

INVESTIGATION AND ANALYSIS OF TLS ELECTRIC POWER SYSTEM HARMONICS

Tzong-Shyan Ueng, Yu-Chih Lin, Jai-Ming Lee, Jui-Chi Chang, NSRRC, Hsinchu, Taiwan

Abstract

The electric power system of Taiwan Photon Source will be installed during its construction. Many power electronic devices which produce large nonlinear currents will be used in the new power system and the accelerator facility. Thus, the excessive harmonic waveform distortion on the normal waveform will be presented continuously. These excessive harmonic currents will result in transformer and cable over-heating and many types of circuit faults, and also wasting energy. A project is initiated to study these harmonic effects which will appear in the electric power system of Taiwan Photon Source. Several different types of harmonic minimizing methods were studied at Taiwan Light Source in order to find a reliable and economical solution to mitigate the harmonic distortion.

INTRODUCTION

Taiwan Photon Source (TPS) has been under construction since January 2010. Its goal is to be a first grade advanced synchrotron radiation photon source. All of the accelerator and the experimental facilities have been carefully designed. In order to fulfil this goal, the power quality is one of the important factors must be guaranteed. One of the power quality issues which gains attention in recent years is the harmonic distortion in the power system. In recent years the increasing use of nonlinear electronic devices has produced large amount of harmonic currents. The harmonic current can cause overheating of electrical distribution system wiring, transformers and many other effects which can damage the devices in the same power system. It should not be overlooked, or it can become a serious problem. For the construction of TPS, many nonlinear electric devices, such as variable frequency drives (VFD), uninterrupted power supplies and magnet power supplies, will be installed in the utility system, thus the harmonic distortion in the power system becomes a major concern. The harmonic distortion in the power system of TLS does not pose any immediate threat to its operation. Recently, for the purpose of energy saving, many VFDs have been installed to the motor driven system in the TLS utility system. The measured harmonic distortion in the power system is getting larger. In order to understand the behavior of harmonics and search for a better method to minimize it, a project has been initiated to study the effects of harmonic distortion at the electric power system of TLS. Besides finding a method to reduce the harmonic distortion in the power system of TLS, the result can also be used as a guideline for improving the future electric power system of TPS.

OBSERVATION

The electric power used in NSRRC is provided by Taiwan Power Company (Taipower) through two distribution feeders from Taipower's substation, which delivers the power to NSRRC's main substations. The harmonic distortion in NSRRC's power system has been monitored with multifunction power meters for more than two hundreds locations. At some of the selected locations the measured data have been recorded every 10 seconds. If detailed information is needed, Fluke power quality analyzers would be used to measure the data on-site

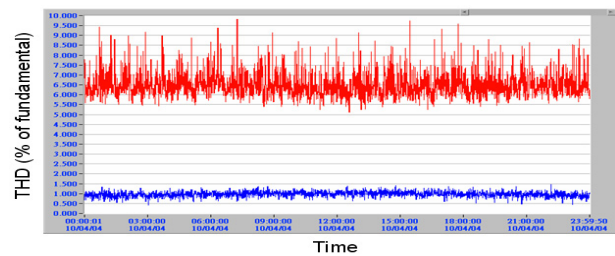


Figure 1: The measured total harmonic distortion of current (red line) and voltage (blue line) at PCC.

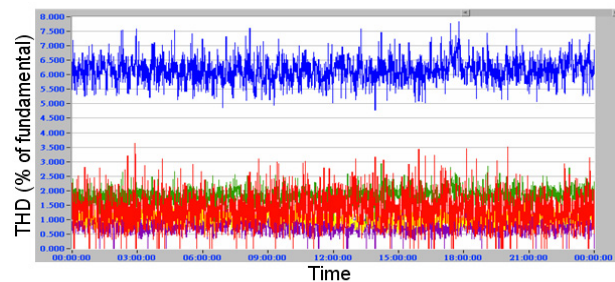


Figure 2: Harmonic distortion of current at PCC. The harmonic data shown are 3rd(red), 5th(blue), 7th(green), 11th(yellow) and 13th(purple).

At the point of common coupling (PCC) between Taipower and NSRRC, the measured harmonic levels for both feeders were about 5.5% for the current and 1% for the voltage several years ago. During the recent years, many nonlinear devices were added into the utility system, the harmonic distortion was gradually increased to more than 8% at PCC. In figure 1 and figure 2, the measured harmonic distortion at one of the feeder is shown.

In figure 3, the harmonic current distortion produced from the operation of a VFD for a cooling pump is shown. During the night the temperature of water was lower than 25° C, the motor ran with low load, thus the harmonics

produced were very small. After 7:30 a.m., the temperature rose to greater than 25° C, the VFD ran almost with full power for cooling down the water temperature until it was lower than 25° C. During the operation of VFD, the 5th, 7th, 11th, 13th order harmonics appears as the motor running.

