Solving Generator Loading Problems for an Offshore Oil Platform

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INTRODUCTION

Abstract

Offshore oil drilling platforms typically use generators to provide power. Complications can occur when large variable frequency drives (VFD) or DC drives are used for down-hole/product pumping or drilling applications.

This paper discusses the problems (flicker, mechanical resonance, poor power factor, high harmonic current, and reduced production capacity) that occurred on one North Sea oil drilling platform, and shows how an active harmonic filter corrected these problems. Data from power analyzers are presented to define the scope of the problem and the results of the applied solution. An economic evaluation defines the payback from increased production.

Case Study

The operators of an oil platform located in the North Sea, off the coast of the Netherlands, faced a serious problem. By 2002, the platform had been in operation for nearly 20 years. At this time its production was approximately 2000 barrels a day, but actual output was 98% salt water. For this reason, the operators decided to downsize its production. However, they experienced a multitude of operational problems upon initiating these downsizing efforts.

The platform’s original configuration included two 6.25 Megavolt Ampere (MVA) gas-turbine-driven generators operating in parallel, plus an identical backup generator. The loads consisted of:

- 5 down-hole pumps rated at 600 kW each, operating at 6 kV
- 2 export pumps rated 700 kW each, operating at 6 kV
- 1 water injection pump rated 400 kW, operating at 6 kV
- The lighting, living quarters, and office loads typical of oil platforms

This made for a total load of 800 kVA. The export pumps and water injection pump operated directly on the AC line at 6 kV. The lighting, living quarters, and office loads all operated on a single bus rated at 380 VAC. The five down-hole pumps operated on 480 V variable speed drives (VSD), which were installed 13 years prior to increase pump efficiency.

The changes to the platform included removing a generator, three down-hole pump systems, an export pump, and the water injection pump. The remaining export pump was reduced from 700 kW at 6 kV to 300 kW at 380 V. This resulted in approximately 3 MVA of loads operating on one 6.25 MVA generator.

After this conversion, when one of the down-hole pumps were operating, the platform experienced serious problems including:

- Constant flickering of the entire lighting network that adversely affected worker productivity
- Mechanical resonance that caused the entire structure to "shiver"
- Capacity limitations of the down-hole pumps resulting in financial losses

SITE ANALYSIS

The total load on the generator was about 3 MVA, and the generator was rated for 6.25 MVA. Since this was less than 50% of its rating, the operators believed that the generator was more than adequate for the load and the cyclical variations that would occur. However, they did not realize that a 30 Hz voltage oscillation was present.

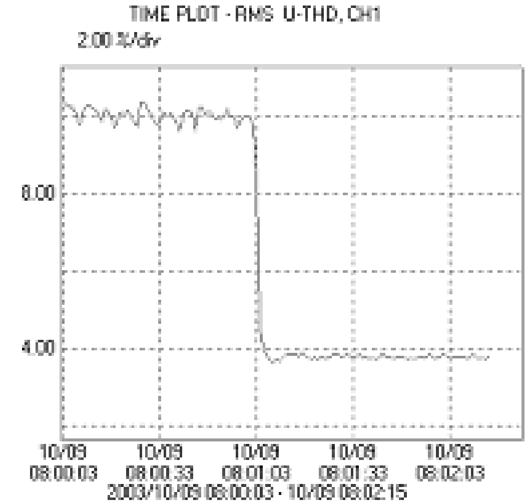
The automatic voltage regulator (AVR) on the generator was the first item inspected. The initial prognosis speculated that the regulator was failing to hold regulation, and thus generator instability occurred. The AVR was replaced with more technologically advanced equipment. However, all efforts to improve the function of the generator via improved AVR function were unsuccessful. The mechanical resonance and flicker continued no matter how the AVR was adjusted.

When this effort proved unsuccessful, a detailed power system analysis was performed. A Fluke 123 scope meter and a Fluke 61 infrared thermometer were used to inspect the equipment. A Hioki 3196 power monitoring system was used to monitor several points in the low voltage network. Also, Hioki 9624 PQA HiVIEW software was used to prepare reports. Harmonic levels were measured against EN 50160 power quality standards.

