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CTM-82

C STELLARATOR ASSOCIATES

INFORMAL TECHNICAL MEMORANDUM

POWER GROUND GRID SYSTEM

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POWER GROUND GRID SYSTEM

General:

An electrical ground grid system will be buried beneath the Outdoor Substation, Motor-Generator, D-C Switchgear, C-Stellarator and Radio Frequency Buildings. This ground grid should be sized to carry the largest ground currents that could flow during the most severe fault conditions that are likely to occur during the expected life time of the facility. This ground grid will also serve to limit the overvoltage which equipment may be subjected to during any fault condition. In addition, the ground grid may serve as a zero voltage reference point for some instrumentation.

It is the purpose here to recommend an acceptable ground grid system based upon attached outlined assumptions and computations.

Outdoor Substation:

The present outdoor substation is fed from the Public Service Electric and Gas Company's 132 KV system through a transformer rated 30,000/50,000 KVA to 4.16 KV buses. The present 132 KV system fault currents may be adequately handled by the 4/0 cu. wire recommended by Commonwealth Associates, Inc. In the future, the 7000 HP motors may be replaced with 25,000 HP motors, and an a-c power transformer of approximately 60,000/100,000 KVA capacity added to supply the increased power requirement. At that time it may be advisable to reinforce the outdoor substation ground, depending upon the then existing system ground fault conditions.

Unit Substations and Motor Control Substations:

The low voltage 4.16 KV/460 volt substations will be generally grounded in keeping with their load equipment characteristics. 4/0 cu. wire will be adequate for all of these locations.

Motor Generator Room:

This location has both a-c and d-c power sources. All equipment other than the large motor generator units (presently 12-4090 kw and 1-2000 kw d-c generators) and the d-c bus framework may be adequately handled by the 4/0 cu. wire.

It is recommended that the area directly beneath the motor generators and the associated d-c bus contain a ground grid structure composed of 500 MCM copper wire. The 500 MCM wire is adequate to handle the maximum fault current expected from four generators in parallel. It may be noted here that each generator is capable of momentarily producing, at its terminals, a fault current of 83,230 amperes at a rate-of-rise of 13.75×10^6 amperes per second, and that four such generators in parallel could momentarily deliver approximately 330,000 amperes.

It is important to maintain isolation between the ground grid and all reinforcing rods. Therefore, it is recommended that the 500 MCM ground grid be of insulated wire or special care be taken to maintain insulation during construction. It is recommended that a suitable "copperized" terminal pad be made available at each building column for connection to the ground grid, because these terminal connections must make positive electrical contact.

D-C Switchgear Room:

The d-c switchgear room will essentially be a continuation of the M-G room and the ground grid beneath this switchgear room should be of 500 MCM wire size. Isolation between the C-S Building ground grid, the M-G Building, and the switchgear room ground grid may be accomplished through removable lead connections, if necessary.

C-Stellarator Building:

The electrical ground grid system is particularly important in this building, because there are various types of power feeding into this area, and because of the type of test work involved. There may be two separate "C" machines in this area, hence, the ground grid should be a unified system that may easily be separated into two sections, if necessary. It is recommended that a ground rod be drilled into the ground at the center of each area until a prescribed low ohmic ground resistance is reached. (The actual ohmic resistance will be determined at a later date when more information regarding the soil electrical characteristics is known.) Each ground rod should be of at least $\frac{1}{2}$ square inches of area to be thermally capable of handling a maximum ground fault current for at least 2 cycles, based on a 60 cycle system.

Each ground rod will be connected to a ground grid mesh of 500 MCM wire, with an insulated removable ground lead made accessible above the basement floor for use as ground reference for all equipment.

Currents induced in the ground grid by pulsating currents flowing in the d-c bus wire were specifically considered. The most severe conditions were assumed. The calculations based upon these assumptions are attached, for reference. The results indicate that, even under these most severe conditions, the induced current magnitude is small. The induced currents will be negligible in the proposed grid, because the grid-to-bus spacing will be greater than the spacing assumed in the computation.

