POWER QUALITY & ENERGY EFFICIENCY IMPROVEMENT AT THE WYNN MACAU, CHINA HOTEL & CASINO

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Abstract – *Single-phase electronically controlled nonlinear lighting loads, connected phase-to-neutral in a three-phase, four-wire electrical distribution system, generate extremely high levels of positive-, negative- and third-order, zero-sequence harmonic currents.*

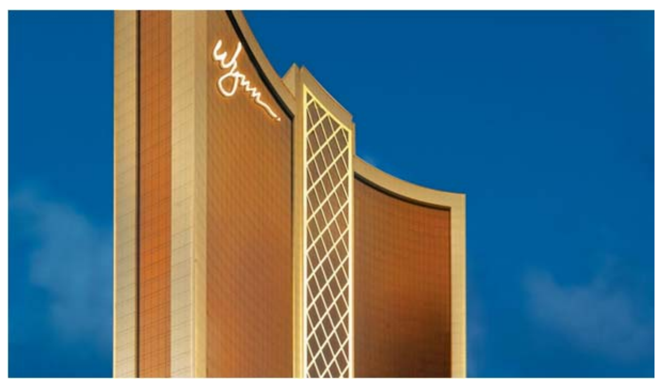
Without harmonic mitigation, single voltage distribution systems, which exclude low voltage distribution transformers, are inherently unsuited as a power source for these troublesome nonlinear electronic loads. Single voltage distribution systems are common in Asia and Europe where the distribution and utilization voltage is 400/230-volts or higher.

I. INTRODUCTION

The Diamond Feature, at the Wynn Macau Hotel & Casino, is a very large lighting display, located on the exterior concave façade of the hotel's Encore Tower. The display extends from the seventh floor up to the fiftieth floor. The top twenty floors of this display are shown in *Figure 1*. The Diamond Feature includes approximately 70,000 randomly controlled, dimmable cold cathode fluorescent lamps. The display is supplied from a 400/230-volt, 50Hz, three-phase, four-wire electrical distribution system riser.

As a source of positive-, negative- and third-order, zero-sequence harmonic currents, these troublesome phase-to-neutral connected nonlinear lamps had an extremely negative impact on the hotel's electrical distribution system and its loads.

The hotel's first complaints included flickering lights in the upper floor guest rooms, unusual humming and vibration in the five remote distribution panels that supply the Diamond Feature and low power factor at the system's main switchboard. The Diamond Feature's electrical distribution system is detailed in the One-Line Diagram presented as *Figure 2*.

