DEVELOPMENT OF A DSP-BASED DIGITAL CONTROL THREE PHASE SHUNT ACTIVE POWER FILTER FOR MAGNET POWER SUPPLY SYSTEM*

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Abstract

There will be 240 quadruple and 168 sextuple magnet power supplies installed in TPS storage ring, power factor of these power supplies is an important issue to be concerned. A digital control three-phase shunt active power filter (APF) for quadruple and sextuple magnet power supplies is implemented and the power factor is better than 0.98. The APF power stage employs a three-phase switch-mode rectifier (SMR) to reduce the input current harmonics distortion and correct the power factor [1]. The digital control circuit of the three-phase shunt active power filter is implemented by using a multi-channel 12 bits analog-to-digital converter、high resolution Pulse Width Modulated (PWM) and a TMS320F28335 digital signal processor (DSP). The system configuration is described in three function blocks include principle of compensation、design of the snubber protective circuit and control strategies. Finally, the feasibility and validity of proposed scheme is simulated with Matlab simulink and verified by the homemade digital control three-phase shunt active power filter.[2~3]

INTRODUCTION

In storage ring of TLS, the INVERPOWER power supplies used as the quadruple and sextuple magnet power converter, the input AC/DC converter includes the three-phase 12-pulse transformer and full bridge diode rectifier circuit, and input current of this rectifier includes large distortion and harmonic current. Therefore, a digital control three-phase shunt active power filter to improve the input current harmonics、the power factor、balance of three-phase input current, and power quality. Table1 list the main parameters of quadruple and sextuple magnet, table 2 is the main parameters of specification of quadruple and sextuple magnet power supplies.

To confirm the accuracy of digital regulation control policy before implementation of the circuitry, this DSP-based digital control three-phase shunt APF was simulated with Matlab simulink, the behavior of shunt APF configuration power converter, non-linear load, and the P-I compensator are included in this simulation. There are three main components are embedded in the digital regulation control circuit, Texas Instrument TMS320F28335 DSP controller、high resolution of PWM, and the performance is verified with the INVERPOWER power supplies as the load.

Table1: Storage ring quadruple and sextupole magnets

Magnet	Quadruple	Sextupole
No. of magnets	240	168
Peak current	188A	135A
Inductance	13.6/23.5mH	5.8mH
Resistance	72.2/81.6mΩ	43.8mΩ

Table 2: Specification of quadruple & sextupole magnet power supplies

Magnet	Quadruple	Sextupole
Output(A/V)	250A/30V	250A/30V
Short term stability	±1.25 mA	±6.25 mA
Resolution	18bits	16Bits
Accuracy	±10mA	±50 mA

THE STRUCTURE OF SHUNT ACTIVE POWER FILTER

The shunt active power filter converter could be roughly divided into four functional blocks: non-linear load of INVERPOWER power supply /three-phase SMR configuration power rectifier /DSP TMS320F28335 controller and USB-JTAG transmission interface / multi-channel 12bits analog-to-digital of voltage and current feedback sensor circuit. Fig. 1 shows the structure of shunt active power filter converter.

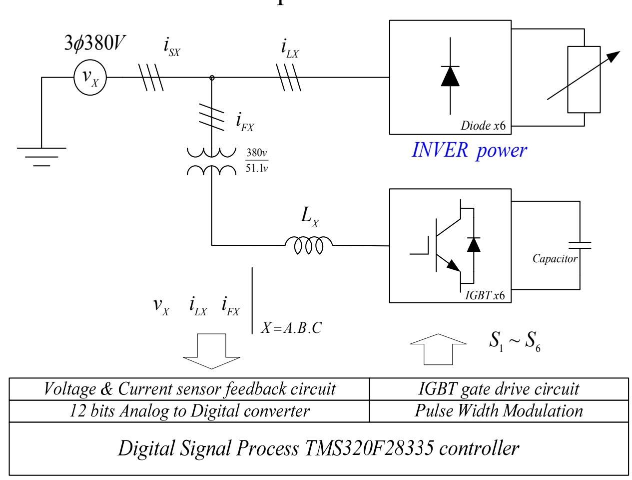

Figure 1: The structure of three-phase shunt APF

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CONTROL POLICY

The control strategy is an energy balancing method in this thesis. Control basic concept is that the compensated current could be got from the subtraction between average real power and load current. Fig. 2 is current loop and voltage loop compensator block diagram. This method can control balance and sinusoidal of the system currents when the load currents are distorted and unbalanced. The energy balance policy control method is presented below:

$$\begin{bmatrix} I_{FA}{}^{*} \\ I_{FB}{}^{*} \\ I_{FC}{}^{*} \end{bmatrix} = \begin{bmatrix} I_{LA}\text{-}I_{SA} \\ I_{LB}\text{-}I_{SB} \\ I_{LC}\text{-}I_{SC} \end{bmatrix} = \begin{bmatrix} I_{LA}\text{-}\frac{\overline{P_L}}{V_S^2}V_A \\ I_{LB}\text{-}\frac{\overline{P_L}}{V_S^2}V_B \\ I_{LC}\text{-}\frac{\overline{P_L}}{V_S^2}V_C \end{bmatrix} \quad (1)$$

Where I_{LA} 、I_{LB} and I_{LC} denotes the load currents, the $\overline{P_L}$ is average real power of non-linear load, the V_S is per-unit value of the sinusoidal input voltage and I_{SA} 、I_{SB} and I_{SC} are input current.

