CASE STUDY

Implementation of Active Harmonic Filters at Ford Motor Company SA – Silverton Plant

1 SCENARIO

Ford Motor Company is a global automotive and mobility company based in Dearborn, Michigan. Ford Motor Company of Southern Africa (FMCSA) has been an active participant in the South African motor industry since 1923 when they began assembling Model T cars in a disused wool shed in Port Elizabeth. FMCSA has become one of Southern Africa's leading automotive companies.

The Silverton Assembly Plant in Pretoria assembles light commercial vehicles that are supplemented with passenger vehicle imports from a number of different countries.

The Struandale Engine Plant in Port Elizabeth has significantly upgraded and expanded its machining and assembly capabilities for this programme, and now has an annual production capacity of 250,000 machined component kits, comprising of engine heads, blocks and crankshafts for the Duratorq TDCi engine. Approximately 75,000 of these are used for local engine assembly to power the new Ranger built at the Silverton Assembly Plant. The remaining 175,000 component sets are destined for export to Ford engine assembly plants in Thailand and Argentina.

FMCSA recently invested ± US$272 million into South Africa, which has transformed both plants into world class facilities to produce the new Ford Ranger and Duratorq TDCi engine for local consumption and export to 148 countries worldwide. Annual capacity has been increased at the Silverton Assembly Plant to 110,000 units.

Cost saving initiatives are always high on the agenda in any business, and with Ford it is no exception. This case study describes the implementation of new technology, Active Harmonic Filters, at the Ford Silverton Plant in order to reduce direct and indirect costs that are caused by harmonic pollution on the electrical power system.

2 HARMONIC PROBLEM

Various unplanned plant shutdowns as a result of circuit breaker trips, equipment failures and malfunction of certain equipment occurred in the Ford Silverton Plant in recent times, some of which are believed to be a result of poor Power Quality on the electrical distribution networks feeding to the plant equipment. Power Quality (PQ) audits that were conducted since 2015 have indicated high levels of harmonic distortion on most of the transformers' LV outputs in the three Substations that feed to the Bodyshop, Paintshop and Assembly Line.

The current harmonics that are caused by the non-linear loads, which include Robot Controllers, Welders, Variable Speed Drives on motors (pumps, compressors), UPSs, Fluorescent Lights, and other loads that have some kind of AC/DC rectifier on the input, cause distortion on the voltage waveforms on the LV output of the transformers. As transformers also have impedance, voltage distortion appears at the transformer's secondary terminals when harmonic currents flow through it.

Distorted voltage waveforms on the transformer's LV output is not ideal, since other sensitive equipment that may be supplied from the transformer's LV output will receive the distorted voltage waveforms, which can have a detrimental impact on the performance and reliability of these equipment.

Common symptoms of problematic harmonic levels include overheating of motors, drives, cables, thermal tripping of protective devices and logic faults of digital devices, all of which can result in downtime.

In order to reduce voltage distortion on a transformer's output, two factors can be modified: the transformer impedance can be reduced, or the level of harmonic currents through the transformer can be reduced. The former is neither practical nor economical to implement. Energy Insight proposed an engineering solution to reduce the high harmonic current levels through the transformers in the three Substations in order to reduce voltage distortion levels on the LV distribution networks.

3 SOLUTION

By comparing the pros and cons of Passive versus Active Harmonic Filters, Energy Insight proposed to implement an Active Harmonic Filter solution on the transformer outputs in the three Substations. The product that was proposed is the Accusine PCS+ Active Harmonic Filter (AHF) of Schneider-Electric.

The AHF employs current transformers to measure the source current to determine the content of harmonic current present. By injecting the synthesized current, harmonic currents through the transformers are greatly mitigated, thus reducing the harmful effects of harmonic current and reducing voltage distortion in order to permit other equipment to operate properly and enjoy a long product life span.

Apart from mitigating current harmonics that are generated by the non-linear loads, the AccuSine PCS+ can also be configured to improve the load's power factor by injecting the corrective fundamental (50Hz) component of reactive current into the network. This is commonly known as Power Factor Corection (PFC). A third function can also be enabled, which is the balancing of unbalanced load currents. This is done by injecting the negative sequence reactive component of unbalanced load currents into the network, thereby improving the balancing of three-phase currents drawn from the source.

A total of 19 x AHF units was proposed, to be installed on the LV (400V) output of 14 x distribution transformers in the three Substations. The rating of the AHF units range from 60A to 300A. On some of the transfomers where the current distortion levels were high, the use of two AccuSine units in parallel was proposed.

For this project, the goal of the AHF solution will be to largely cancel out the whole spectrum of current harmonics (3^{rd} to 51^{st}), to reduce the Current Total Harmonic Distortion (THD) to levels below 5% of fundamental, and as a result to reduce the Voltage THD to levels below 3%.

Figure 1 shows a single line diagram of a typical installation where two AccuSine AHF units are connected in parallel on the LV output of a distribution transformer.