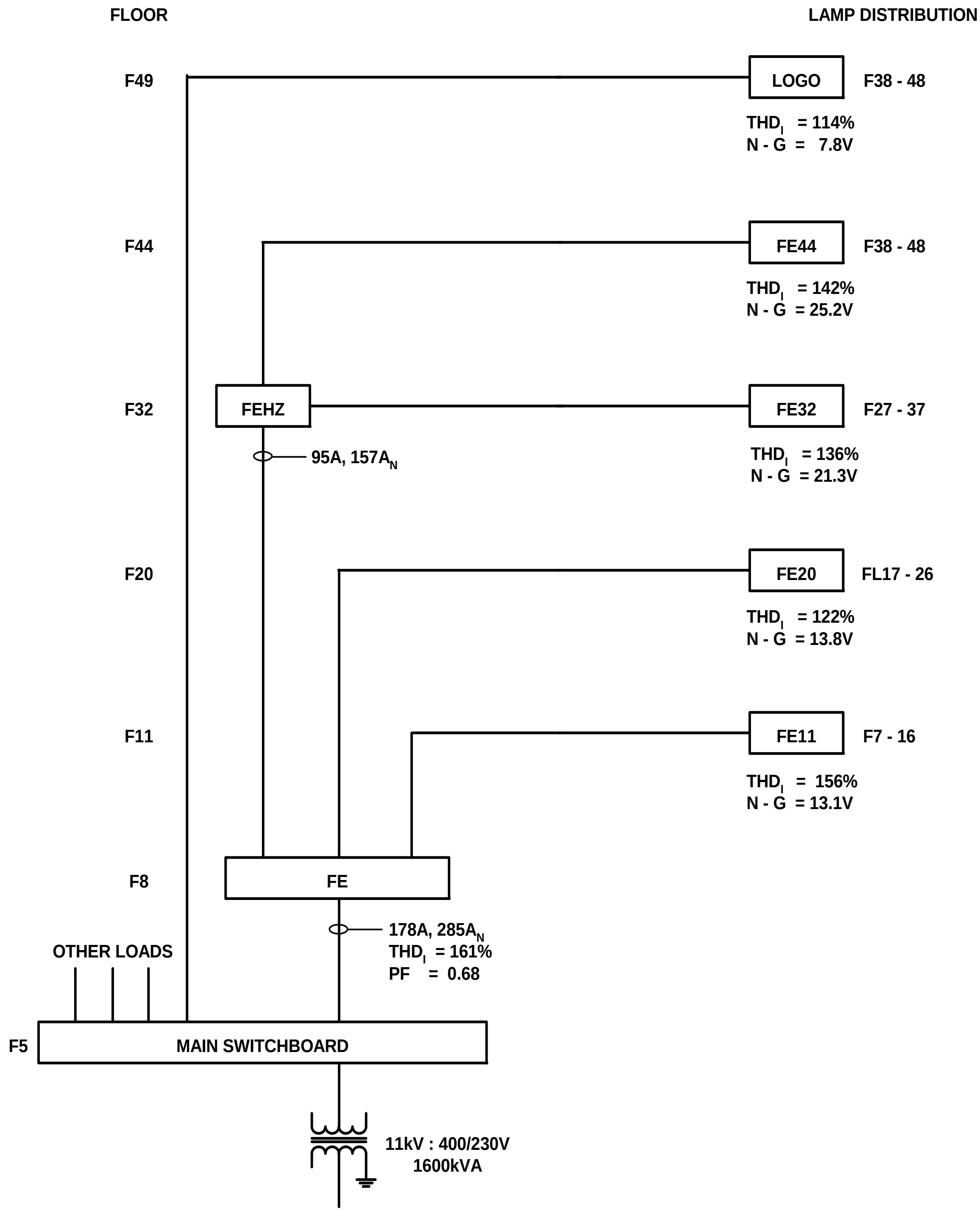


The Diamond Feature
Figure 1

The facility's engineering staff and JBA Consulting Engineers, who had been retained to evaluate performance issues on the hotel's electrical distribution systems, quickly concluded that these symptoms were the result of extreme harmonic current loading. To confirm these suspicions, a local testing company was engaged to measure harmonic profiles at several locations including the six remote distribution panels, one of the two subpanels and the main switchboard. Some of these 'as found' measurements are included on the One-Line Diagram in *Figure 2*.

With reference to *Figure 2*, extremely high levels of current distortion were recorded at the six remote panels that supply the lighting controls. These results confirmed their suspicion regarding panel noise and vibration.

In an Ohms Law relationship with the system's harmonic impedances, these harmonic currents produced an unacceptable level of voltage distortion at the main switchboard. At 8.8% THD_V, distortion was well above the IEEE Std 519-1992 recommended 5% limit. As a result, this level of baseline voltage distortion was imposed on all other loads supplied by the main switchboard. Since the lights in the guest rooms are also nonlinear, their harmonic currents further elevated voltage distortion at their locations. The upper level rooms were most affected since longer circuits produce higher harmonic impedances, higher harmonic voltages ($E_H = I_H * Z_H$) and higher voltage distortions.



Diamond Feature's Electrical Distribution System (As Found)
Figure 2

II Proposed Solutions

To resolve the observed operational issues and improve power factor, FES prepared a harmonic mitigation plan, with guaranteed outcomes. This plan, which would also provide energy efficiency improvement, was presented to JBA Consulting Engineers five days after receiving their request for a proposal. JBA assessed the mitigation plan then passed it on to the owner's representative for their approval. PQI subsequently discovered that its proposal was one of three presented to the owner for evaluation.