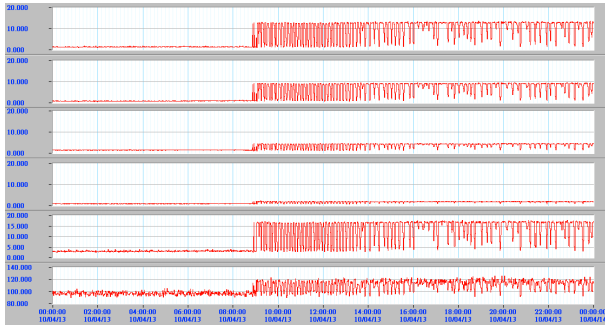


Figure 3: Harmonic distortion of current. The data shown (from above) are 5th, 7th, 11th, 13th, THDI (%) and real power (KW).

ON-SITE TEST OF HARMONIC FILTERS

Since harmonic distortion is increasing in the power system of NSRRC, finding an effective and economical method to attack this type of problem becomes important. Many on-site studies have been centered on the suppression of harmonic distortion produced by variable frequency drives which were installed in the utility system for the energy saving purpose. In order to find a best method to meet our purpose, we are experimenting some of filtering methods in our power system to investigate their effects.

The Active Harmonic Filter

The active harmonic filter using pulse current rectifiers with IGBT (Insulated Gate Bipolar Transistor) technology has proven very effective in mitigating harmonics. It connects in parallel with the load being compensated and generates varying amount of current of equal amplitude but opposite phase angle to cancel the harmonic currents produced by the nonlinear load. The harmonic content feed back to the power system can thus be minimized.

One active harmonic filter system has been installed at one branch of NSRRC's power system to see how effective it is. In the top of figure 4, the block diagram shows the concept of the harmonic current cancellation. In the figure, I_a was source current after the filter was turned on and compensated by the filter, and I_b was the load current, I_f was the compensating current produced by the filter. In the central row of figure, the waveforms of currents measured by the meters at points before and after the filter are shown. The spectra of harmonic contents at the corresponding locations are shown in the bottom row of figure 4. In the right plot the spectrum of current produced by the load and also sampled by the filter is shown. In the middle plot it shows the spectrum of current produced by the filter, which has the opposite phase for

canceling the harmonic current produced by the load. The plot in the left shows the spectrum of the current from the feeder. It indicated that the contamination of source current by the harmonic current produced by the load has been reduced, and the waveform shows much close to the sinusoidal waveform.

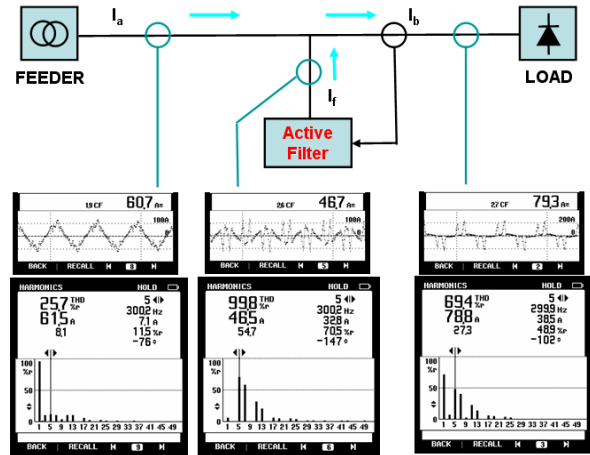


Figure 4: The measured waveform of harmonic currents and spectra at each of the corresponding locations when the active filter is in operation.

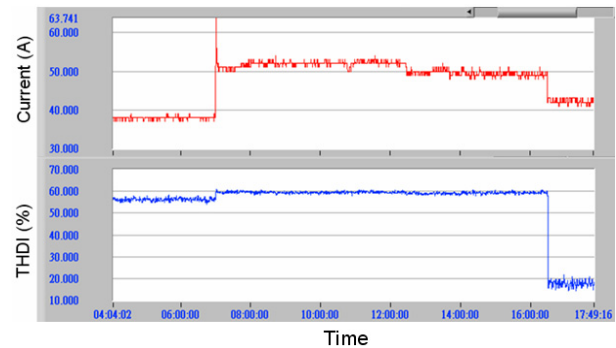


Figure 5: In the top plot, the electric current used in the branch is shown; in the bottom plot the total harmonic current distortion is shown.

In figure 5, the result of test run of active harmonic filter on the installed branch is shown. The top plot in figure 5 shows the magnitude of electric current used at the corresponding branch, while the bottom plot shows the harmonic distortion. From the beginning of the day the active filter was turned off. After 7 a.m., the use of electric currents was increased due to the daily activity. There were 5 motors with VFDs in this branch for the air handling unit. There were two motors with VFDs used before 7 a.m., the other 3 motors were in low load mode. After 7 a.m. all 5 motors were in full operation. The harmonic distortion was very large during this period. At 16:20 p.m., the active harmonic filter was turned on. From the plot, it showed that the harmonic distortion was reduced from 60% to 18% and electric current was also reduced 15% in this branch. This really reduced the harmonic distortion a lot and also reduced the use of electric power.