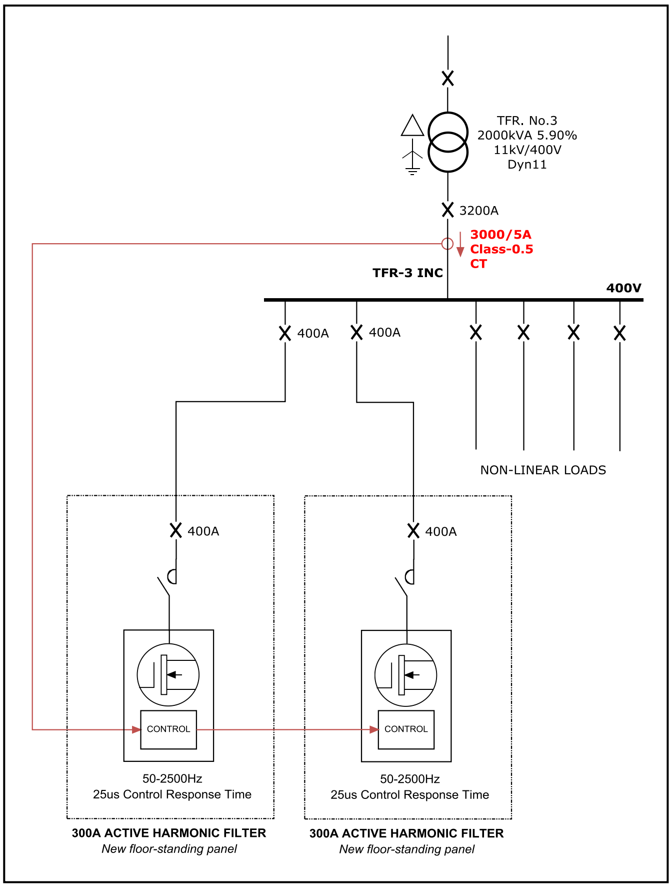

Figure 1: Single Line Diagram of a Typical AccuSine PCS+ AHF Installation

4 BENEFITS

Benefits that FMCSA can expect by implementing the Active Harmonic Filter Solution at the three Substations include the following:

1. Reduced Peak RMS Currents through the 14 x Transformers due to the reduction of harmonic currents and fundamental reactive currents (Power Factor Correction).
2. Reduced losses (copper and core) in the 14 x Transformers in the Substations.
3. Reduced kVA demand on the transformers due to the reduction of the RMS current through the transformers. This will contribute to the reduction of the kVA Demand cost component in the monthly electricity bill. This is a direct cost reduction.
4. Extending the life of transformers. Transformers will run at lower temperatures due to reduced losses.
5. Reduced indirect cost due to unplanned plant downtime in the various Plants, some of which is believed to be caused by poor Power Quality on the LV distribution networks.
6. Source balancing of unbalanced load currents, which can improve the balancing of the supply voltage on the Main LV bus bars, feeding to other sensitive equipment.

5 RESULTS

In the Substation that feeds to Paintshop, a total of 10 x 300A AHF units were installed and commissioned in April 2018 on the LV outputs of 6 x 2,000kVA transformers. The total installed capacity of these ten AHF units is 3,000 Amp @ 400V = 2,078kVA. The units were configured to mitigate the odd current harmonic orders from the 3rd to the 29th, to correct the power factor on each transformer to at least 0.98 (lagging), and to perform source current balancing using the remaining capacity of the AHF units. Most units were configured to control the Current Total Harmonic Distortion THDi on 1%.

Figure 2 shows some of these AHF units that were installed in this Substation.

Figure 2: AccuSine PCS+ AHF Units in Paintshop Substation

Figure 3 shows a snapshot that was taken of the current waveforms that are measured and displayed on the HMI Controller of one of two AccuSine AHF units in parallel. The waveforms shown are I_{out} (output of the AHF unit), I_{load} (distorted load current), and I_{src} (transformer current), all for phase 1. The sum of the load current and two times the AHF output current (because of two units in parallel) results in the almost sinusoidal source current (blue line).

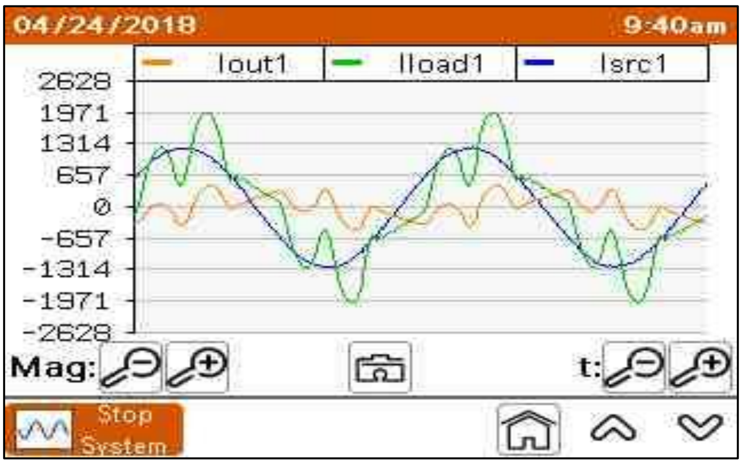

Figure 3: Screenshot from an HMI Controller on one AccuSine AHF Unit

The table below shows a summary of the results obtained on one of the transformers (TRX-3) in the Paintshop Substation (Sub-10).

Of note is the reduction of THDi from 14.6% to 1.06%, the reduction of THDv from 4.78% to 2.02%, the reduction of the transformer current by 9.6%, and the reduction of the kVA demand through the transformer by 5.9%.

