THE STUDIES OF POWER SYSTEM HARMONICS AT TLS

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Abstract

The power system harmonic distortion in the utility system of NSRRC is investigated for improving the power system performance. The monitored power quality data at the point of common coupling is examined and compared with industry standards. In addition, the harmonic characteristics of electric power for the accelerator magnets and adjustable speed drives which contribute the most harmonics are analyzed. Furthermore, the approach to mitigate the harmonic effects for improving the power quality is studied.

INTRODUCTION

Power quality problems have been studied in recent years at Taiwan Light Source (TLS). Besides improving the present TLS power quality, useful information can be learned in order to minimize the power quality disturbance for the future Taiwan Photo Source (TPS). The power quality disturbance is generally defined as any change in power that interferes with the normal operation of electrical equipment. If the accelerator is to be operated smoothly, all the power quality problems should be minimized. Among the subjects in power quality problems, the harmonic distortion has been studied recently at some selected branches of the electric utility of TLS with POWER SCADA and three-phase power recorder. With the monitored data, the harmonic distortions at these positions were analyzed and compared with the IEEE standards.

At present, the power distribution system delivers electric voltage of 11.4 kV and power demand of 5500 kW to NSRRC. There are 2 primary feeders, feeder A and feeder B. Feeder A is primarily for providing the power to the main cooling water systems and the public utility of most of the buildings. Feeder B provides the power for the accelerator facility and its related devices. In the situation one feeder stops providing the power, the other feeder can still provide the power for all of the facility to operate.

HARMONIC DISTORTION AT PCC

In Fig. 1, the one-day harmonic distortion data at point of common coupling of feeder A (PCC A) of NSRRC monitored with POWER SCADA are shown. Because this feeder provides the electricity for the cooling water systems and many public utilities, the variation of its load is closely related to the daily activity. The automatic power factor regulators (APFR) and static capacitor bank have been installed in the low voltage feeders for the reactive power compensation, thus the power factor is maintained at 99.9%. If one refers to the IEEE Std 519-1992 standards [1], which specifies the total voltage harmonic distortion for 69 kV and below is 5%, the voltage harmonic content at this feeder, 1.1%, is much lower than the voltage distortion limits.

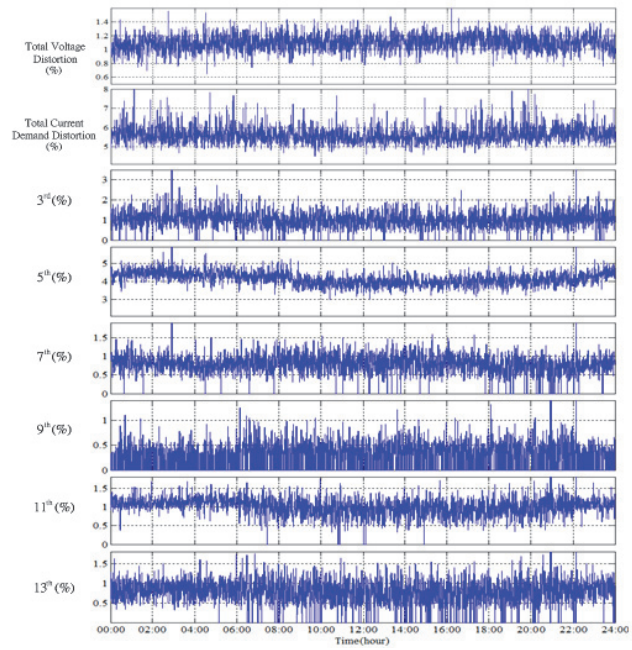

Figure 1: One-day harmonic trend at point of common coupling of feeder A.

The feeder of 11.4 kV which provides the power to NSRRC has short circuit capacity of 250 MVA. Its maximum short-circuit current at PCC, I_{SC}, is 12.66 kA and the maximum demand load current I_L is 288 A. Thus, the short-circuit ratio I_{sc}/I_L is calculated as 43.96. According to IEEE Std 519-1992, the total current harmonic distortion limits for 120 V through 69 kV with this I_{sc}/I_L is 8%. Its distortion limits for individual harmonic order are 7% for 3rd, 5th, 7th, 9th order harmonics, and 3.5% for 11th, 13th order harmonics. The total current harmonic distortion limit of NSRRC feeder A shown in Fig. 1 is about 5.8%; and for each individual harmonic order are 3rd=1.2%, 5th=4.1%, 7th=0.8%, 9th=0.5%, 11th=1.1%, 13th=0.8%. This shows that it is within the limit of IEEE standard.

The one-day harmonic distortion data at point of common coupling of feeder B (PCC B) of NSRRC monitored with POWER SCADA are also shown in Fig. 2. This feeder provides mainly the power for the operation of TLS accelerator and its related equipments. Its power factor has also been maintained at above 99.9%, too. The total voltage harmonic distortion of this feeder is about 0.6%, and total current harmonic distortion is 4.1%, which are all within the IEEE Std 519-1992 recommended distortion limits.