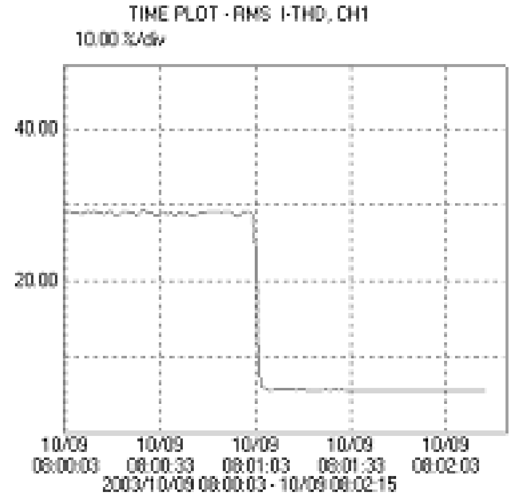
EN 50160 addresses the total harmonic voltage distortion for each harmonic up to the 25th order. The supply voltage should have less than or equal to 8% THD(V). With both down-hole pumps operating, the generator could not meet this requirement.

The input power at each VSD was examined, with the results below:

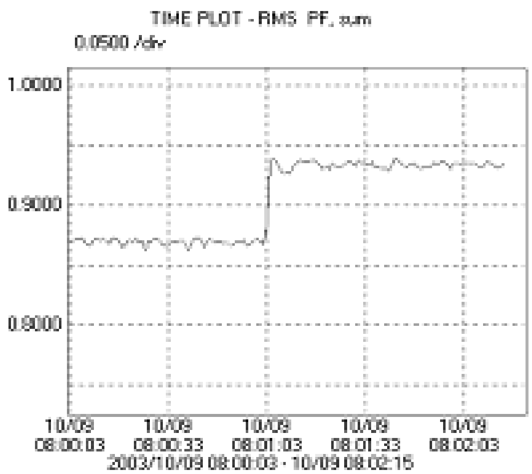
Figure 1: Timeplots and Measurements of K8 VSD



Voltage Distortion



Current Distortion

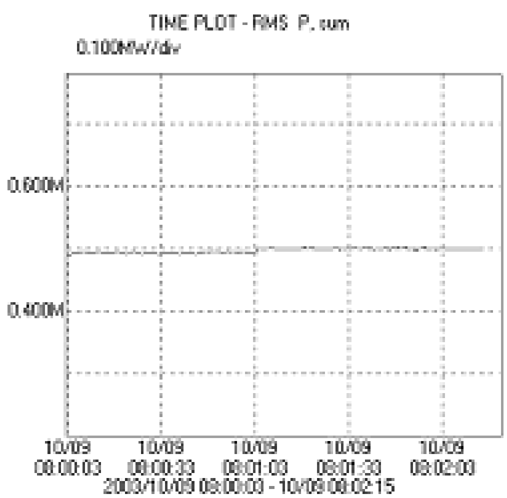


Power Factor

DMM [No.1 10/09 08:02:15.123 Ext (Stop)]

POWER		VOLTAGE		CURRENT	
P1	0.1668MW	U1	481.22 V	I1	0.6456kA
P2	0.1688MW	U2	480.48 V	I2	0.6538kA
P3	0.1674MW	U3	480.62 V	I3	0.6470kA
Psum	0.503MW	THD-U1	3.78 %	THD-I1	5.84 %
S1	0.1793MVA	THD-U2	4.24 %	THD-I2	6.49 %
S2	0.1815MVA	THD-U3	4.50 %	THD-I3	8.96 %
S3	0.1794MVA	Upk+1	0.7248kV	Ipk+1	1.035kA
Ssum	0.540MVA	Upk+2	0.7358kV	Ipk+2	1.179kA
Q1	0.0659Mvar	Upk+3	0.7305kV	Ipk+3	1.163kA
Q2	0.0666Mvar	Upk-1	-0.7320kV	Ipk-1	-1.104kA
Q3	0.0646Mvar	Upk-2	-0.7298kV	Ipk-2	-1.138kA
Qsum	0.197Mvar	Upk-3	-0.7522kV	Ipk-3	-1.090kA
PF1	0.9300	Uave	480.77 V	KF1	1.62
PF2	0.9302	Uunb	0.13 %	KF2	1.82
PF3	0.9330			KF3	2.20
PFsum	0.9311			Iave	0.6488kA
				Iunb	0.88 %