Measurement	Unit	Without Compensation	With AccuSine PCS+	% Change
Voltage (average line-line)	V	394	396	+0.5
Current (average phase)	A	1,425	1,288	-9.6
Current Unbalance Factor	% of Average Current	4.28	2.58	-39.7
Real Power	kW	893	886	-0.8
Reactive Power	kVAr	318	70	-78.0
Apparent Power	kVA	948	892	-5.9
Displacement Power Factor	PU	0.94	0.997	+6.1
True Power Factor	PU	0.929	0.997	+7.3
THDv	% of Fundamental	4.78	2.02	-57.7
THDi	% of Fundamental	14.6	1.06	-92.7
Vh5 (5th order voltage)	% of Fundamental	4.03	1.03	-74.4
Vh7 (7th order voltage)	% of Fundamental	2.20	0.66	-70.0
Ih5 (5th order current)	% of Fundamental	14.85	0.26	-98.2
Ih7 (7th order current)	% of Fundamental	5.55	0.18	-96.8

Table 1: Paintshop Substation Results Summary:TRX-3

Figure 4 shows the Transformer Output Voltage with and without the AccuSines activated. There was no significant impact on the RMS Output Voltage. The average line-line voltage slighlty increased by 0.5%, as a result of the stabilizing effect that the AccuSine units provide through leading reactive current injection into the network.

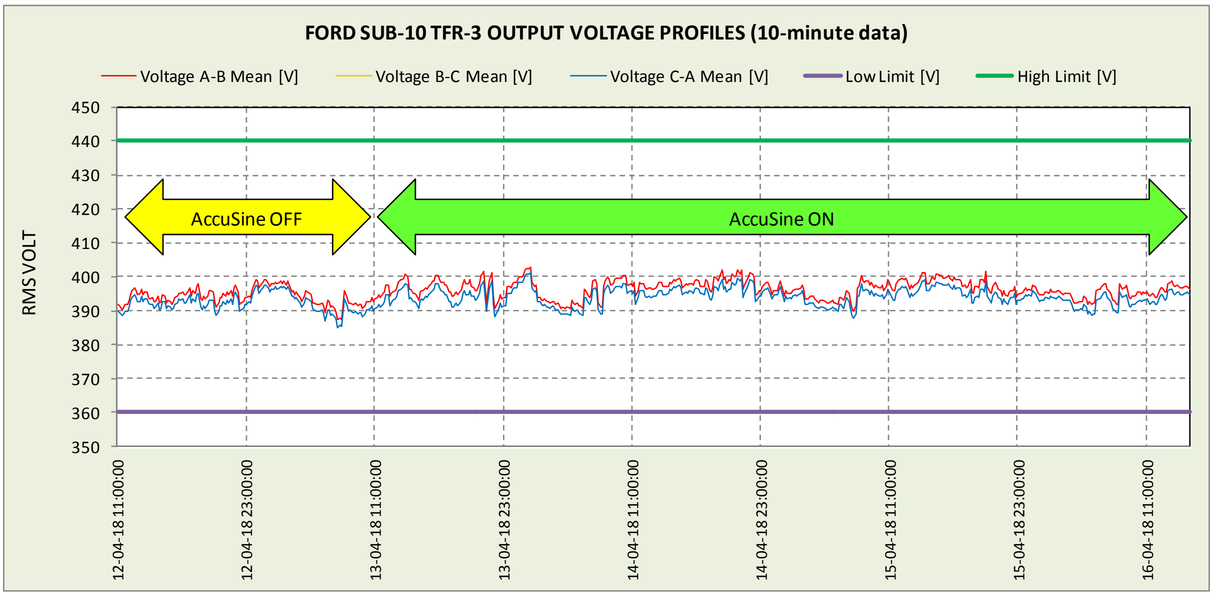

Figure 4: Paintshop Substation Transformer Output Voltage

Figure 5 shows the Transformer Output Current with and without the AccuSines activated. There was a significant reduction in the RMS Output Current on all three phases. On average the RMS value of the phase currents reduced by 9.6%.

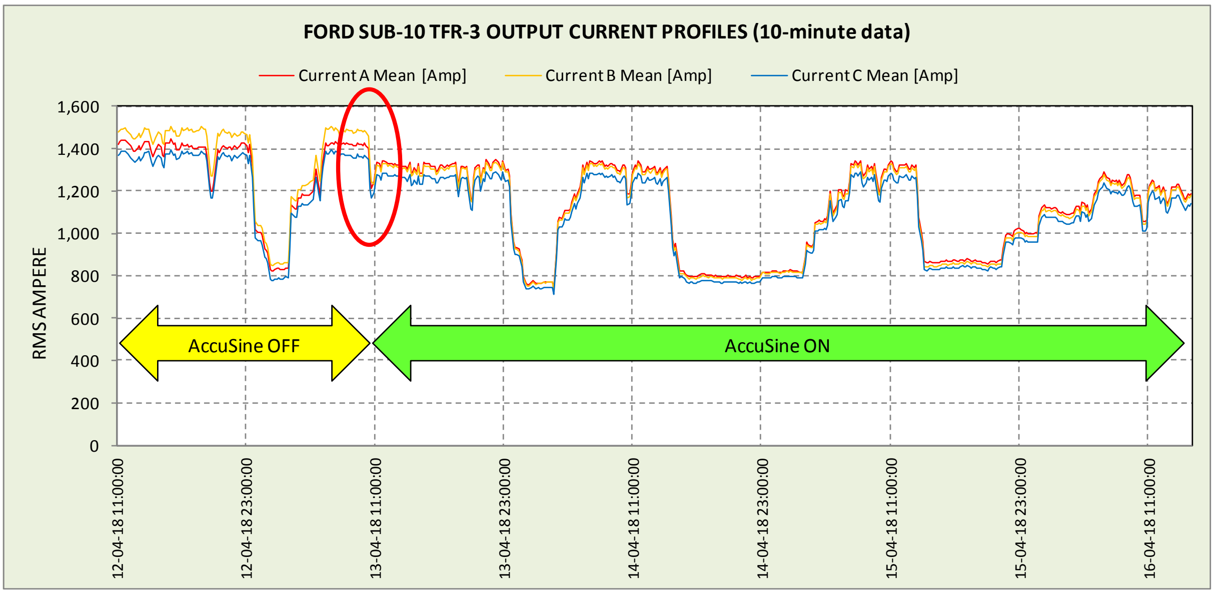

Figure 5: Paintshop Substation Transformer Output Current

Figure 6 shows the Transformer Output Current Unbalance Factor with and without the AccuSines activated. There was an almost 40% reduction in the Current Unbalance factor.