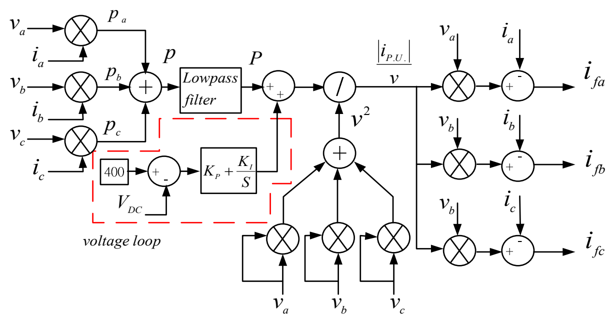


Figure 2: Current and voltage loop compensator block diagram

SIMULATON OF THE CONTROL POLICY

In order to confirm the accuracy of the control policy and applicability of the digital regulation control circuit, the behaviors of digital regulation control circuit 、 current compensator and the structure of three-phase shunt active power filter were simulated with MATLAB simulink.

In Fig. 3 is the block diagram of current compensator, this set-up is according to the preface 1 of the equation and the current value of the compensator could be calculated.

This simulation is achieved with system under conditions with ideal mains voltage 、switching lose with dead time and low noise, but natural environment influence terms must also be considered in order to simulate realistically.

Fig. 4(a) shows the simulation result of power supply without the shunt active power filter, waveforms and FFT analysis of three-phase voltage 、 harmonic load current are demonstrated. The total harmonics distortion value of harmonic load current is 26.74%. Fig. 4(b) shows the simulation result of power supply with the shunt active power filter. The total harmonics distortion of harmonic load current is 1.99%.

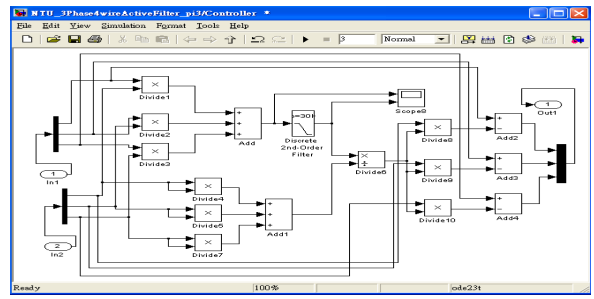
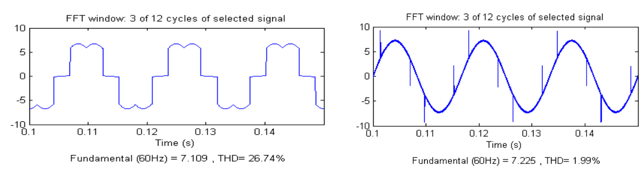


Figure 3: Current compensator internal block diagram



(a) (b)

Figure 4: Simulation results (a) Normal operation (b) used the APF converter

EXPERIMENTAL RESULTS

In order to test and efficiency of shunt active power filter with the DSP control, non-linear load, feedback/drive circuit and 3-phase power source for implementation prototype. Fig. 5 shows waveforms of the single phase that includes the input voltage 、the load current 、the compensation current and the total input current. Fig. 6(a) shows the THD of harmonic load current is 24.33%. Fig. 6(b) shows the THD of source current is 10.70%. So, the digital control three-phase shunt active power filter is effectively to reduce the THD value of input harmonic current. Fig. 7(a) and 7(b) shows the load current of INVERPOWER power supply and the source current of three phase.

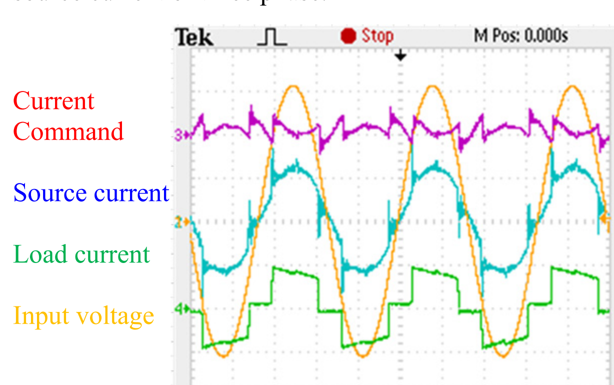


Figure 5: the single phase waveform

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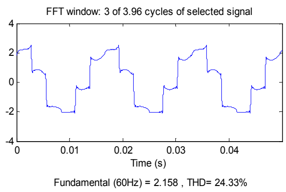
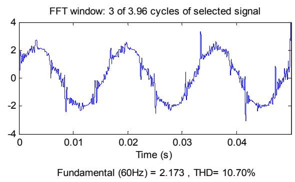
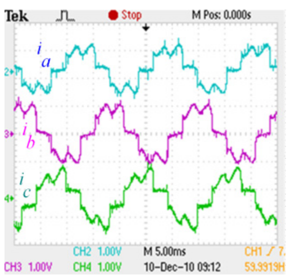