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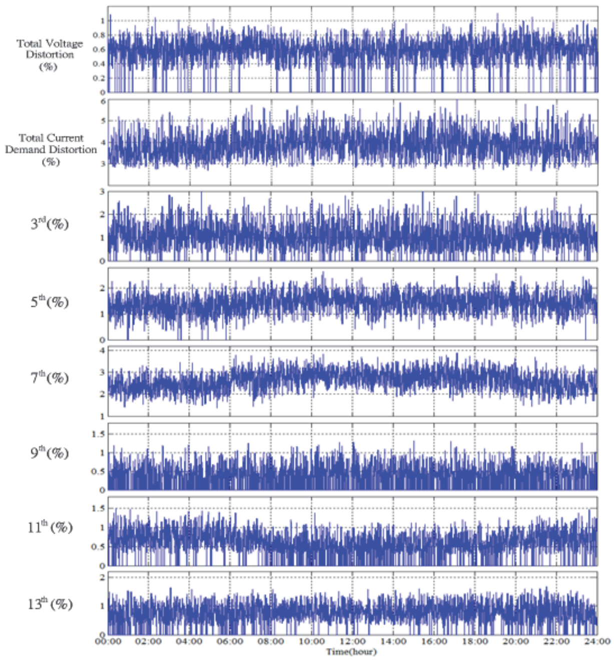

Figure 2: One-day harmonic trend at point of common coupling of feeder B.

HARMONIC DISTORTION IN MAGNET POWER SUPPLY AND RF SYSTEM

The measured current harmonic distortions of magnet power supplies and RF system of TLS are shown in Table 1. In the table, one sees that the harmonic current distortions of dipole magnet and sextupole magnet are mainly 5th, 7th, 11th, 13th order. This is typical characteristic harmonics produced by the 6-pulse converter. The 6-pulse converter will produce harmonics of the order of $6N \pm 1$ (N = 1, 2, 3, ...). As for the power supplies of quadrupole magnets, correction magnets and RF system, besides containing the same type of harmonic distortions, they also show uncharacteristic harmonic distortions, such as 2nd, 3rd, 4th, 6th, 8th, 9th order components. The third order harmonic distortion is also shown very large.

Table 1: The harmonic contents of magnet system power supply and RF system

Harmonic Order	2	3	4	5	6	7	8	9	10	11	12	13	THD
Dipole (%)	0.13	0.31	0.07	20.20	0.08	3.10	0.08	0.17	0.07	2.99	0.09	2.85	21.5
Quadrupole (%)	3.70	11.76	2.66	11.15	0.54	5.78	1.07	0.74	0.73	6.87	0.12	3.91	19.9
Sextupole (%)	0.23	0.84	0.06	5.94	0.08	3.26	0.04	0.26	0.18	9.34	0.30	6.02	15.2
Correction magnet (%)	2.07	3.05	1.06	24.97	1.74	13.39	0.3	1.1	0.64	3.19	0.69	2.82	35.4
RF	0.28	11.55	0.13	3.29	0.07	0.67	0.04	0.99	0.03	1.75	0.02	1.35	12.3

Fig. 3 shows the single phase voltage and current waveforms measured at the input of power supply for dipole magnet. In the waveform of voltage, the line notching phenomenon can be seen. This voltage notching can introduce malfunction of the device and harmonics on the distribution system [2]. In the most severe cases, the voltage can be reduced to zero and creating an extra zero crossover to cause the biggest problems. Due to the influence of 6-pulse converter the waveform of voltage at the feeder of magnet power supply contain characteristic harmonics. Its total harmonic distortion is measured about 3.4%.

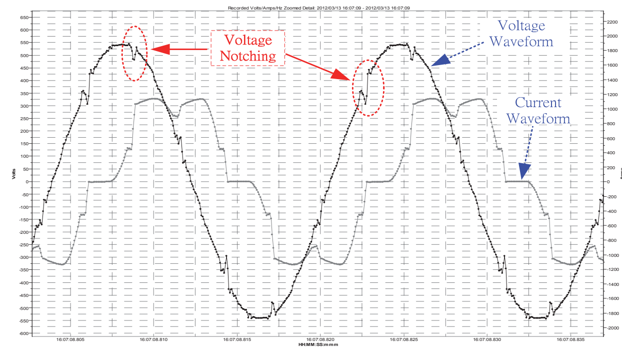

Figure 3: The voltage and current waveforms measured at the input of power supply for dipole magnet.