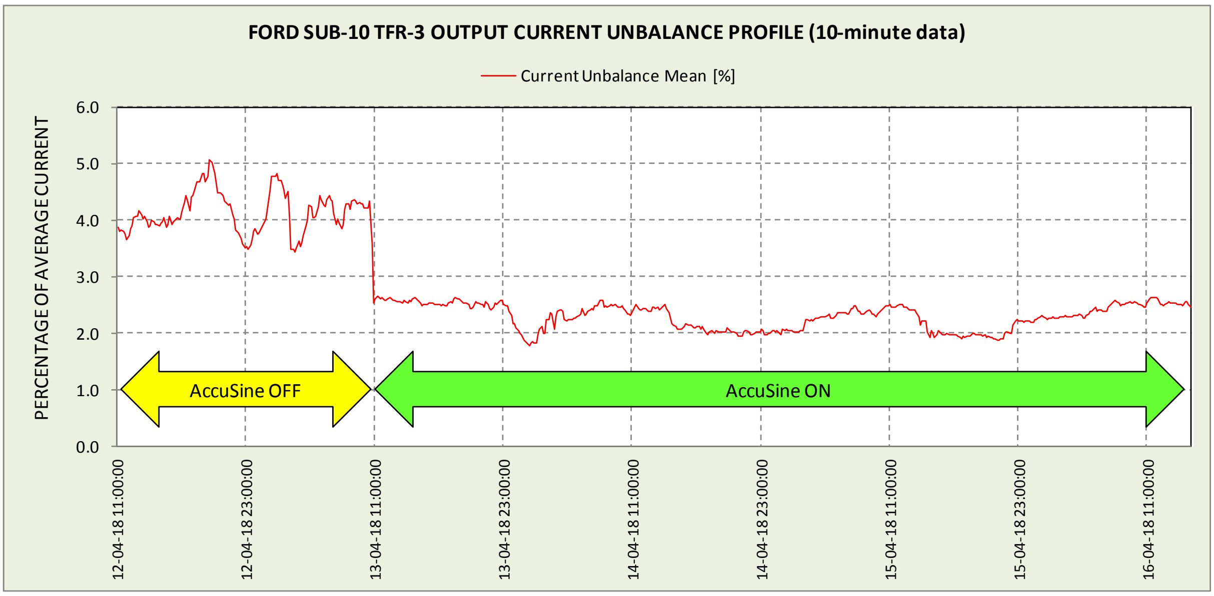

Figure 6: Paintshop Substation Transformer Output Current Unbalance Factor

Figure 7 shows the Transformer Output Power with and without the AccuSines activated. There was a 78% reduction in the Reactive Power due to the leading reactive current injection of the AccuSine units. The Apparent Power was reduced by 5.6%.

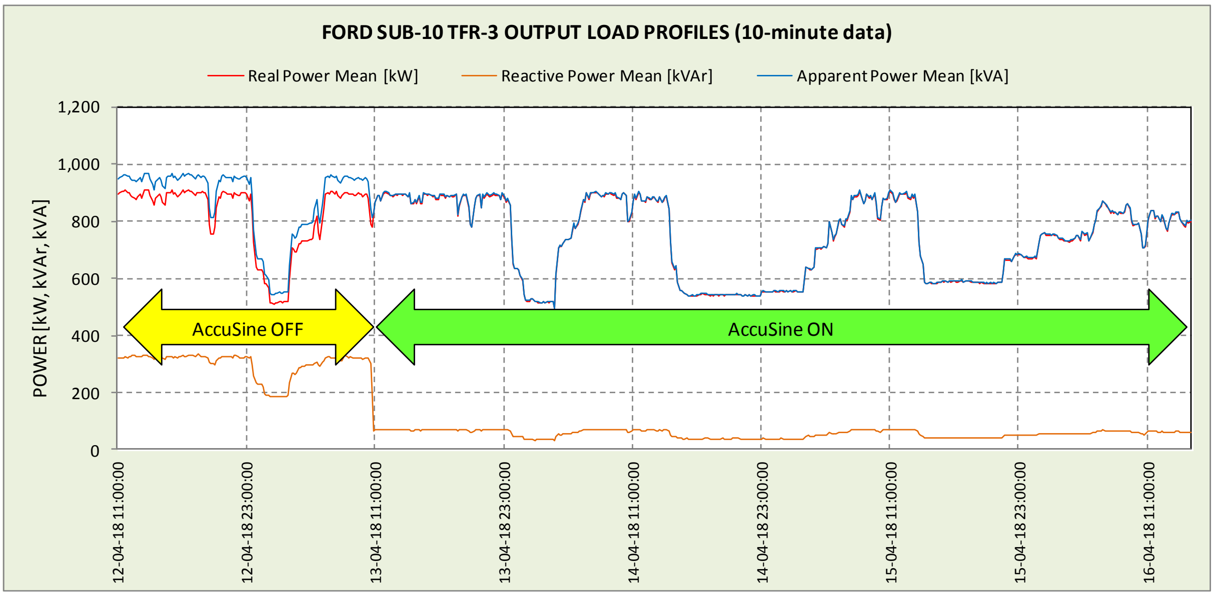

Figure 7: Paintshop Substation Transformer Output Power

Figure 8 shows the Transformer Displacement Power Factor with and without the AccuSines activated. There was a significant improvement in the Power Factor from 0.94 (lagging) to 0.997 (lagging).