The Wynn organization elected to proceed with a solution prepared by Schneider Electric. The Schneider solution required the application of an active harmonic filter (AHF) at each of the Diamond Feature's five remote distribution panels. These devices are designed to analyze a circuit's harmonic current profile, and then inject harmonic currents, which are equal in magnitude but 180° out-of-phase, into the circuit. This effectively cancels the load-generated harmonic currents.

Unfortunately, the Diamond Feature's lamp and controllers produce a current rise-time and duration that was well beyond the AHF's ability to track or mitigate. This problem actually caused the AHF to increase current and voltage distortion. Schneider next applied a one-to-one, K-Rated distribution transformer at the line-side of the eight floor subpanel 'FE', which supplies four of the five remote distribution panels. We assume their intent was to increase the current waveforms' rise-time and duration, and reduce harmonic current magnitudes. This addition caused a further increase in voltage distortion, which produced an unacceptable failure rate of the dimmable cold cathode fluorescent lamps. As a result, the AHFs and K-Rated transformer were removed from service.

With these serious issues unresolved, the owner directed JBA to undertake harmonic modeling of the 'as built' distribution system. Upon completion, JBA produced a comprehensive report that described the performance of the system under nonlinear loading (baseline). Their calculations closely approximated the site measurements taken one year earlier.

JBA's report then detailed anticipated outcomes based on solutions offered by General Electric and FES International, Inc. Their report concluded that only FES's engineered approach would reduce current distortion at the remote distribution panels and voltage distortion at the main switchboard to acceptable levels, the key requirement with respect to the flickering light problem, and noise and vibration at the five remote distribution panels. Based on this conclusion, FES was authorized to proceed.

III. The FES Solution

To resolve all identified issues, the FES harmonic mitigation plan proposed the application of ultra-efficient harmonic mitigating transformers, manufactured by Power Quality International, at the line-side of each of the five remote distribution panels that supply the Diamond Feature. With reference to *Figure 3*, transformers 'T-11', 'T-20', 'T-32' & 'T-44' would be used to convert the Diamond Feature's six-pulse loads into a twenty-four-pulse load at the eighth floor subpanel 'FE' and at the main switchboard. Transformer 'T-49', by phase-shifting its loads against the main switchboard's other nonlinear loads, would be used to create a twelve-pulse harmonic profile at the main switchboard.

These transformers would also be used to create separately derived, grounded neutral busses adjacent to each remote distribution panel. This scheme would dramatically reduce neutral-to-ground voltages at the lamp controllers.

To accomplish these goals, FES selected PQI's Type DV, ***Distribution TransFilters***™. These devices are available in a variety of primary-to-secondary phase-shifts. Creating a twenty-four-pulse load requires that the four load groups be phase-shifted in increments of 15°. This technique requires 0°, -15°, -30° and -45° phase-shifts. Type DV transformers also include secondary windings that cancel zero-sequence flux. This feature virtually eliminates zero-sequence flux in the magnetic circuit and circulation of zero-sequence currents in the transformers' primary 'delta' connected windings. This design feature reduces the transformers' zero-sequence impedance by approximately 80%.

With reference to *Figure 3*, the transformers supplying remote panels 'FE44' and 'FE32' phase-shifted their six-pulse loads by 30°, creating a twelve-pulse load at subpanel 'FEHZ'. Likewise, the transformers supplying remote panels 'FE20' and 'FE11' also phase-shifted their six-pulse loads by 30°, creating a twelve-pulse load at subpanel 'FE'. However, the four load groups, phase-shifted in 15° increments, produced a twenty-four-pulse load at subpanel 'FE' and at the main switchboard.

