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Response of co-generation plant to power swings of AGS Booster

M. Meth

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Collider Accelerator Department

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ACCELERATOR DEVELOPMENT DEPARTMENT

Brookhaven National Laboratory

Upton, N.Y. 11973

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INTRODUCTION

It has been proposed that a 20 megawatt co-generation plant be installed on site of the Brookhaven National Laboratory. Concern has been raised that the pulsating power for the AGS Booster would adversely affect the alternator of the co-generation plant. The problem has been studied and the conclusion reached that the Booster power swing would be predominately reflected in the LILCO power grid. The co-generation plant would operate at an almost constant power level. The basic reason for this response is in the wide differences in the impedance levels of the LILCO grid and the co-generation plant.

In terms of an equivalent electrical network the LILCO grid is a constant voltage source and the co-generation plant is a constant current source. When paralleled and subject to a variable load, the constant current source will deliver a constant power to the port and the constant voltage source, a variable load, see Fig. 1.

SYSTEM DESCRIPTION

Brookhaven National Laboratory is energized by two 69KV feeders from the LILCO substation at the southeast corners of the Lab site. This substation is named Brookhaven Substation. The impedance level of the BNL port on the LILCO grid is given in terms of its short circuit capacity (SCC). The value of the SCC at the LILCO grid and the two substations on site is given below.

LOCATION	SCC
Lilco Grid	2310MVA
Temple Pl.	1950MVA
Fifth Ave.	1810MVA

The proposed co-generation station is a 20MW plant. Assume that the alternator develops 13.8KV, a 5:1 step-up transformer would be required to couple into the 69KV line. Transformers in the range of 20MVA normally have reactances in the range of 6% on a pu basis. Specifying a high leakage transformer, the reactances is initially specified as 9% and is connected to the grid at the BNL Fifth Ave. Substation. The Booster is energized by a dedicated 69KV line from the LILCO Substation. The system is diagrammatically indicated by the one-line drawing of Figure 2.

An equivalent network of this electrical system is given in Fig. 3. The LILCO grid is modeled by the generator $V_1 \angle \delta_1$ and a reactance of 2.05 ohms; the co-generation plant by $V_2 \angle \delta_2$ and a reactance of 21.38 ohms. The distribution system on site is modeled by two reactances with a total value of 0.6 ohms. Viewed at the LILCO port the SCC of the co-generation plant is 216MVA.

The voltage and torque angles of the generators adjust to control the power flow. If the power flow from LILCO is P_1, the power flow from the co-generator is P_2, and the distribution voltage $\bar{V}_L$ is $V\underline{|\theta}$,, then the power flow is given by

$$P_1 = \frac{V_1 V}{2.05} \sin(\delta_1 - \theta)$$

$$p_2 = \frac{V_2 V}{21.98} \sin(\delta_2 - \theta)$$

Figure 3 also contains the phasor diagram depicting the terminal voltages and the torque angles.

LOAD CALCULATIONS

Assume that the base load for the Laboratory is 55MW and that the Booster power swing is ± 10MW. The load distribution is calculated from two loadings, 45MW and 65MW. The difference in generator power is attributable to the Booster swing of 20MW.

The system is initialized at a load of 45MW and a load voltage of $39.8\underline{|0°}$ KV. The value of the terminal generator voltages are $\bar{V}_1 = 39.8\underline{|0.618°}$KV and $\bar{V}_2 = 40\underline{|5.315°}$. The power flow from the generators are P_1=25MW and P_2=20MW. The equivalent network is given in Fig. 4A. Based on a Thevenin's Equivalent Circuit representing the LILCO Port, see Fig. 4B, the load voltage $\bar{V}_L$ for a power of 65MW (R_L = 73.1 ohms) is calculated as $39.79\underline{|-0.452°}$ KV. The power flow from the two generators are 43.3MW and 21.7MW respectively.

Based on these calculations Table I has been generated and describes the power flow due to the Booster Power Surge of ±10MW.