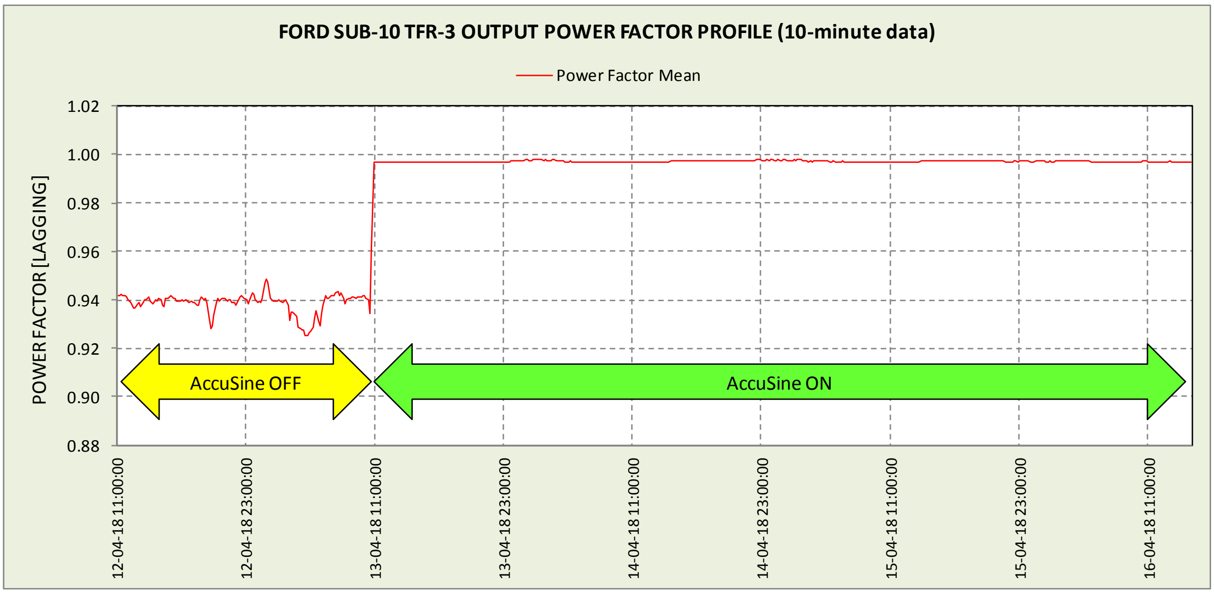

Figure 8: Paintshop Substation Transformer Displacement Power Factor

Figure 9 shows the Voltage Total Harmonic Distortion with and without the AccuSines activated. There was a reduction of 58% in the THDv, which is significant.

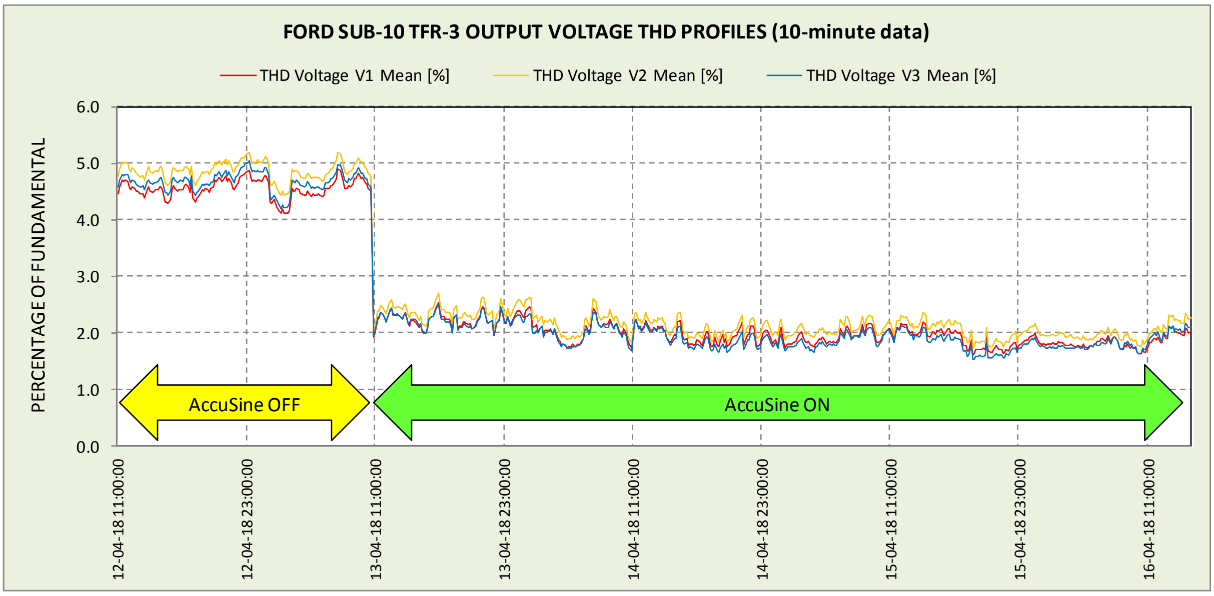

Figure 9: Paintshop Substation Transformer THDv

Figure 10 shows the Current Total Harmonic Distortion with and without the AccuSines activated. There was a reduction of almost 93% in the THDi, which is an outstanding result. The THDi setpoint is set on 1%, and the AccuSine units controls the THDi on this value under all loading conditions.

