Design considerations for filters on interconnected offshore power systems

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Abstract: Due to a revised drilling program it became desirable to drill on oil platforms linked by a long sub-sea cable. The distortion levels caused by this drilling were predicted to be too high under certain system configurations. This paper describes the problems which must be considered when designing filters for such an offshore power system. A computer model of the system, validated using site measured data, was used to investigate the possibility of connecting an additional filter to the system. This system has a number of resonance conditions which must be avoided due to the harmonics produced by the 6 pulse drives used on both platforms.

Keywords: offshore power systems, filters, time-domain analysis, frequency-domain analysis.

Background

The Alwyn North area is situated in the UK sector of the northern North Sea 400 km north-east of Aberdeen. The Alwyn North field was developed in 1986 and its satellite Dunbar brought on stream in 1994. The Dunbar platform is 22 km to the South West of Alwyn North and is connected to Alwyn by two 22 km, 21 kV sub-sea cables. The cable capacitance on isolated platforms is the cause of ringing on the voltage waveform [1]. However the presence of such long cables introduces a much larger capacitance to the system and can reduce the system natural frequency down to as low as 220 Hz [2]. For different system configurations of generators, cables and filters these resonances move and can be excited by the harmonics from the 6 pulse thyristor drives used by the drilling operations. The resonance and other problems associated with the connection of an additional filter to the Alwyn 600V drilling bus is the subject of this paper.

Electrical system configuration.

The electrical system as it is presently configured is as shown in Figure 1. The generation, all on the North Alwyn end of the system, consists of three 20MW Avon gas turbines and five 2MW Crepelle diesel generators. The present harmonic problems are most acute when drilling with the diesel generators, due to the higher impedance of these machines lowering the system resonant frequency. Until relatively recently all drilling has been carried out on the Dunbar end of the cable. However it became desirable to extend the drilling program at the Alwyn end of the system whilst continuing drilling on the Dunbar platform. This represents additional harmonic sources on the power system and there was concern as

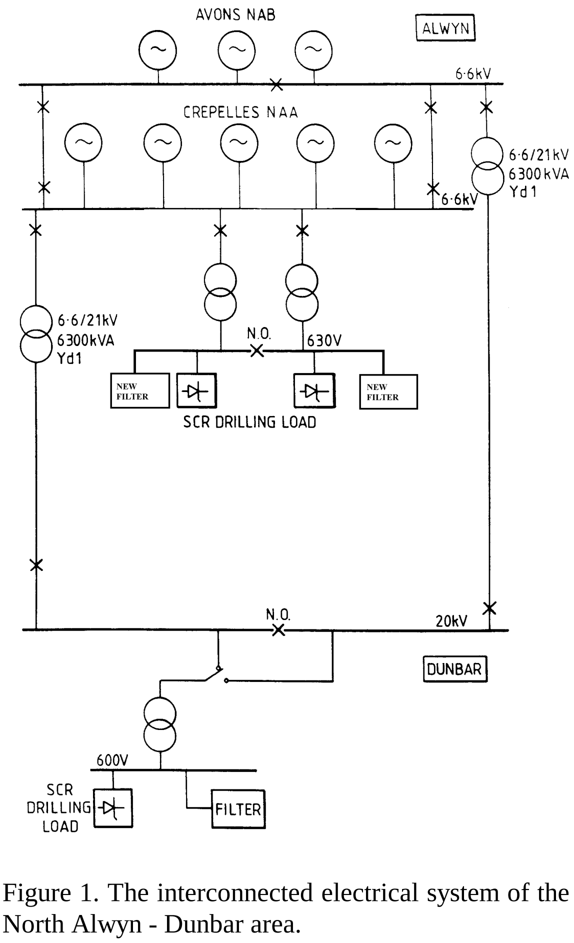

Figure 1. The interconnected electrical system of the North Alwyn - Dunbar area.

to potential harmonic and distortion problems. In order to predict such problems a model of the system was developed using the SABER simulator. This was done using system component parameters and validated by taking measurements on the actual system.