LOAD POWER (MW)	LILCO PORT TERMINAL VOLTAGE (KV)	TORQUE ANGLE		POWER FLOW (MW)	
		LILCO	CO.GEN.	LILCO	CO.GEN.
45	$39.8 \angle 0°$	0.618°	5.315°	25	20
55	$39.8 \angle -0.226°$	0.844°	5.541°	34.15	20.85
65	$39.79 \angle -0.452°$	1.070°	5.767°	43.3	21.7

TABLE I
SUMMARY OF POWER FLOW DUE TO BOOSTER POWER SWING

Note that power loading affects the phase angle and does not affect the amplitude of voltage at the LILCO port. The small change in angle of the terminal voltage has a much larger effect on the power flow from the LILCO grid than it does on the power flow from the co-generation plant.

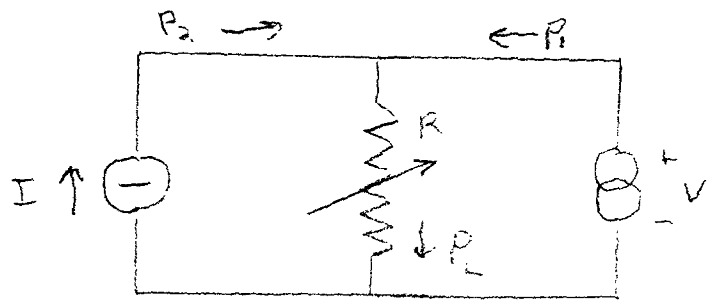
PROJECTION

The leakage inductance of the transformer is 56.6mhy and limits the co-generation power swing to 1.7MW for a Booster power swing of 20MW. The power swing can be further reduced by increasing the inductance in series with the co-generator. This can be done by increasing the leakage of the transformer, employing the sub-transient reactance of the alternator, or placing an iron-core reactor in series with the co-generation distribution system. The power swing is inversely proportioned to the reactance of the line. As an example, if the total inductance is increased to 200mhy, the power swing is 0.5MW in the co-generation plant.

The maximum allowable power swing is limited by the mechanical design of the generator. Generally limited by the stress of the windings and the torsional stress of the shaft and rotor.

REFERENCE

Tarboux, J.G., Introduction to Electric Power Systems; International Textbook Co., 1944, see chapter 21.