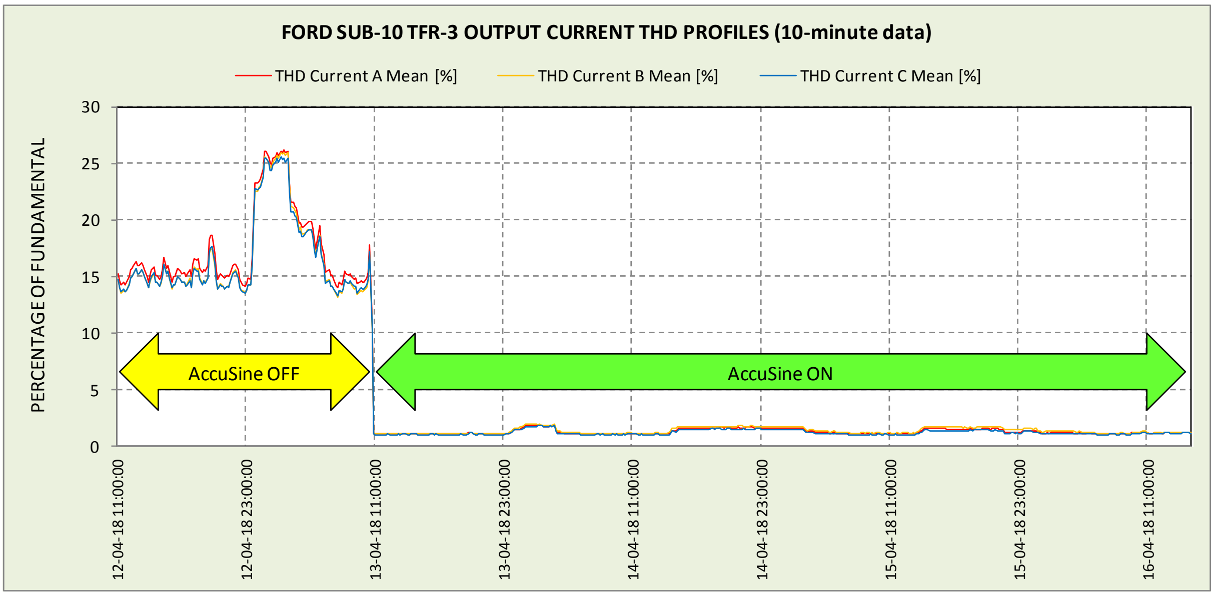

Figure 10: Paintshop Substation Transformer THDi

Figure 11 shows the Voltage Harmonic Spectrum with and without the AccuSines activated. There was a significant reduction in the magnitude of all the individual voltage harmonics orders, the most significant being the reduction of the 5^{th} and 7^{th} orders. The 5^{th} order was reduced by 74%, and the 7^{th} order by 70%.

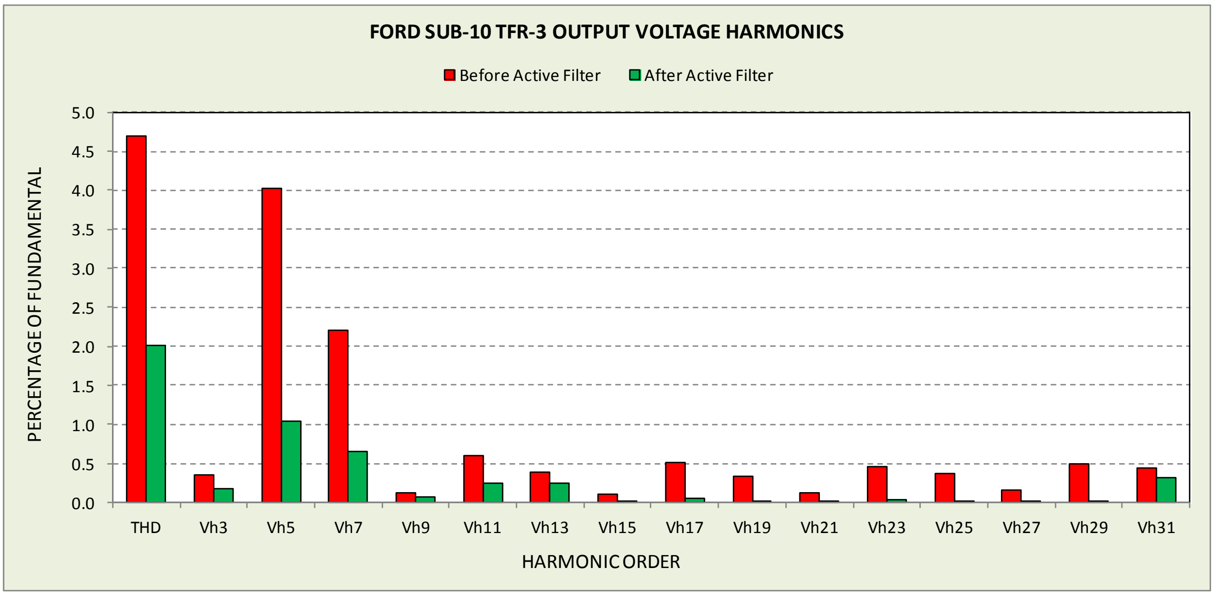

Figure 11: Paintshop Substation Transformer Voltage Harmonic Spectrum

Figure 12 shows the three-phase Voltage waveforms with and without the AccuSines activated. Without the AccuSine units activated, the presence of waveform distortion is evident in the top graph on each phase. The waveforms in the bottom graph, with the AccuSine units activated, are almost purely sinusoidal. THDv is down to 2%.