The recommended ground grid system in this area is physically arranged so that the ground wires which are parallel to the Stellarator long dimension and to the d-c buses are geometrically centered. (See figure I)

The action of the ground grid as an r-f ground plane need not be considered because a specific r-f ground plane will be established at the floor of the C-room.

Radio-Frequency Building:

The 60 cycle a-c power fault currents in this area may be adequately handled with the proposed 4/0 cu. grid.

References:

1. Matterhorn Recommendations of Electrical Grounding and Shielding
by N. W. Mather - March 1958

2. Grounding of Industrial Power Systems
AIEE #953 - October 1956

3. Grounding Grids for High-Voltage Stations
E. T. B. Gross, B. V. Chitnis, L. J. Stratton
AIEE Paper 53-239

4. Transient Performance of Electric Power Systems
Rheinhold Rudenberg, McGraw-Hill Book Company
N. Y., N. Y. - 1950

ASSUMPTIONS AND CALCULATIONS:

A. C. Supply

1. Outdoor Substation 132/4.16 KV.

(a) Public Service Electric & Gas Company estimate the future short-circuit capacity to be 10,000 MVA at the junction between the 132 KV System line and the tap to the C- Stellarator.

Maximum three phase current at 132 KV is $\frac{10,000,000}{132 \times \sqrt{3}} = 43,700$ Amperes.

Conclusion: 4/0 cu. wire is adequate to handle this three phase current. (It will experience considerably less current at the substation than this maximum, because the substation is two miles from the junction.)

(b) 4.16 KV - Maximum three phase fault at the Pulse Bus is limited to 350,000 KVA because of transformer impedance.

Maximum three phase current at 4.16 KV is

$$\frac{350,000}{4.16 \times \sqrt{3}} = 48,500 \text{ Amperes}$$

Conclusion: 4/0 cu. is adequate to handle this three phase current. (It will experience much less ground current because of transformer impedances, and the transformer ground resistor used to limit fault currents to 1000A.)

(c) All major equipment should be connected to ground grid with at least 4/0 cu. wire.

(d) Fences, instruments and such may be connected with 2/0 cu. wire or larger.

2. Unit Substations and Motor Control Substations should follow the recommendations and wire sizes of the 132 KV/4.16 KV Substation, Part I.

3. R. F. Building ground grid should follow the recommendations and wire sizes of the 132 KV/4.16 KV Substation, Part I.

D. C. Supply

Each d-c generator can produce at its terminals a fault current (16.4) x (full load rating).

fault current = 16.4 x 5075 = 83,230 Amperes

fault current rate-of-rise = 13.75×10^6 Amps/second

1. Motor-Generator Building

(a) Terminal connections are likely to be most vulnerable to faults and may involve one or more generators.

(b) The d-c bus is insulated, but a breakdown of major insulation due to an abnormal failure could fault four generators in parallel.

Conclusion: Ground faults are likely to fall within the range of 83,230 to 330,000 amperes, depending upon the number of generators in parallel and the location of the fault. The copper cross section therefore, should be adequate to carry the fault current for a period of 2 cycles, based on 60 cycles per second, and should not be less than 500 MCM wire.

2. D. C. Switchgear Building

The same fault conditions exist in the d-c switchgear building as in the d-c section of the M-G building, but the fault current is limited to some extent by the bus impedance.

Conclusion: The conclusion given in part I of D. C. Supply is valid here.

3. C-S Building

(a) The same fault conditions exist in the C-S building as in the d-c section of the M-G building, but the fault current is limited by the bus impedance.

Conclusion: The conclusion given in part I of D. C. Supply is valid here.

(b) Induced Current Study. Refer to Calculations and Figure I.

Conclusion: The most severe condition produces only a small magnitude of induced current into the ground grid system. With a ground grid as proposed the induced currents will be negligible because of the physical arrangements.