P_1 = power from voltage source $= \frac{V^2}{R} - VI$

P_2 = power from current source $= VI$

P_L = power absorbed by load $= \frac{V^2}{R}$

$$\frac{V^2}{R} > VI$$

Figure 1

PARALLELING OF A VOLTAGE AND A CURRENT SOURCE. R IS A VARIABLE LOAD

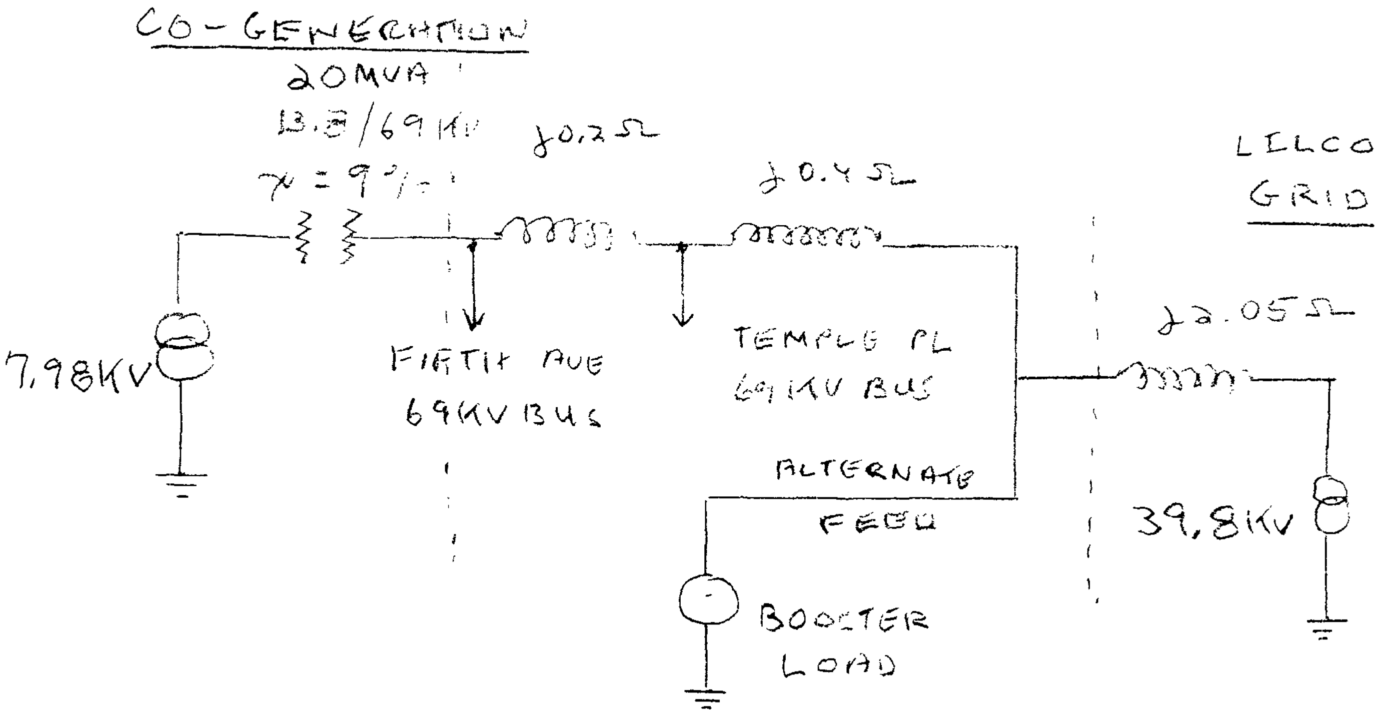


Figure 2

PROPOSED ELECTRICAL SYSTEM OF BNL WITH CO-GENERATION PLANT AND AGS BOOSTER