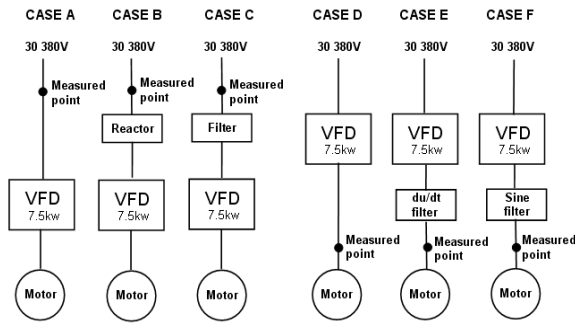


Figure 6: Block diagram for measuring the performance of passive filters.

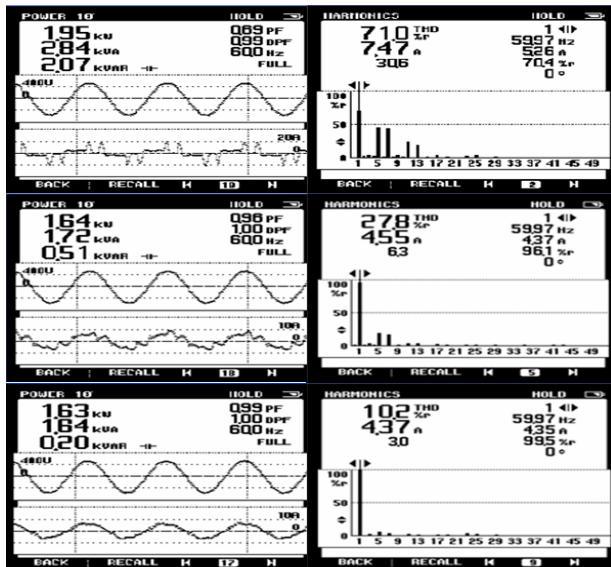


Figure 7: The waveforms of voltage (top curve) and current (bottom curve) are show in the left side of figure, and the harmonic current spectra are shown in the right. From top plot to bottom plot are for by pass, reactor and filter, respectively.

The Passive Filter

Several passive filters have been studied for their performance also. In figure 6, the cases of B, C are the configuration for studying the harmonics produced by the passive filters connected in series at the input of VFD. In case B, a harmonic suppression line reactor of 5% impedance was added at the input of VFD; and in case C, a matrix filter was used. Both types of filters have been proven effective in reducing harmonics emitted by VFD onto the incoming power line. The data was measured at the input to the VFD and shown in figure 7. In case A, there was no filter added. The waveform of current in case A was completely different from the sinusoidal waveform; and the total harmonic distortion of current was 71%. In case B, it showed that the THDI was reduced to 27.8%. This is a tremendous improvement on the harmonic distortion. In case C, it showed that the use of matrix filter reduced the harmonic current even more,

down to only 10.2%. The comparison for the individual harmonic order can also be seen in the right side of figure 7. In general, the effective impedance of line reactors varies with load, thus, the harmonic mitigation performance will be reduced as the current through them is decreased. As for the matrix filter, it can attenuate each harmonic frequency better than most of the passive filters.

Another study was to use the output filters connected in between the VFD and the motor. Two types of output filters, du/dt filter and sine filter, were selected for studying. Their layouts are shown as in case E and F of figure 6. The du/dt filter can suppresses inverter output voltage spikes and rapid voltage changes that stress motor insulation. In our test it gives good results in eliminating the high order harmonics at higher motor frequency. The sine filter is used to give a near perfect sinusoidal voltage waveform and eliminate the high frequency components of inverter output. At all motor frequency range, the sine filter shows much more effective in eliminating the high order harmonics.

CONCLUSION

Many nonlinear devices will be installed in the future TPS utility system. They will certainly produce large amount of harmonic distortion in the power system. The increased harmonic distortion in the TLS power system due to the recently installed nonlinear devices provides a best test ground to study effective approaches of minimizing it. Considering the present harmonic distortion condition of TLS power system, the passive filters, such as line reactors and du/dt filters having cheaper price, will be able to meet the requirement of minimizing the harmonic distortion. The expansive active harmonic filters will only be considered at some specific locations if necessary. As for TPS, a large amount of nonlinear devices are planed to be installed in the utility system, the harmonic distortion will certainly be large. If the recommended harmonic distortion limits described in IEEE standard 519-1992 [1] are to be met, the active harmonic filters would be required. From our experience, the efficiency of active harmonic filter may not work as good as the manufactures claimed due to the complexity of utility system. In order to minimize the harmonic distortion, the economic solution is to combine line reactors and active harmonic filters in the same branch. The line reactor can attenuate the harmonic current distortion to a smaller degree first, then, the active harmonic filter will reduce further the harmonic distortion to only a few percent to meet the harmonic control requirement.

REFERENCES

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