Site Measurements

A comprehensive series of measurements were taken simultaneously at both ends of the power system under various different system configurations. The resulting correlation achieved between the measured and simulated waveshapes allowed a reasonable degree of confidence in the computer model. An example of the measured and simulated waveshapes is shown in Appendix 1, which shows the measurements at either ends of the subsea cable for drilling on Dunbar without the filter.

A frequency domain model was set up as shown in Figure 2. Due to the large numbers of combinations of generation, cable and non-linear load (192) the frequency domain model was used to identify potential system resonance conditions, which were them simulated in the time domain to predict distortion levels. From this, certain systems configurations were regarded as being unacceptable and have since been avoided in system operation.

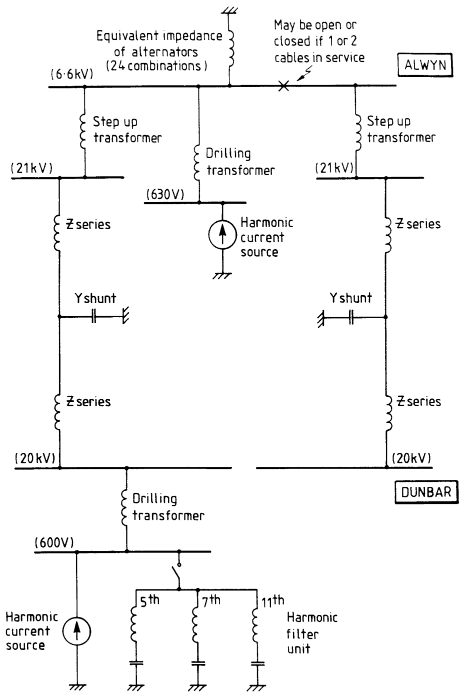

Figure 2. Frequency domain model of electrical network.

Filter design

In order to ensure that the total harmonic voltage distortion levels on the system did not exceed 10 %, generally regarded as acceptable on offshore installations, the possibility of installing a filter on the 600V Alwyn drilling busbar was investigated. This would involve 2 new filters connected to each of the drilling busbars on Alwyn to try and reduce the number of unacceptable system configurations and alleviate the reliance on the Dunbar filter for drilling on Alwyn. The presence of the Dunbar filter reduces the distortion for drilling at Alwyn. It does not act as a filter for the Alwyn harmonics, which the cables have a tendency to do, but alters the frequency response of the system as shown by comparing Figures 3 and 4. Any new filter however must not introduce new system resonances. The present Dunbar filter has tuned arms at 5th, 7th and 12.5th harmonic. The new filter was based on the existing Dunbar filter however required an additional arm due to the higher system fault level on Alwyn. The arms are tuned at the characteristic harmonics of the 6 pulse drive, 5th, 7th, 11th and 13th harmonics. The VAr rating of the proposed filter was varied over the range 100 kVAr to 800 kVAr and the frequency domain response examined for resonance conditions.

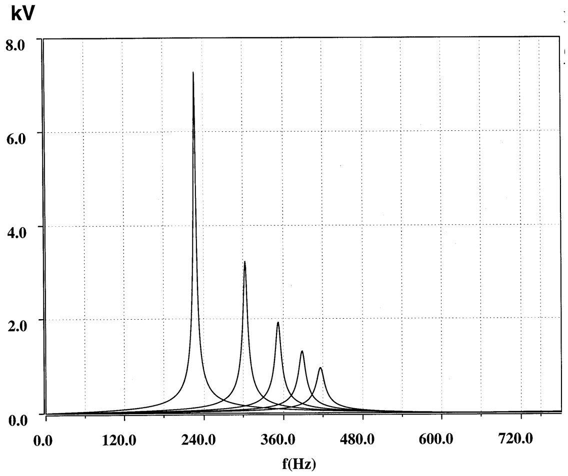

Figure 3. Frequency response, 1-5 Crepelles, no Dunbar filter, 1 cable.

