THE EXPERIMENTAL STUDIES ON SUPPRESSING THE HARMONICS OF BEPC'S AC LINES

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Abstract

The measurement and analysis about the harmonics and the Power Factor (PF) on BEPC power lines was conducted. The harm caused by the harmonics to BEPC operation and the equipments was discussed. An experimental power factor correction (PFC) scheme for converters and its prototype were also presented in this paper.

1 INTRODUCTION

The harmonics components on power lines are very harmful both to the operation of lines themselves and the performance of the loads, such as the electric equipments and instruments on the lines, in the most case, the harmonics on lines are caused by those non-linear loads . According to the theory of Modern Power Electrics, the effect of harmonics on lines is described by the parameters "Power Factor " PF and the "waveform distortion coefficient " γ. They are explained in bellow.

In the case with harmonics pollution in lines, the current waveform is distorted while the voltage waveform is assumed to keep the sinusiod (without significant distortion), then we have the formulas for voltage u(t) and current i(t):

$$u(t)=Um\ \sin\omega t \tag{1}$$

$$I(t)=I_0+\sum_{n=1}^{\infty} I_n \sin(\omega t+\Phi_{in}) \tag{2}$$

the coefficient γ is defined as :

$$\gamma=\frac{I_1}{I_{RSM}} \tag{3a}$$

$$\gamma_n=\frac{I_n}{I_1} \quad (n\neq 1) \tag{3b}$$

where

$$I_{RSM}=I_0+\sqrt{\sum_{n=1}^{\infty} I_n^2} \tag{4}$$

In this case

$$PF=\frac{P_{ac}}{P_{ap}}=\gamma\cos\phi \tag{5}$$

$(\gamma \le 1,\ \cos\phi \le 1)$

Where Pac---the active power

Pap—the apparent power

ϕ--the current phase shift against the Voltage

The Total Harmonic Distortion (THD) is defined by:

$$THD=\sqrt{\sum \gamma_n^2} \tag{6}$$

With the above basic Knowledge, two phenomena on BEPC's lines promoted our considering that it is significant to study the harmonics on BEPC's lines. One phenomenon is that the main system has been tripped off couple times every year due to the thundering and became more frequently in the resent year. Another is that the all of the magnets power supplies which take the main parts of power from the BEPC mains have nonlinear AC-DC converters such as SCR rectifiers and diode rectifiers. The total of apparent power of these power supplies is about 1.5 MVA, that is less than one half capability of the mains transformer T201.It seems that the mains of BEPC are not a very stable system. To study these phenomena, a measurement for harmonic components was performed on these stage equipments of the mains. (refer to Fig. 1), the first stage equipment of the mains was the 3300KVA 110KV/10KV Main Transformer, which are connected to feed 9 set at 800KVA 10KV/380V Branch Transformers (TB1—TB9). The second stage was one of branch transformer TB5, the third stage one was the Quadruple magnets power supply Q7, SCR type with 100KVA rated apparent power and feed by Transformer TB5.

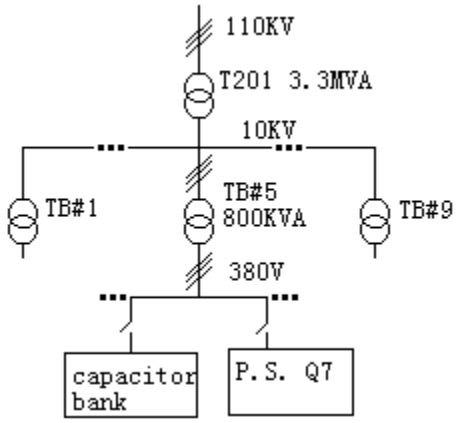


Fig1 diagram of BEPC mains

2 MEASUREMENT RESULT AND ANALYSIS

The harmonic components measurement on the secondary of T201 ,the secondary of TB5, and input lines of Q7 are listed in Table 1-3 respectively. The pictures of those waveforms were taken and present here. The effect to the harmonics due to using PF compensation capacitor bank was inspected at TB5 also, and shown in Table 4

harmonics components	voltage harmonics γ_{un}	current harmonics γ_{in}
0	0	0
1	100	98.4
2	0	5.0
3	0	6.0
4	0	6.8
5	0	2.7
6	0	3.5
7	0	3.0
8	0	4.0
9	0	4.0
10	0	2.9
11	0	9.0
12	0	1.0
13	0	0
14	0	0
15	0	2.8
16	0	0
THD	3.0	16.5

