SLAC SYNCHRONOUS CONDENSER

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Abstract

A synchronous condenser is a synchronous machine that generates reactive power that leads real power by 90 degrees in phase. The leading reactive power generated by the condenser offsets or cancels the normal lagging reactive power consumed by inductive and nonlinear loads at the accelerator complex. The quality of SLAC's utility power is improved with the addition of the condenser. The inertia of the condenser's 35,000 pound rotor damps and smoothes voltage excursions on two 12 kilovolt master substation buses, improving voltage regulation site wide. The condenser absorbs high frequency transients and noise in effect "scrubbing" the electric system power at its primary distribution source. In addition, the condenser produces a substantial savings in power costs. Federal and investor owned utilities that supply electric power to SLAC levy a monthly penalty for lagging reactive power delivered to the site. For the 1993 fiscal year this totaled over $285,000 in added costs for the year. By generating leading reactive power on site, thereby reducing total lagging reactive power requirements, a substantial savings in electric utility bills is achieved. Actual savings of $150,000 or more a year are possible depending on experimental operations.

I. INTRODUCTION

Prior to May 1989, monthly electrical power billing at the Stanford Linear Accelerator Center (SLAC) included charges for energy and peak demand but no charges for power factor. The power factor in May 1989 was 0.79 and a penalty of $1,850 was assessed. It was clear at that time that the penalty would go much higher. A project was initiated to correct the site's power factor using fixed nonswitching capacitors. The objective was to correct the SLAC base load power factor. By March 1990, the time the fixed capacitor project was approved, installed, and operational, the monthly power factor penalty had grown to $31,600. The addition of the fixed capacitors immediately reduced the monthly penalty to a monthly average of $13,800. With the capacitors operational, a second and more aggressive stage of power factor correction was initiated to correct the variable component of site loading above base load. This paper describes the SLAC synchronous condenser, a project approved in July of 1992, and made operational in June of 1994.

II. PROJECT OVERVIEW

Circuit analysis of the SLAC utility system from the previous capacitor project indicated that the base load power factor capacitor would be resonant at close to the eleventh harmonic of the fundamental of 60 hertz. Measurements following actual operation of the capacitor confirmed the previous circuit analysis. This analysis was again used for the synchronous condenser. The site base load was taken as 26 megawatts with the site peak load taken as twice that at 52 megawatts. To be cost effective the variable portion of the new power factor correction needed to achieve at least 0.90 power factor at 52 megawatts. A leading reactive source of 10 megavolt-amperes was necessary.

A rotating machine was selected as opposed to a system of thyristor-switched capacitors so as to reduce and attenuate switching transients and to also improve voltage regulation. Site load variations are comparatively slow as are existing 12 kilovolt voltage regulator tap changes. The 10 megavar rotating machine is a good match to the existing SLAC utility power system which has response times to slow voltage changes in the 10 second range. Fast voltage excursions on the 12 kilovolt substation bus see some degree of attenuation in the iron and windings of the machine but are otherwise ignored by the slower condenser power factor control system.

Existing master substation 12 kilovolt bussing and circuit breakers, as well as physical site building constraints, require that the the machine be located near the SLAC master substation control building. To reduce costs, existing circuit breakers and a relocated portable building are used for the condenser and auxiliary systems. The 510 square foot portable building is designed to be lowered over the condenser to gain a substantial savings over fixed building costs. The condenser's 12 kilovolt circuit breaker and its potential transformers were located in a small new 150-square-foot building adjacent to the portable building.

The condenser is located in a region classified as a seismic zone 4 near the San Andreas fault. The foundation design for the 84,000 pound machine requires a three-foot thick concrete and steel base over undisturbed sandstone. The initial base level is to within 0.024 inches, end to end, along the rotor shaft. Three axis vibration sensors on the machine are designed to shut down the condenser during seismic events that exceed a 0.00375 inch excursion along any axis. Typical operating vibration is 0.0008 inches peak to peak.

III. TECHNICAL

The synchronous condenser is a 10 megavar, 12.47 kilovolt, 3 phase, 60 hertz, 900 rpm, wye connected machine with a solid state exciter mounted on the rotor shaft. The condenser is started with a 200 horsepower, 480 volt, 3 phase, 60 hertz, 1200 rpm induction motor driven by a pulse width modulated variable speed drive. The main rotor shaft is horizontal and is supported at each end by journal bearings with the exciter and starting motor on opposite ends directly coupled to the main shaft. A low pressure, low volume oil lubrication system pumps oil to the bearings. A 1200 psi high pressure oil system lifts the 35,000 pound main shaft to start the condenser from rest. The condenser is microprocessor-controlled for all functions.