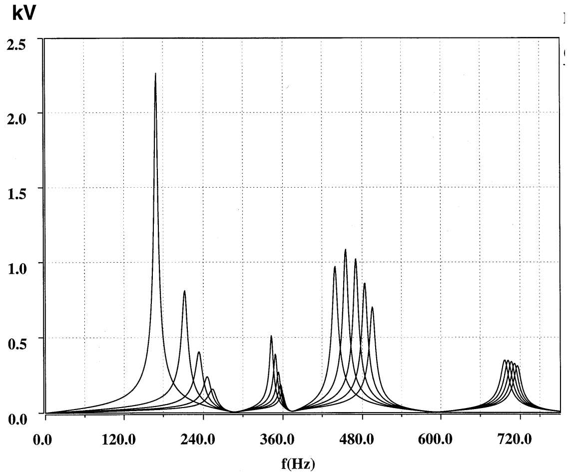

Figure 4. Frequency response, 1-5 Crepelles, with Dunbar filter, 1 cable.

Frequency Response of proposed new filter

The frequency domain model was based on the parameters obtained from the validated time domain model. However because of the unknown nature of the cable resistance with frequency variation the damping in the cable was omitted from the frequency domain model. This gives rise to the very high gains observed. The frequency domain model serves to indicate the relative position and comparative magnitudes of system resonances and their behaviour with changing system configuration, not the absolute magnitudes of the gains.

The frequency response of the system without the Alwyn Filter was shown in Figures 3 and 4. This can be compared to the frequency response of the system with the connection of the high VAr (800 kVAr) filter, Figure 5, and low VAr (100kVAr) filter, Figure 6. The resonance conditions for this case can be seen at 3rd harmonic for generation with 2 Crepelles and no Dunbar filter. As the filter VAr rating varies resonances appear at all low order integer harmonic frequencies above 2nd harmonic. Although not all such harmonics are produced by the 6 pulse drives there are other harmonic sources on offshore installations such as transformers, light fittings, UPS systems and potential non ideal operation of the 6 pulse bridges. These harmonic sources may excite other integer harmonic resonances.

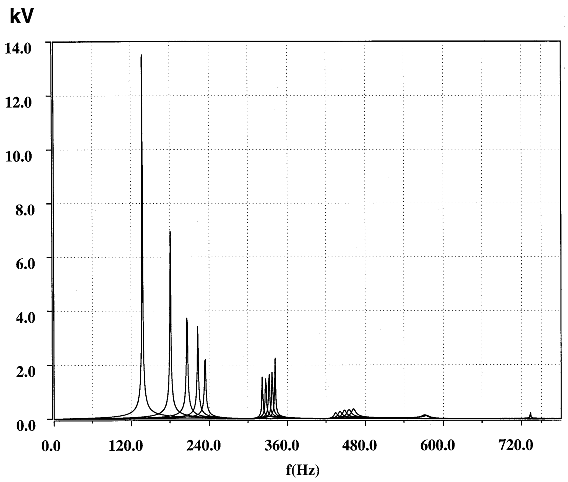

Figure 5. Frequency response, 1-5 Crepelles, no Dunbar filter, 1 cable, 800kVAr Alwyn filter.

With the objective being that as few operational constraints were imposed on the system as possible, the filters at either end of the VAr range looked the most promising since the intermediate resonances were associated with the most likely system generation configurations.

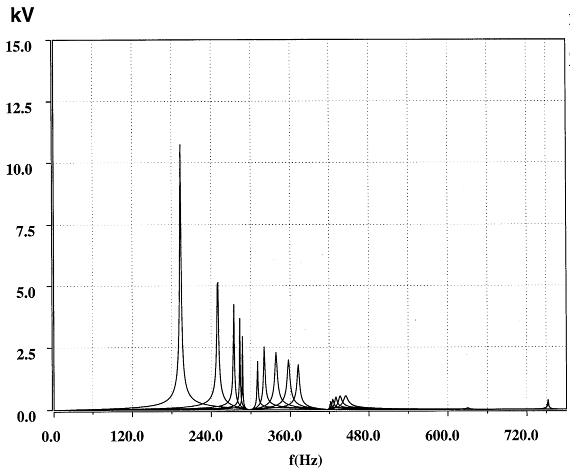

Figure 6. Frequency response, 1-5 Crepelles, no Dunbar filter, 1 cable, 100kVAr Alwyn filter.

A summary of the resonance conditions associated with intermediate filter VAr ratings is shown in Table 1.