HARMONIC DISTORTION IN VARIABLE FREQUENCY DRIVE

The single phase voltage and current waveforms of the variable frequency drive used in the cryogenic system are shown in Fig. 4. The measured harmonic contents are shown in Table 2. The distribution of its harmonic contents shows it belongs to the typical 6-pulse variable frequency drive. Due to the DC choke in the circuit, its total harmonic distortion is reduced, and it also results in the distortion of voltage waveform. If this type of characteristic harmonic content is to be improved, one can use transformer phase shifting method to change the converter circuit to 12-pulse or 18-pulse configuration. In the cryogenic system of NSRRC, the measured operation current in variable frequency drive is 381 A. The measured total current harmonic distortion is 36.8%. In the future, active harmonic filters are planed to be installed in parallel for active mitigation of the harmonic current.

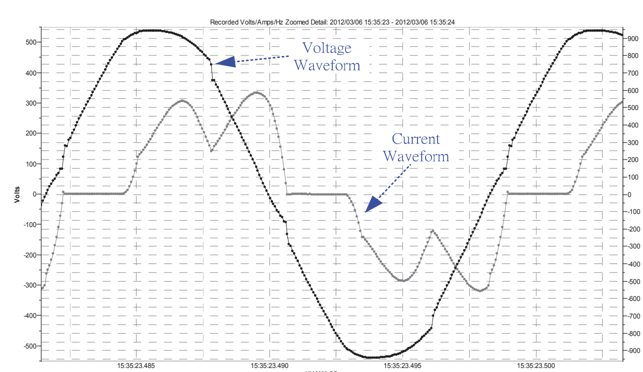

Figure 4: The voltage and current waveforms of variable frequency drive in cryogenic system.

Table 2: The harmonic contents measured at the variable frequency drive in cryogenic system

Harmonic Order	2	3	4	5	6	7	8	9	10	11	12	13	THD
Current Harmonic Distortion (%)	2.90	5.31	0.85	33.63	0.72	8.73	0.40	0.97	0.33	7.93	0.36	2.68	36.8
Voltage Harmonic Distortion (%)	0.11	0.41	0.05	2.21	0.05	1.32	0.04	0.15	0.04	1.01	0.04	0.54	3.1

ACTIVE HARMONIC FILTER

The most wildly used configuration in active harmonic filter application is connected in parallel with the AC system and continuously injects current to compensate the harmonic current due to the nonlinear load. Thus the current supplied by the source remains free of harmonic current distortion. The waveforms of load current and compensation current measured at the active harmonic filter are shown in Fig. 5. The load current is the summation of currents from several variable frequency drives. Its THD was measured as 66.7%. The compensation current is provided from the 66 kVA shunt active harmonic filter. In Table 3, it shows that the characteristic harmonic components of compensation current are mainly of 5^{th}, 7^{th}, 11^{th}, 13^{th} order, but, it has the phase difference of 180^{o} with the load current. Thus, it can compensate the original distorted current. In the case shown here, THD is reduced from 66.7% to 13.8% after the current compensation.

Table 3: The load current and the compensation current measured at the active filter

Harmonic Order	3	5	7	9	11	13	THD
Load Current (%)	4.6	47.8	39.1	1.5	18.2	10.4	66.7
Compensation Current (%)	5.6	69.8	59.8	2.6	29.5	20.7	99.9
Total Current (%)	1.6	6.5	7.9	2.1	6.1	7.0	13.8

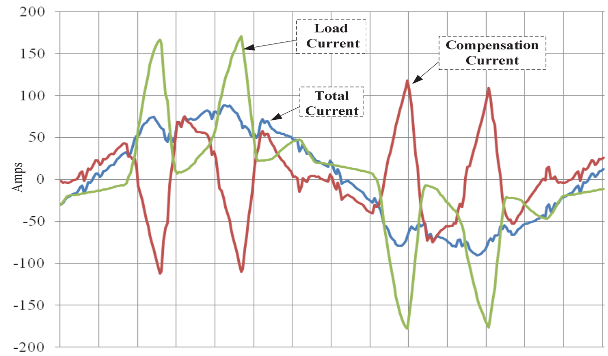

Figure 5: The waveforms of load current and compensation current measured at the active harmonic filter.

CONCLUSION

The harmonic distortion in electric power systems can be produced in the electricity generation, transmission, power conversion and utilization. If a good power quality is to be maintained, the major parameters of power quality must be monitored over a long period of time and its data should be analyzed thoroughly. At present, the harmonic distortion measured at TLS is in principle lower than those specified in IEEE Std 519-1992. The power factor is also higher than 99.9% through installing APFR. For further reducing the harmonic distortion, the passive filters and active harmonic filters will be installed to mitigate the harmonic distortions.

REFERENCES

[1] IEEE Std 519-1992, *IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems*, (New York, 1993).

[2] American Bureau of Shipping, *Control of Harmonics in Electrical Power Systems*, (New York 2006).

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