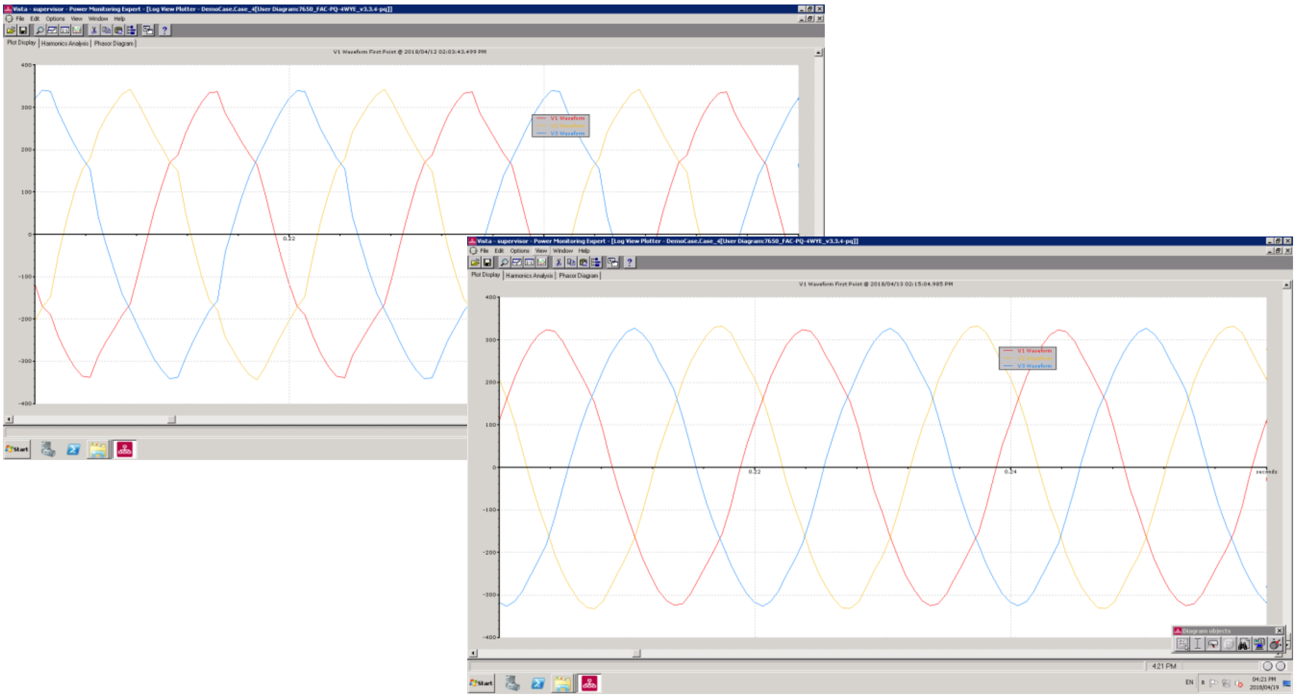

Figure 12: Paintshop Substation Transformer Voltage Waveforms

Figure 13 shows the Transformer Output Current Harmonic Spectrum with and without the AccuSines activated. There was a huge reduction in the magnitude of all the individual current harmonics orders, the most significant being the reduction of the 5th and 7th orders. The 5th order was reduced by 98%, and the 7th by 97%, which is an outstanding result.