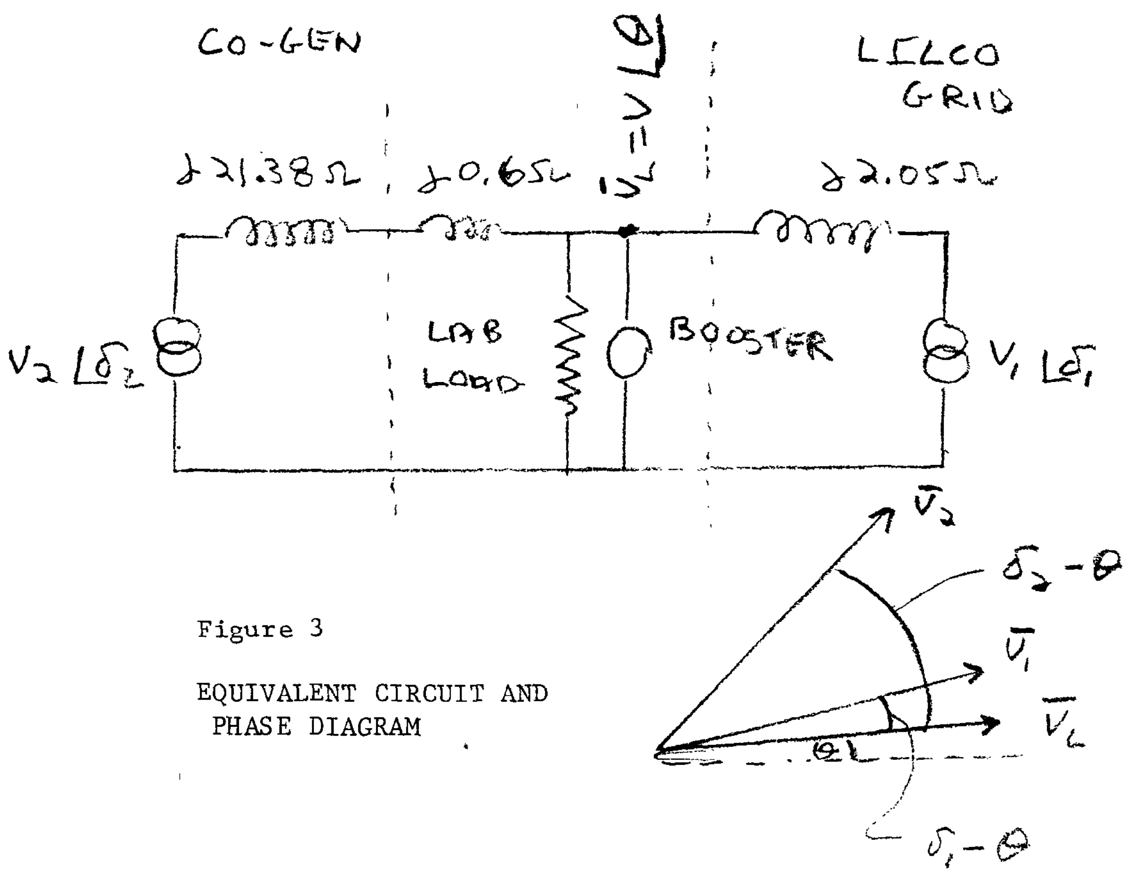


Figure 3

EQUIVALENT CIRCUIT AND
PHASE DIAGRAM

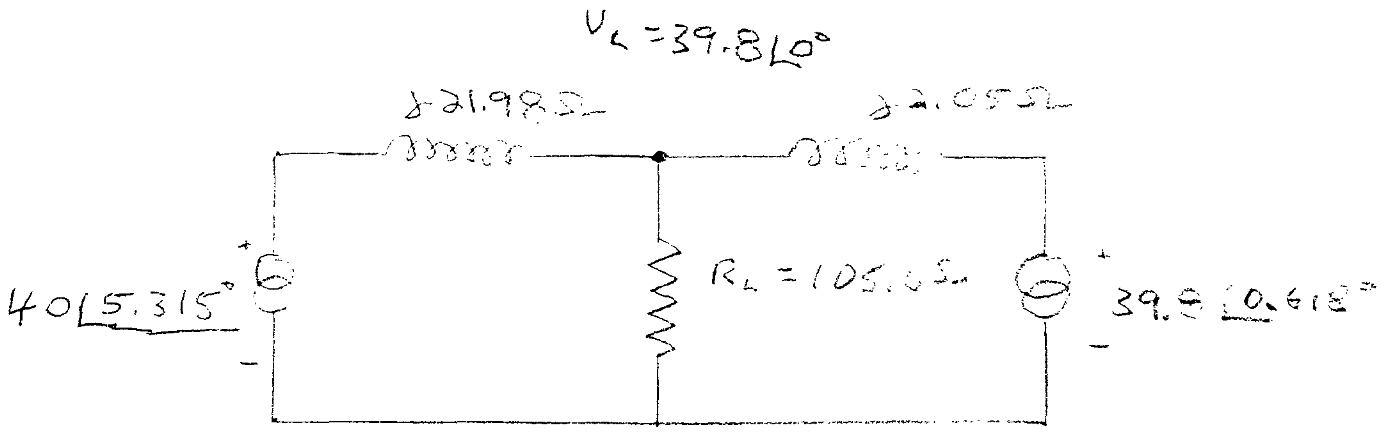


Figure 4A

TERMINAL VOLTAGES FOR A POWER LOAD OF 45 MW.

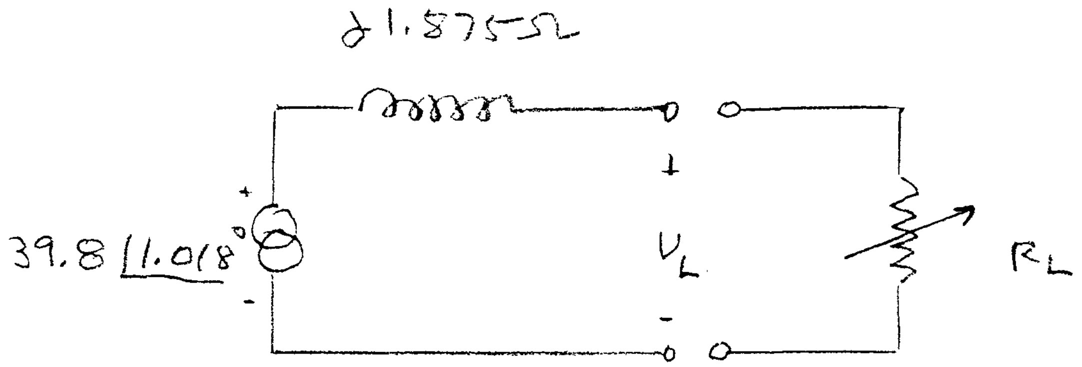


Figure 4B

THEVENIN'S EQUIVALENT FOR LILCO PORT INCLUDING BNL CO-GENERATOR