Filter VAr	1 cable	1 cable D. filt.	2 cables	2 cables D. filt.
800k	-	3rd	4th	4th
660k	5th,7th	-	-	-
500k	4th	-	7th	3rd
160k	3rd	-	7th	3rd
100k	7th	4th	7th	3rd,4th

Table 1. Resonances caused by various sizes of Alwyn filter for Dunbar drilling.

Power factor considerations

The addition of two 800kVAr filters on the Alwyn platform will supply additional reactive power to the system along with the 2 cables and the Dunbar filter. The VAr ratings of the individual components are shown in Table 2.

Source	kVAr
Alwyn filter a	800 or 100
Alwyn filter b	800 or 100
Cable 1	800
Cable 2	800
Dunbar filter	510

Table 2. VAr ratings

One of the potential problems of such a supply of VArs is that when the system is lightly loaded the generators may run with a leading power factor. The generators would run at a larger load angle potentially reducing the steady state and transient stability of the system [3]. This problem would be most acute during run up of the system where there would be no large h.v. motors running. Frequent switching of the new filters and monitoring of system power factor then becomes necessary, which places an additional cost on the system operation. It was also noted that the fundamental component of current drawn by each filter was in the region of 770A, which pushed the kVA ratings of the drilling transformers to their limit.

Low VAr filter problems

From the above discussion the low VAr filter would appear to be a more viable solution. However the physical size of the inductors for the low VAr filter were found to be prohibitively large. The inductors required for the 100kVAr filter were in the region of 5 tons and occupy a volume of $10m^3$ which was physically unavailable on the platform.
An additional problem with this type of filter is that under certain system configurations anti resonances are created very close to the tuned frequency of the filter arm. This is the case shown in figure 7 where there is an anti resonance very close to 7th harmonic. Deviation from the nominal 60 Hz system frequency could bring the system into perfect tune at an integer harmonic. Clearly an undesirable situation.

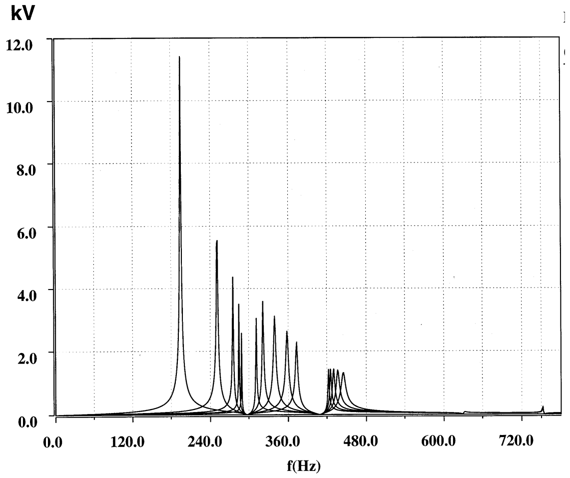

Figure 7. Frequency response, 1-5 Crepelles, no Dunbar filter, 1 cable, 100kVAr Alwyn filter. Excitation from Dunbar drilling busbar.

Conclusions

Waveshapes have been presented that show good correlation between simulation and measured data. Frequency domain plots have been shown to highlight the existing harmonic problems on the Alwyn area. The frequency domain model was then used to look at various potential filters to try and reduce the distortion under heavy drilling conditions. The distortion levels can be reduced but other problems are introduced such as resonances under different system configurations, power factor problems and filter physical size problems. The solution to this particular harmonic problem from both an economic and engineering perspective was to accept restrictions on system configuration under heavy drilling conditions.
These restrictions were put into place in February 1996 and there have been no electrical shut downs attributable to power system harmonics since then.