K8 VSD Measurements (AHF active)



Active Power

DMM [No.3 10/09 08:00:02.172 Ext (Start)]

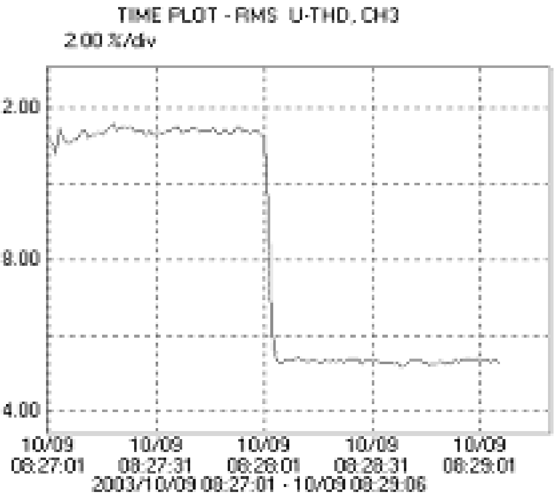
POWER		VOLTAGE		CURRENT	
P1	0.1632MW	U1	481.91 V	I1	0.6784kA
P2	0.1638MW	U2	480.98 V	I2	0.6789kA
P3	0.1627MW	U3	480.99 V	I3	0.6749kA
Psum	0.490MW	THD-U1	10.61 %	THD-I1	29.43 %
S1	0.1886MVA	THD-U2	10.54 %	THD-I2	29.32 %
S2	0.1887MVA	THD-U3	10.88 %	THD-I3	29.64 %
S3	0.1873MVA	Upk+1	0.7323kV	Ipk+1	0.997kA
Ssum	0.565MVA	Upk+2	0.7307kV	Ipk+2	1.014kA
Q1	0.0946Mvar	Upk+3	0.7298kV	Ipk+3	0.999kA
Q2	0.0938Mvar	Upk-1	-0.7355kV	Ipk-1	-0.990kA
Q3	0.0928Mvar	Upk-2	-0.7299kV	Ipk-2	-0.991kA
Qsum	0.281Mvar	Upk-3	-0.7326kV	Ipk-3	-1.016kA
PF1	0.8651	Uave	481.29 V	KF1	5.49
PF2	0.8678	Uunb	0.17 %	KF2	5.52
PF3	0.8687			KF3	5.49
PFsum	0.8672			Iave	0.6774kA
				Iunb	0.51 %

K8 VSD Measurement (without AHF)

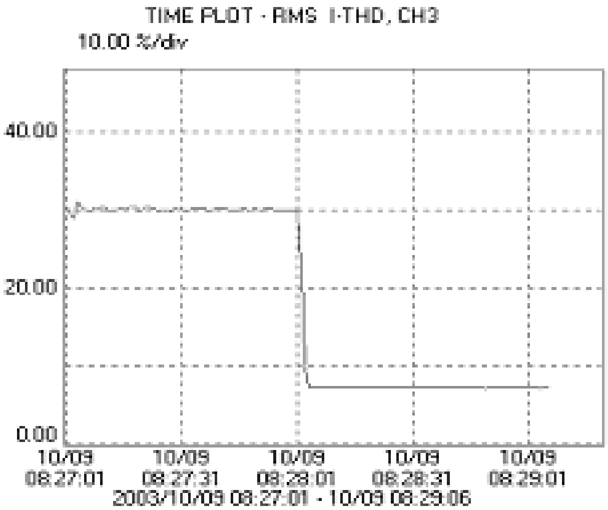
Output frequency is 50 Hz: 08:01 without filter
08:03 harmonic and PF correction active

NOTE: For K8 VSD the THD(V) is about 9% while the THD(I) is about 29%. Additionally, note that the displacement power factor is about 0.85.

