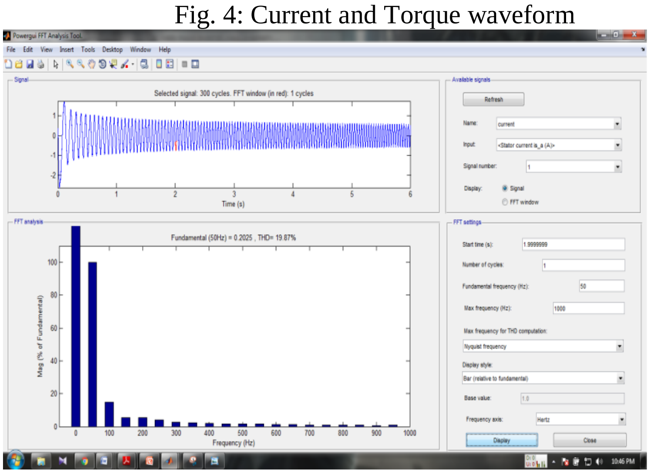

Fig. 5: THD of three phase inverter with H-infinity controller

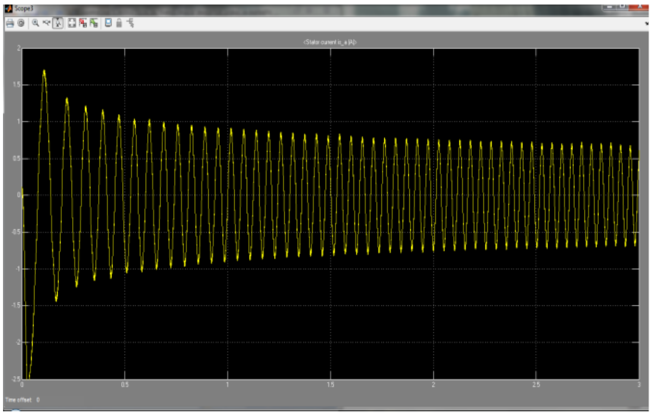

Fig. 6: Current Waveform

V. Conclusion

Thus the harmonics in the three phase inverter has been greatly reduced with the help of the H-infinity controller. With this controller the robustness of the three phase inverter is increased to a greater extend. Due to this the losses in the three phase inverter is reduced.

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