IV The Power Quality Outcome

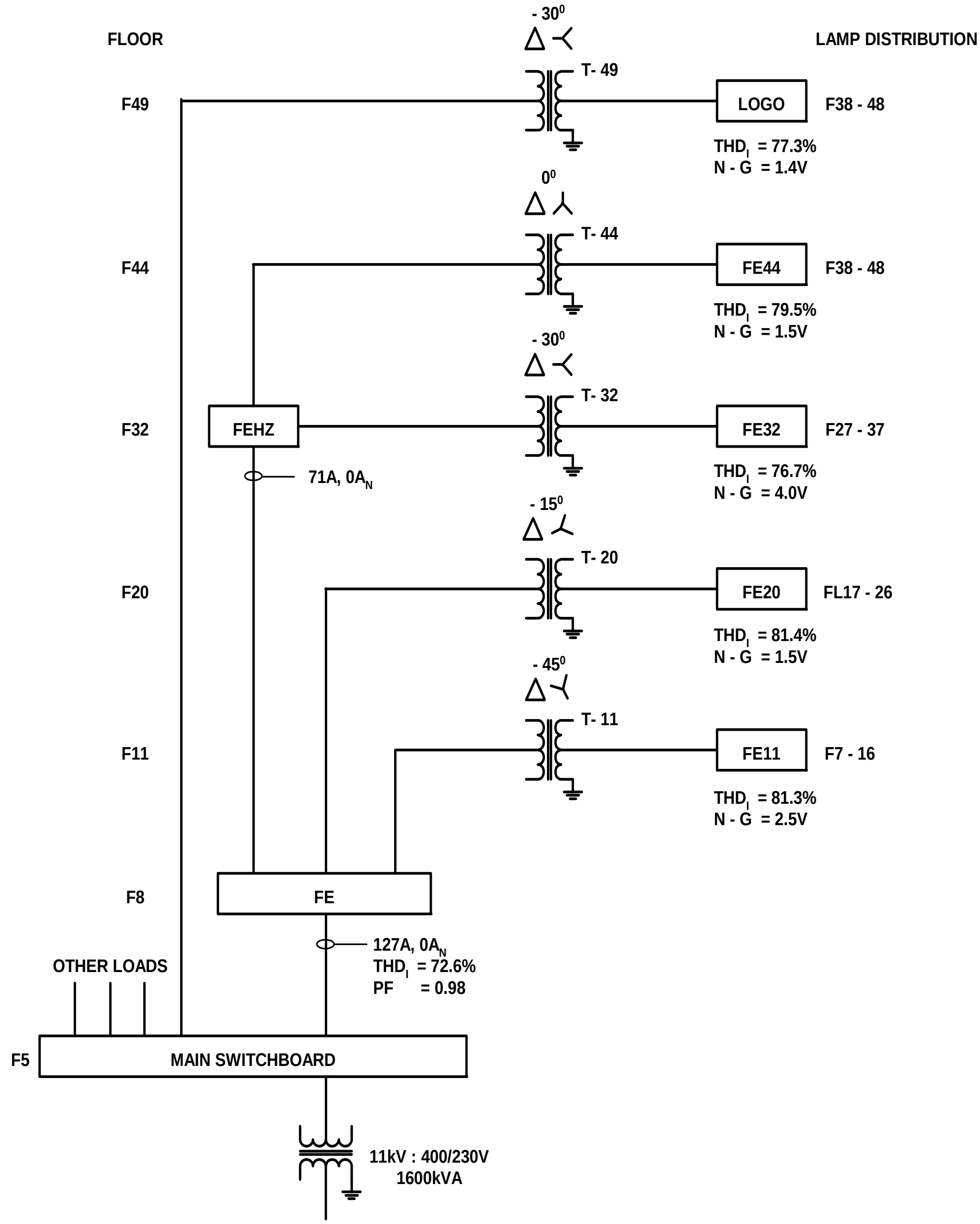
With the five harmonic mitigating transformers in place, but disconnected, FES's representative recorded a new set of 'as found' measurements. These new baseline measurements were witnessed and recorded for future 'before' and 'after' comparisons. The five harmonic mitigating transformers were then connected and energized. With the Diamond Feature in service, a new set of measurements were witnessed and recorded. Several of the critical power quality measurements are contained in *Table 1* and on the *Figure 3* diagram.