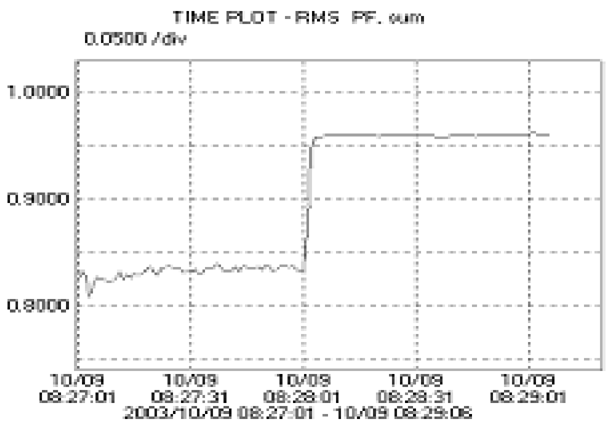
Figure 2: TIMEPLOTS AND MEASUREMENTS OF K4 VSD



Voltage Distortion



Current Distortion

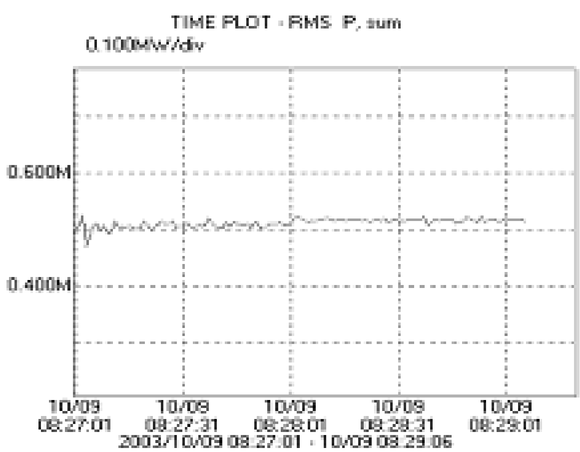


Power Factor

DMM [No.1 10/09 08:29:06.048 Ext (Stop)]

POWER		VOLTAGE		CURRENT	
P1	0.1708MW	U1	482.34 V	I1	0.6383kA
P2	0.1719MW	U2	482.41 V	I2	0.6407kA
P3	0.1692MW	U3	482.43 V	I3	0.6337kA
Psum	0.512MW	THD-U1	4.98 %	THD-I1	6.76 %
S1	0.1777MVA	THD-U2	5.14 %	THD-I2	5.77 %
S2	0.1785MVA	THD-U3	5.24 %	THD-I3	7.31 %
S3	0.1765MVA	Upk+1	0.7681kV	Ipk+1	0.980kA
Ssum	0.533MVA	Upk+2	0.7692kV	Ipk+2	1.035kA
Q1	0.0489Mvar	Upk+3	0.7646kV	Ipk+3	1.008kA
Q2	0.0479Mvar	Upk-1	-0.7525kV	Ipk-1	- 1.011kA
Q3	0.0503Mvar	Upk-2	-0.7585kV	Ipk-2	- 1.012kA
Qsum	0.147Mvar	Upk-3	-0.7328kV	Ipk-3	- 1.003kA
PF1	0.9613	Uave	482.39 V	KF1	2.12
PF2	0.9633	Uunb	0.05 %	KF2	2.07
PF3	0.9586			KF3	2.24
PFsum	0.9611			Iave	0.6376kA
				Iunb	0.53 %

K8 VSD Measurements (AHF active)



Active Power

DMM [No.15 10/09 08:27:00.110 Ext (Start)]

POWER		VOLTAGE		CURRENT		
P1	0.1619MW	U1	481.59 V	I1	0.7146kA	
P2	0.1630MW	U2	481.49 V	I2	0.7115kA	
P3	0.1618MW	U3	481.36 V	I3	0.7150kA	
Psum	0.487MW	THD-U1	11.40 %	THD-I1	30.88 %	
S1	0.1986MVA	THD-U2	11.36 %	THD-I2	30.78 %	
S2	0.1970MVA	THD-U3	11.39 %	THD-I3	30.72 %	
S3	0.1988MVA	Upk+1	0.7462kV	Ipk+1	1.193kA	
Ssum	0.595MVA	Upk+2	0.7437kV	Ipk+2	1.179kA	
Q1	0.1149Mvar	Upk+3	0.7419kV	Ipk+3	1.185kA	
Q2	0.1122Mvar	Upk-1	-0.7429kV	Ipk-1	- 1.200kA	
Q3	0.1154Mvar	Upk-2	-0.7414kV	Ipk-2	- 1.179kA	
Qsum	0.343Mvar	Upk-3	-0.7406kV	Ipk-3	- 1.191kA	
PF1	0.8155	Uave	481.48 V	KF1	6.23	
PF2	0.8236	Uunb	0.08 %	KF2	6.29	
PF3	0.8142			KF3	6.25	
PFsum	0.8178			Iave	0.7137kA	
				Iunb	0.57 %	