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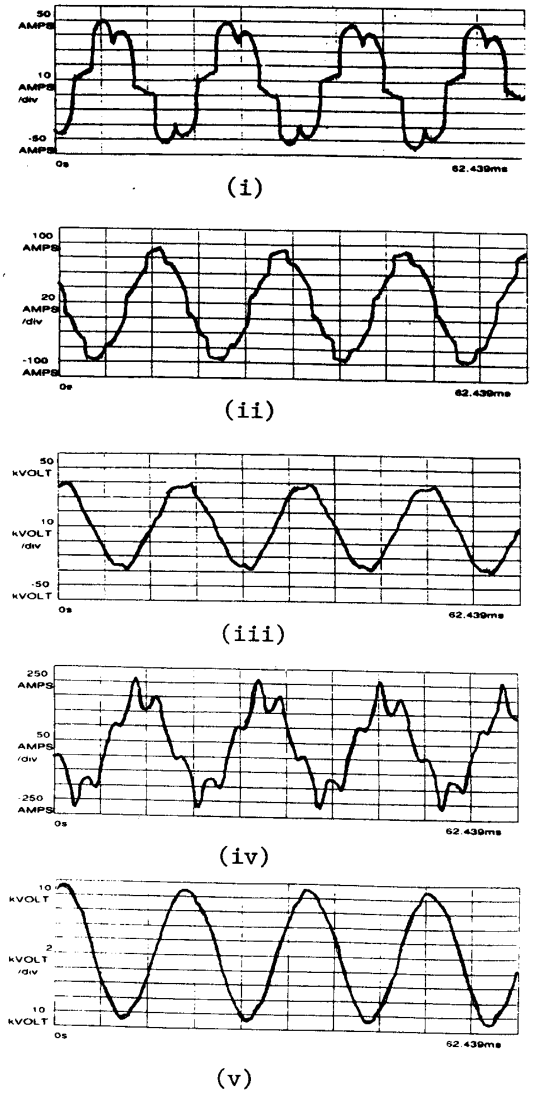
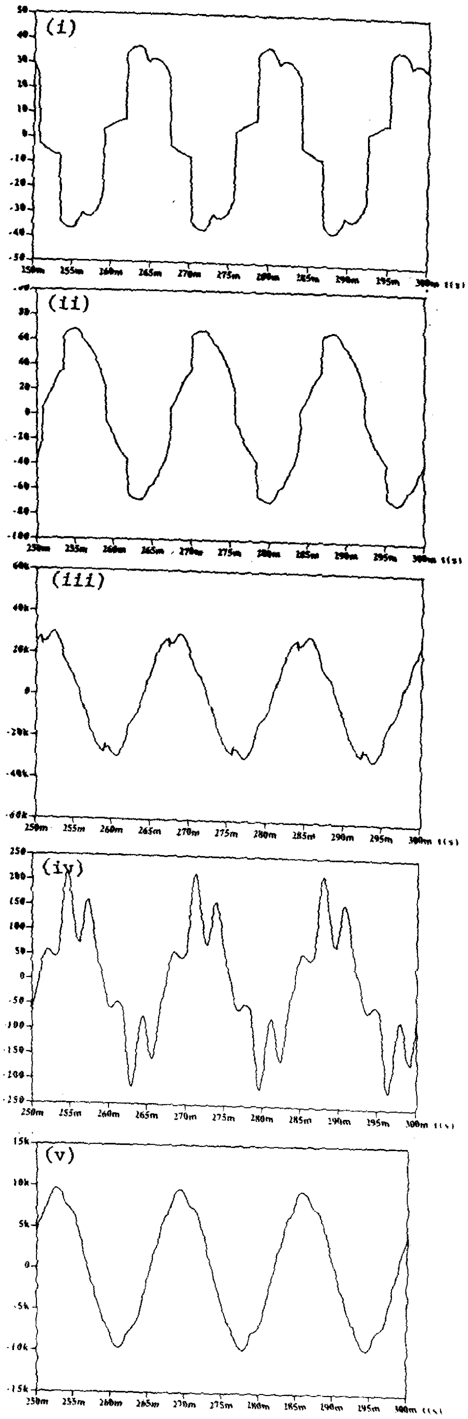
Appendix 1



Measured waveshapes. Dunbar filter not in operation.
(i) Dunbar drilling feeder current,
(ii) Cable current Dunbar end,
(iii) Dunbar 20 kV busbar voltage,
(iv) Cable current Alwyn end,
(v) Alwyn 6.6 kV busbar voltage.



Simulated waveshapes for measured case shown previously.
(i) Dunbar drilling feeder current,
(ii) Cable current Dunbar end,
(iii) Dunbar 20 kV busbar voltage,
(iv) Cable current Alwyn end,
(v) Alwyn 6.6 kV busbar voltage.