Starting and synchronizing are accomplished without operator intervention. As the machine approaches synchronization, the starting drive motor overspeeds the condenser and then allows it to drift down through synchronous speed. Should the speed change, slip, be excessive, synchronizing is blocked and the rotor is accelerated again but with less energy added. The process repeats until slip is low enough to insure lock-in without pullout. The exact moment of pull-in is computed and considers the breaker contact travel time. The condenser motors when first energized. Only enough field current is present to insure pull-in. As a consequence, starting the condenser produces no discernible electrical system disturbances at the site. The total time for run-up and synchronizing is just over 6 minutes. A contolled shutdown requires 50 minutes to achieve a full stop and 15 minutes if the pulse width modulated starting drive is used for brakeing.

SLAC 12.47 kilovolt utility busses, numbers one and two, provide reference phase angle information to control the condenser. A desired power factor operating point of 0.90 is preset for a typical site load of 52 megawatts. A comparitor circuit in the condenser power factor controller measures actual and preset power factors then produces a dc signal level that controls the condenser field and voltage regulators. The time constant for this control is a factor of 10 faster than the site 12 kilovolt distribution system voltage regulator so as to isolate site voltage control from site power factor control.

IV. SITE POWER QUALITY

Because revenue operations have taken priority over operations analysis, only a small number of samples to compare and evaluate utility waveform improvements have been taken. However, in all cases, the quality of the utility power has been better with the condenser operating than without it operating. Measurement to measurement differences have been attributed to site loading changes that alter the harmonic content of the waveform. The greatest changes are in the current waveforms which vary widely with various combinations of rectifier loads at the site. Table 1 describes a sample of condenser effects on the site utility waveforms.

	Without Condenser	With Condenser
% THD Voltage Neutral to Ground	40.7	39.6
% THD Current A Phase	44.0	1.0
% THD Voltage A Phase to Neutral	1.4	1.3

Table 1: Percent total harmonic distortion compared, with and without the synchronous condenser operating.

V. AVOIDED POWER COSTS

Operation of the synchronous condenser reduces power factor penalties by generating expensive kilovars from relatively inexpensive kilowatts. A typical kilowatt at SLAC is purchased for $0.03 per kilowatt whereas depending on the power factor a kilovar can cost as much as $1.38 per kilovar per kilowatt demand. The condenser has no flywheel or end shaft load so its primary load is windage. The machine moves 30,000 cubic feet of air a minute for cooling with a power consumption of only 150 kilowatts. It generates 10,000 kilovars at full output and will go to 11,500 kilovars for peaking on margins.

The Western Area Power Administration Rate Order 59 [1], distributes power factor penalties as indicated in Table 2. This table also notes the SLAC power factor level before and after the synchronous condenser project.

WAPA–59 Power Factor	$ Rate kvar/kw	SLAC pf Level
0.95	$0.00	
0.94	$0.09	
0.93	$0.17	
0.92	$0.24	
0.91	$0.32	
0.90	$0.39	Jan ’95
0.89	$0.46	
0.88	$0.53	
0.87	$0.60	
0.86	$0.66	
0.85	$0.73	
0.84	$0.79	
0.83	$0.86	Jun ’92
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0.75 & below	$1.38	

Table 2: WAPA rate order 59 [1], with SLAC power factors for Jan ‘95 and Jun ‘92.

During the months of November and December 1994, and January 1995, SLAC’s average monthly power factor penalty, at 0.90 power factor and 47.4 megawatts, was $18,486 per month with the synchronous condenser in full revenue operation. Site power factor in June, July, and August of 1992 was between 0.83 and 0.84. The 0.83 power factor of 1992 at today’s WAPA rates would generate a power factor penalty of $40,764 for 47.4 megawatts. Actual average monthly savings at SLAC in early 1995 have been just over $20,000 a month during SLC operations with a polarized beam..

The total synchronous condenser project cost is $686,971. For 10 months of full laboratory operation each year, the simple payback is 3.43 years. Maintenance costs are minor, being primarily for spectral analysis of oil and for vibration samples. Since the main shaft spins unloaded, the bearings will have long lifetimes with only infrequent maintenance.

VI. UPGRADES

With the operation of PEP-II loads beginning sometime in 1997, peak electrical demand at SLAC will exceed 70 megawatts. Additional power factor correction will be needed at that time. Based on experience thus far, either fixed or variable power factor correction can be employed.

VII. ACKNOWLEDGMENTS

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VIII. REFERENCES

[1] Western Area Power Administration, *Central Valley Project Notice of Rate Order* No. WAPA-59 (July 2, 1993). Federal Register, vol. 58, no. 126, pp. 35948–35949.