Table 1 Harmonic components on the secondary of T201

harmonic components	current harmonics coefficient (%) 1.55Gev	2.0Gev	voltage harmonics coefficient (%) 1.55Gev	2.0Gev
0	0	0	0	0
1	97.7	98.4	99.9	99.8
2	1.0	1.0	0	0.5
3	1.5	3.4	3.0	3.7
4	0	0	0	0.3
5	8.8	9.7	2.5	3.3
6	2.0	1.5	0	0
7	7.3	6.5	0	0
8	2.7	2.3	0	0
9	0.4	0.6	0	0
10	2.4	1.6	0	0
11	16.0	1.3	0	1.5
12	1.5	0.7	0	0
13	4.0	4.3	0	0
14	0	0.5	0	0
15	0	0.6	0	0
16	0	0	0	0
THD	22.0	17.6	5.0	5.5

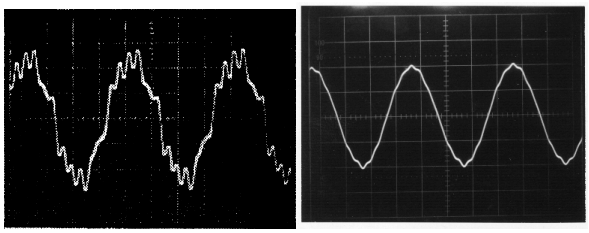
Table 2 Harmonic component on the secondary of TB5

harmonic components	output current I=50A	output current I=145A
1	98.9	99.5
2	0.4	0
3	0.8	1.2
5	1.7	1.4
7	2.8	1.5
9	1.3	2.0
11	7.1	1.6
13	9.8	7.7
15	1.7	1.9
23	5.9	0
THD	14.8	10.2

Table 3 Harmonic component on the secondary of Q7

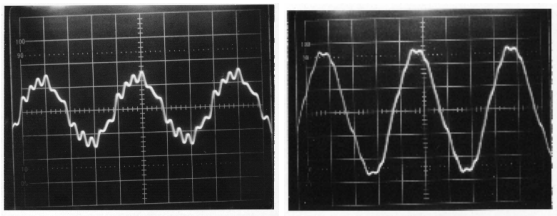
harmonic	with compensation	without compensation
1	97.2	99.9
2	0.2	0.7
3	2.6	2.1
4	0.7	0.6
5	12.2	2.2
6	2.1	0.4
7	7.8	1.4
8	2.7	2.1
9	1.2	1.2
10	2.4	0.4
11	17.3	1.1
12	2.0	0.1
13	2.4	0.6
14	0.8	0.3
15	1.1	0.3
16	1.1	0.3
0	3.0	2.4
THD	23.6	4.75

Table 4 The effect from C bank at TB5



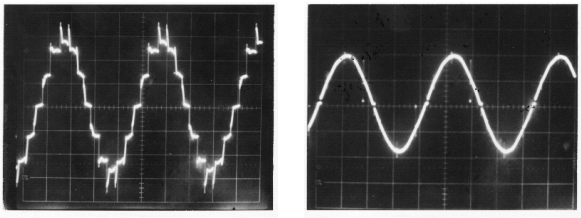
voltage current

Fig 2 the waveform of voltage and current on T201 secondary



voltage current

Fig 3 the waveform of voltage and current on TB5 secondary



voltage current

Fig 4 the waveform of voltage and current on Q7 input lines

According to the measurement results we can have following facts:

1. The harmonic components and the waveforms on the three stage lines were similar. And the value of THD were increased while the output current of power supply was set to lower,.(refer to Table 2) since its SCR rectifier conducting angle at low current was less than the one at higher current, so that, the magnets power supplies are the main source of harmonics for BEPC lines.
2. The voltage waveforms both of T201 and TB5 were distorted in some level became of the current harmonics effect.
3. The high order harmonic components (THD) were amplified to more than 3 times by the compensation capacitor .(see Table 4)
4. Refer to the 6 phase SCR rectifier of P.S. Q7, there were a few non-characteristic harmonic components in the current waveform.