K8 VSD Measurement (without AHF)

Output frequency is 50 Hz: 08:27 without filter
08:28 harmonic and PF correction active

NOTE: The timeplots for K4 VSD show similar results of about 11% THD(V) and 30% THD(I) with DPF of about 0.84. The results clearly indicate high level harmonic contributions to the 6 kV bus.

GENERATOR CONSIDERATIONS

Generator manufacturers advised that automatic voltage regulators (AVR) are capable of maintaining regulation as long as the voltage distortion is below 10–15% THD(V) and displacement power factor (DPF) is not less than 0.75 at medium load conditions (0.80 DPF at full load). AVR struggle to maintain line voltage when either or both parameters are exceeded, resulting in line voltage oscillation. As line voltage varies the loads will respond by varying the current drawn in order to maintain the KW required for operation of the load. This causes the AVR to struggle more. The voltage/current oscillations cause mechanical resonance in the rotating load. When the mechanical resonance coincides with the frequency of the mechanical structure, resonance of the structure occurs.

To stop the voltage oscillation, THD(V) must be reduced, DPF raised, or both. Depending upon load circumstances changing, either of the parameters will likely stop the voltage oscillations and thus stop the mechanical resonance and the flicker.

The site operators found that starting one of the 6 kV motors, or slowing the VSD by one to two hertz stopped flicker and resonance of the structure immediately.

Starting an AC motor that operates directly on the AC lines affects the harmonic levels and the DPF of the system. The addition of the motor impedance in parallel to the generator impedance effectively lowers the total system impedance and thus lowers the THD(V) without varying the VFD load settings. Additionally, the introduction of a linear load effectively lowers the THD(I) due to the increase in linear current without any changes in the harmonic current.

Starting an AC motor may raise the DPF after the initial start cycle if the load on this motor has a higher DPF than the pre-existing system. The net effect would be to raise overall DPF. Whether this is sufficient to allow the AVR to regulate properly must be evaluated. In this case the DPF was actually high enough that harmful effects due to poor DPF was not the issue.

Another way of reducing THD(V) is to reduce the load of the VSD. This can be done on centrifugal loads by reducing the speed. The amount of harmonic current required decreases as the load is reduced. Thus the generator regulator sees decreased THD(V) and stops oscillating the line voltage because the regulator now regulates parameters within tolerances.

THE SOLUTION

The best solution would correct DPF and lower the harmonic content. The purpose was to lower the total loading of the generator so the AVR could perform under design conditions. Various methods of passive filtering were reviewed.

Passive filters

One possible solution was using passive filters, tuned to remove the 5th harmonic. This solution would lower the overall THD(I) by eliminating about 80% of the 5th harmonic current. Additionally, the DPF would be improved by the reactive current injection at base frequency by the passive filter.

A 5th harmonic filter is primarily a displacement power factor correction device injecting leading kVAr. The harmonic correction component is actually rated at about 20% of the kVAr rating of the filter. To obtain the amount of 5th harmonic current correction necessary (approximately 114 amperes per VFD), the size of the passive filter kVAr rating would be excessive at approximately 475 kVAr per VFD. To attain unity DPF, 315 kVAr of correction would be required.

The selected unit would cause leading DPF for each VFD/pump system at its current loading conditions. When the speed of variable voltage inverters increases (as desired for this application) less KVAR is required to correct for DPF. So the total DPF for each pump would trend toward leading because the DPF of SCR converters are better at higher load levels. The result of applying 5th harmonic tuned filters would cause the DPF at the generator to trend toward leading and thus the AVR would lose regulation and stop the generator.