Measurements Taken Before & After Mitigation
Table 1

Panel	*Before Mitigation*	*After Mitigation*	*Reduction*
LOGO	114%THD_I 7.8V N-G	77.3% THD_I 1.4V N-G	32.2% 82.1%
FE44	142% THD_I 25.2V N-G	79.5 THD_I 1.5V N-G	44.0% 94.1%
FE32	136% THD_I 21.3VN-G	76.7% THD_I 4.0V N-G	43.6% 81.2%
FE20	122% THD_I 13.8V	81.4% THD_I 1.5V N-G	33.3% 89.1%
FE11	153% THD_I 9.8V N-G	81.3% THD_I 2.5V N-G	46.9% 74.5%
FE	120% THD_I 8.8% THD_V 13.1V N-G 178$A_Ø$/285A_N 0.68 PF	72.6% THD_I 2.29% THD_V 0.0V N-G 127$A_Ø$/0.0A_N 0.98 PF	39.5% 74.0% 100% 28.7$\%_Ø$/100$\%_N$

V The Operational Outcome

With the system modifications complete and the Diamond Feature in service, observations confirmed that the flickering light problem in the upper floor guest rooms had been resolved. Voltage distortion levels, which caused the problem, were now measured at only 1.5% THD_V in the guest rooms.



Diamond Feature's Electrical Distribution System (As modified by PQI)
Figure 3

With reference to the measurements included in *Table 1*, harmonic current distortion at the five remote distribution panels was reduced by an average of 40%. Although still very high, the reduction was enough to reduce the noise problem to a barely audible hum with no perceivable vibration.

VI OTHER BENEFITS

With reference again to *Table 1*, there were two additional benefits resulting from harmonic current mitigation: RMS phase currents were reduced by 28.7% at subpanel 'FE' and Neutral current, which was 60% higher than phase currents, was eliminated. In addition, the lighting load's power factor was raised from 0.68 to 0.98.

VII FUTURE OPPORTUNITIES

The foregoing RMS current reductions and power factor improvement will obviously result in a reduction in the cost of power. The author hopes to provide an Energy and Power Quality Improvement Solution for the entire facility in the future.

VIII AN ALTERNATE DISTRIBUTION SYSTEM DESIGN

In developing a harmonic mitigation plan, FES examined all possible options that would resolve the identified problems. One alternative, which was considered, included the application of ultra-efficient Type DY ***Distribution TransFilters***™. These transformers would have been installed at the same locations shown in *Figure 3*. However, as an alternative to supplying the lamp controllers at 230-volts, phase-to-neutral, the Type DY transformers' would supply the controllers at 240-volts, phase-to-phase. With this option, the subsystems would have been converted from four-wire to three-wire. The transformers' neutral terminal would have been grounded but otherwise unused. Supplying these loads phase-to-phase would have a dramatic effect on harmonic current content, 'penalty losses' and voltage distortion. Nonlinear single-phase loads, connected phase-to-phase, do not generate zero-sequence current. To mitigate positive- and negative-sequence harmonics, the transformers' phase-shifts would have remained as shown on *Figure 3.*

This option was discussed with JBA. Although technically superior, the cost of modifying the remote distribution panels and lamp controllers was prohibitive. This alternative design is presented, since it represents the best option for future displays.

VIII BIOGRAPHY

Gregory Ferguson was born in Toronto, Canada in 1937. He received a B.Sc. Degree in Engineering Technology from Ryerson University, Toronto. With over 50 years experience in power system engineering, he is the founder and president of FES International, Inc. (1968 Canada & 1991 US) and founder and past president of Power Quality International, Inc. (1993). His Canadian incorporations also include Electrical Testing Instruments Ltd. (1973). Prior to incorporating these companies, Greg was a Protection & Control Engineer at Ontario Hydro-Electric Power Commission and a Protection & Control Department Head at Scarborough Public Utilities Commission (Toronto). In 2008, he became a Life Member of IEEE.