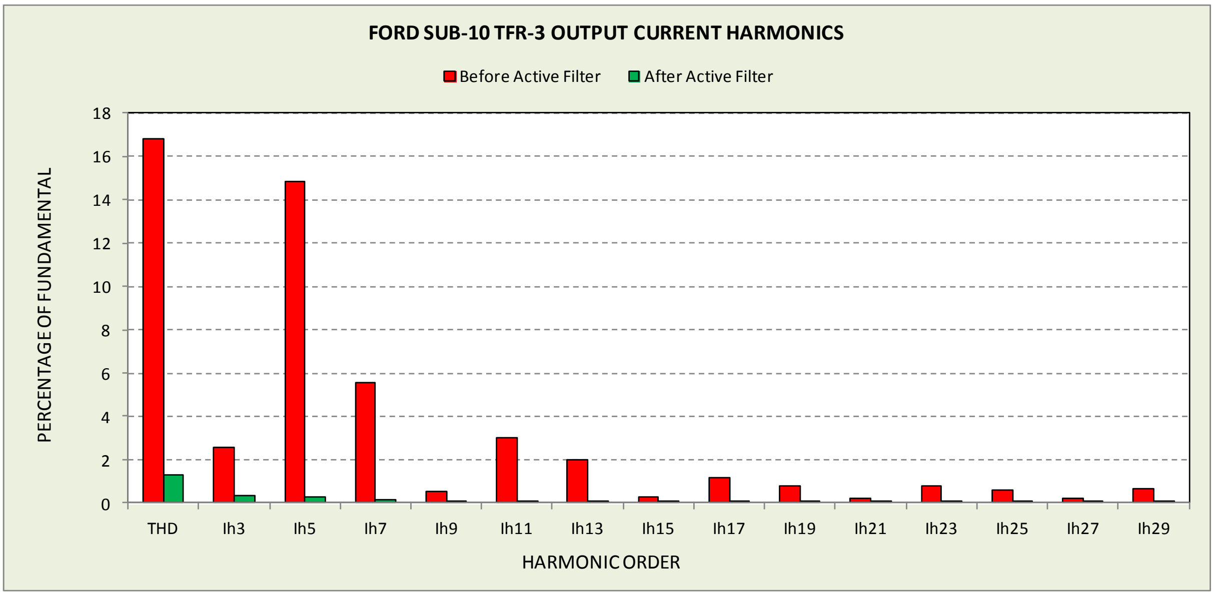

Figure 13: Paintshop Substation Transformer Current Harmonic Spectrum

Figure 14 shows the Transformer Output Current waveforms with and without the AccuSines activated. Without the AccuSine units activated, the presence of the 5th and 7th orders is evident in the top graph on each phase. The waveforms in the bottom graph, with the AccuSine units activated, show much less distortion. THDi is down to 1%.

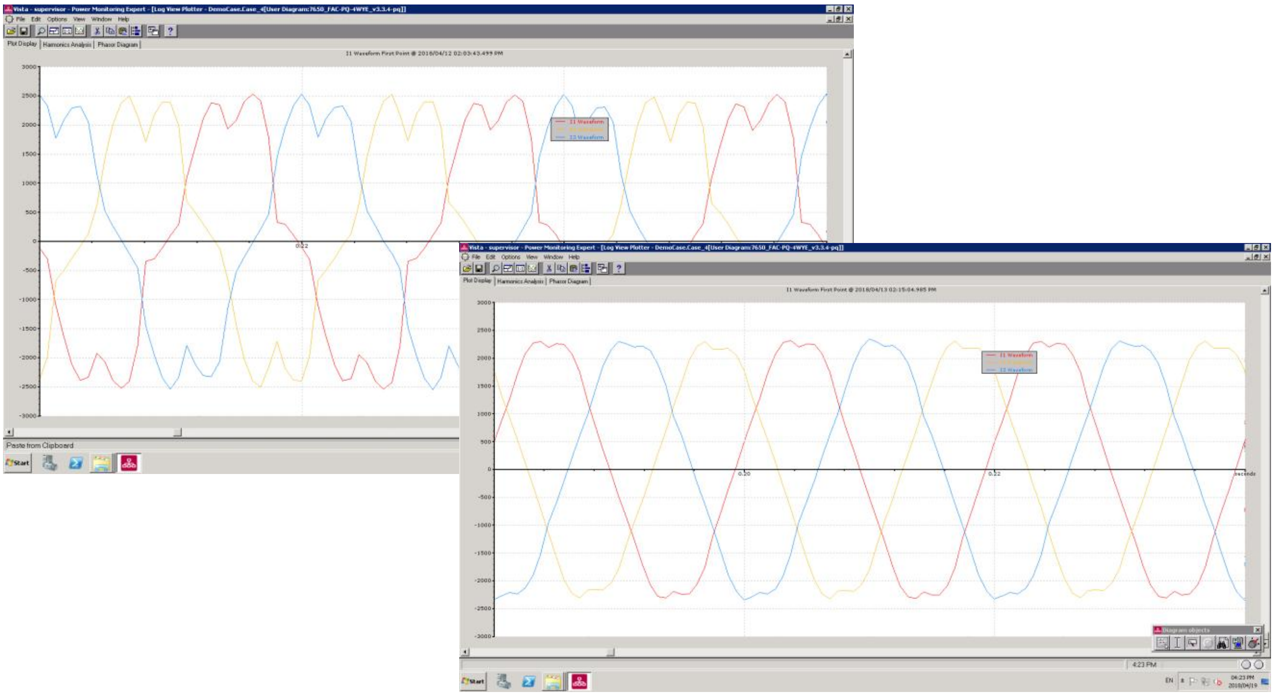

Figure 14: Paintshop Substation Transformer Current Waveforms

6 CONCLUSIONS

The AccuSine PCS+ Active Harmonic Filter Solution was successfully implemented in the Paintshop Substation at Ford Silverton Plant. Results for the other two substations where the other nine Active Filter units are installed, are pending since those units still need to be connected to the Transformers, and be commissioned. This is expected to be done by end of June 2018.

The current harmonic distortion through all six transformers in the Paintshop substation were reduced to very low levels, resulting in a Current Total Harmonic Distortion of 1% on most transformers. The reduced current distortion through the transformers resulted in a significant reduction in the distortion of the transformers' output voltage waveforms. This will benefit other sensitive loads that are connected on the transformers' outputs, and should result in a reduction of nuisance trips and equipment malfunction that were previously experienced. Furthermore, the reduced current harmonics through the transformers will result in a reduction of transformer core losses.

The RMS current through the transformers were significantly reduced, resulting in a reduction of kVA demand on the primary side of the transformers, and a reduction of transformer winding losses.

Due to the reduction of winding and core losses in the transformers, they will operate at lower temperatures, thereby extending their live span.

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