(a)

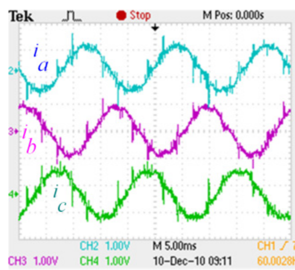


(b)

Figure 6: FFT analyze of current (a) load current; (b) source current



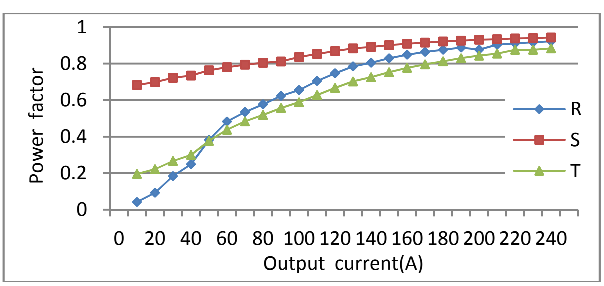
(a)



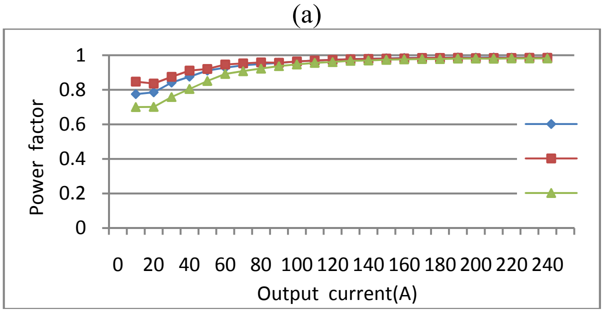
(b)

Figure 7: (a) the load current of INVER power
(b) the source current of three-phase

The power factor and source current of system is measured by a step of 10 amperes on output current of INVERPOWER power supply, and the power factor of half-load is in under 0.83. The characteristics of INVERPOWER power supply are non-linear 、low power factor and unbalanced current output, and power factor of source current shows in Fig. 8(a). Fig. 8(b) shows the performance of shunt active power filter, with injection of the compensation current for balancing loading, and the power factor of the half-load is mostly better than 0.98.



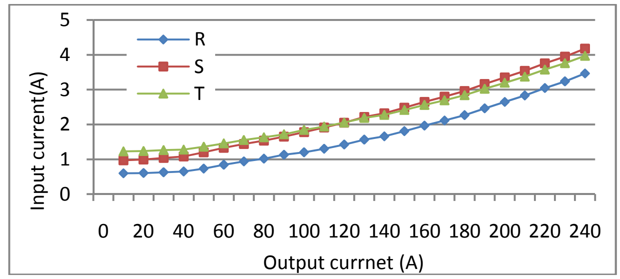
(a)



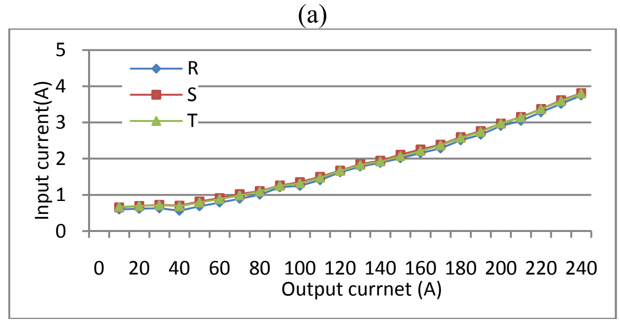
(b)

Figure 8: power factor of INVER power supply
(a) Normal operation (b) used the shunt APF converter

In Fig. 9(a) Show, the unbalance three-phase current while operating as the INVER power supply. Improve the unbalance input current of the INVER power supply with shunt APF converter, such as Fig. 9(b).So it is effectively to improve the load current and assign with shunt APF converter.



(a)



(b)

Figure 9: input current of INVER power supply
(a) Normal operation (b) used the shunt APF converter

CONCLUSIONS

Digital control three phase shunt APF is implemented to reduce the harmonic of source current for quadruple and sextuple magnet power supplies in the TLS. The power factor of the three-phase source current are improved from 0.75 to more than 0.98, the THD of source current is reduced from 24.33% to 10.70%, and three-phase source current are balanced at the half-load (1500watt). This shunt APF is a prototype, and that can be employed and improved on the power quality of TLS power supply.

In the future, this prototype machine will integrate current/voltage interlock protective circuit to enhance hardware structure for normal and safe operation.

REFERENCES

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[3] TMS320F283xDSP Technical Reference.

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