3 DISCUSSION ON THE HARMONICS EFFECT

The current harmonic components are the very harmful factor for BEPC operation

1. Firstly, they will distort the voltage waveform of the mains, and then the distorted voltage will turn back to have the power supply produced non-characteristic current harmonic in the input lines and more ripple in the output current.
2. the irregular voltage waveform on mains will make the performance of instruments bad, especially those one synchronized by the lines. And some equipments such as motors of pump will vibrate due to distorted lines feeding , then their lifetime is going down.
3. The distorted current waveform will result in an unstable operation of BEPC mains system. The core of transformer might be saturated by the peak current under the thunder and lightning interfering, and trip off whole of BEPC mains.
4. The power factor PF will be reduced seriously since the coefficient γ was reduced with the harmonic components going high. The capacitor bank could decrease the current delay angle ϕ but reduce the γ simutaneously.

4 THE STUDIES ON IMPROVING PF

To suppressing the effects of the harmonics pollution and improving the power factor of converters, two experimental studies projects were conducted. The first, design a set of LCR type notch filters on the input lines of the converter, they will attenuate the specified harmonic components effectively. The second, design a new rectifier circuit with linear charater called as Power Factor Correction (PFC) to eliminate the harmonic source. Various PFC circuits were developed by the engineers and scientists in the world during the last 5 years, with those references, a single phase PFC rectifier was designed, the topology is shown in Fig.5, its main loop is composed of rectifier bridge, the choke L for energy storage, the input PWM switch T, diode D and capacitor C, the key technique of it is that the sinusoid waveform of rectified voltage is sampled as the reference signal for the current regulator, the PWM switch T is controlled by the output of the regulator, and then the current waveform through the L will be modified closing to the waveform of voltage. This PFC circuit was realized on a prototype of 2KW converter, the PF=0.95 was obtained. Fig. 6 gives out the performance of the prototype.

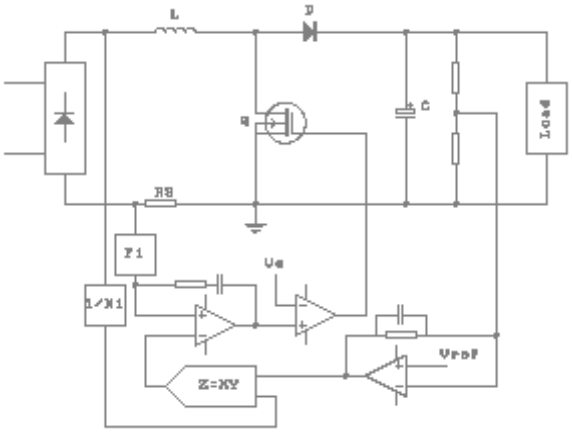
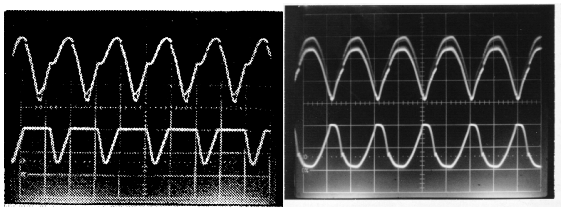


Fig 5 the block diagram of the PFC circuit



before PFC after PFC

Fig 6 the current waveforms of the PFC

5 CONCLUCION

The magnets power supplied are the main harmonic source to accelerator power lines. The harmonic component is a significant harmful factor for accelerator's stable operation. The converters with PFC circuit will eliminate the harmonic source of non-linear rectifier effectively. It is significant to develop the PFC technique for magnets Power supply of accelerator in large scale, and that require us to make great and creative effort.

6 REFERENCES

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