Active harmonic filters

Next, active harmonic filters (AHF) were considered, for their ability to inject precise load requirements for both reactive (DPF correction) and harmonic current. AHF monitor the AC line current to determine the precise amount of reactive and harmonic current the loads need to operate. The net result is to off load the source from providing both reactive and harmonic current. This precisely met the requirements of this application.

As an additional impetus, AHF are standard products that could be repositioned anywhere else when this platform was decommissioned.

Harmonic measurements of K8 VSD showed that 268 amperes (rms) of harmonics and 180 amperes of reactive current were present. Correction of DPF to 0.95 was desired to insure proper operation of the generator. To achieve 0.95 DPF, 73 amperes of reactive current was required. Since the output of an AHF is the rms sum of these currents, the AHF needed to inject 278 amperes of correction.

Harmonic measurements of K4 VSD revealed 248 amperes of harmonic current and 222 amperes of reactive current. To achieve 0.95 DPF, 123 amperes of reactive current is required. The rms sum of 248 amperes of harmonic and 123 amperes of reactive current is 277 amperes.

An AHF rated at 300 amperes was selected and provided for each VSD. Additionally, 3% input line reactors were installed at the input of the VSD converter. The purpose of the line reactors was to protect the snubbers (resistor-capacitor circuits) on each thyristor from the high frequency output of the AHF and to limit the harmonic current drawn by the VSD when a very low impedance AHF is operating. A very low impedance source for harmonic current would result in much higher levels of harmonic current flowing to the loads. This harmonic current may exceed the AHF capability and thus reduced the desired results considerably.

THE RESULTS

Referring to the timeplot data for K8 VSD it can be seen that the THD(I) was reduced to 7% or less from about 29%. This resulted in a THD(V) drop from about 9% to less than 4%. Also, note that the DPF was corrected from approximately 0.86 to 0.94.

Looking at the timeplot data for K4 VSD shows a reduced THD(I) level of under 7% from about 32% and a reduced THD(V) of about 5% from the 11% level. Additionally note that the DPF is improved to about 0.96 from about 0.85.

The results were outstanding. No more flicker. No more mechanical resonance. The operators are quite satisfied with the results

Equally important, these improvements permitted the operators to increase the speed of each VSD about 2 hertz. This may not sound like much but the income generated by this increase was approximately $2000 per day for the facility. The entire job of installing two AHF and two 3% input line reactors was about $150,000. The operators were quite happy to see the 75-80 day payback especially since they expect to shut down this rig in about two years.

CONCLUSION

Offshore platforms have unique electrical systems supplied for the most part by on board generator systems. The loads are mostly AC or DC motor drives that load the generators with harmonics. Some of these loads employ thyristor rectifiers that also contribute reactive current needs for the generator. Either may be detrimental to the operation of the generator.

Solutions employing passive filters are difficult to apply. They often cause leading DPF that asynchronous generators cannot tolerate while providing minimal harmonic reductions. They are usually large physically and therefore difficult to install on space limited platforms. This passive solution is also unique to the application for which designed.

Employing multi-pulse rectifiers is possible and quite beneficial for reducing harmonics. Multi-pulse rectifiers do not adjust DPF. The physical space required is large. Additionally, the drives become custom designs with two or three rectifiers in the converter. The transformer adds heat losses and inefficiencies into the equation as well. In this case a twelve-pulse modification was explored. Modifying the existing products in the field was impractical.

Active harmonic filters offer many advantages over the above two methods for improving harmonics and DPF. AHF can be applied to any nonlinear load for harmonic reductions. AHF can be employed to correct for either leading or lagging DPF. AHF inject only the required current for either harmonics or DPF. AHF can be programmed to correct DPF to unity with no detrimental effects on the electrical system. AHF are installed parallel to the loads thus reducing criticality of the filter in the event of AHF downtime. The loads continue to function. In general, the space required for AHF installed on a system basis is smaller than any other solution. Finally, AHF can be relocated at will.

AHF resolved the harmonic and DPF issues to permit the generator to function properly. Flicker was resolved. Harmonics were greatly reduced and DPF was improved as well. Mechanical resonance of the generator and the platform structure no longer occurs. As the operators of this platform have learned, AHF provide the opportunity to obtain planned production with very fast payback. AHF are the optimum solution for this application.

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