D. C. Bus Induced Ground Current Calculations

1. Assumptions for most severe condition.

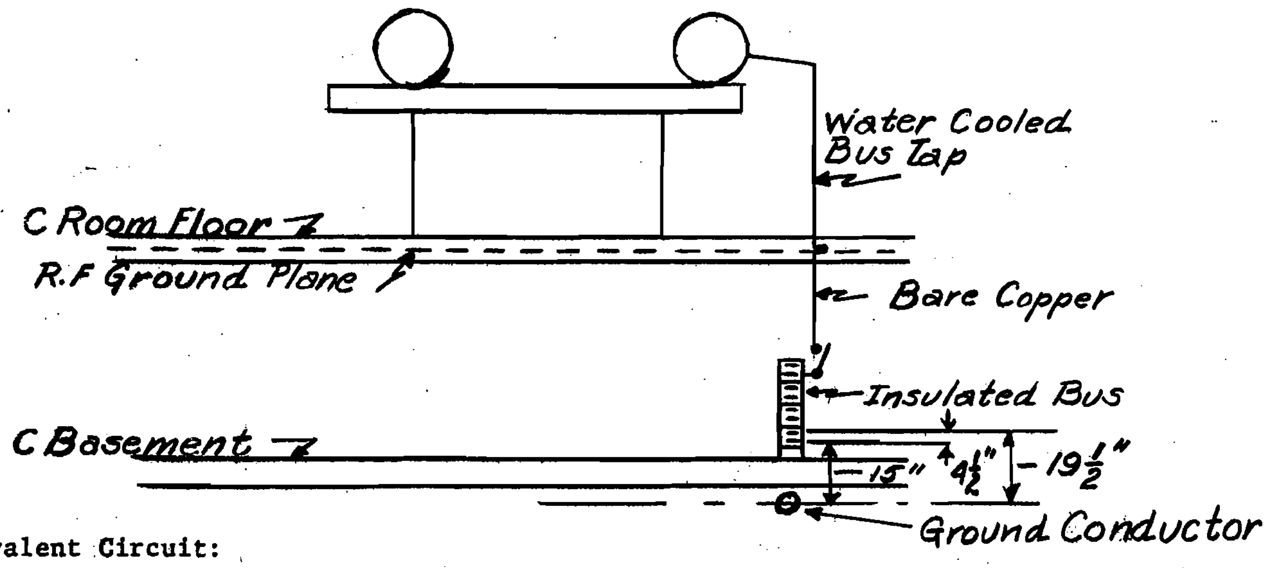
(a) One ground conductor only.

(b) Ground conductor minimum distances to bus is 15" for one polarity and $19\frac{1}{2}$" for opposite polarity.

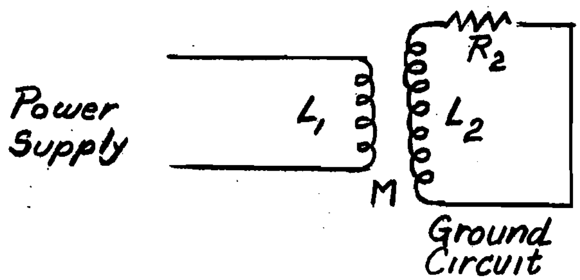
(c) Length of bus and ground conductor paralleling each other 100 ft.

(d) Rate of change of pulse current is $\frac{1}{2}$ second from 22,500 amperes to zero.

(e) Maximum amplitude of pulse 22,500 amperes from any one generator.



Equivalent Circuit:



M = Mutual Inductance

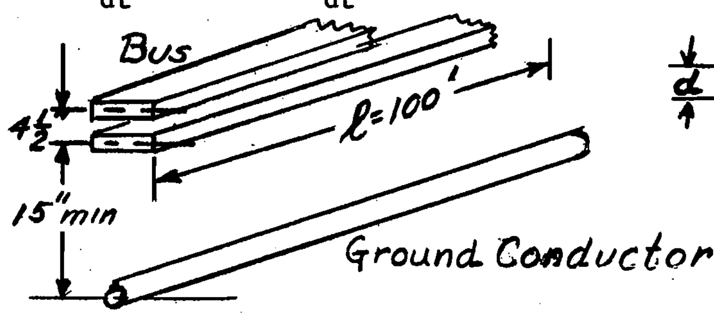
L_2 = Self Ind. of Grd Cond.

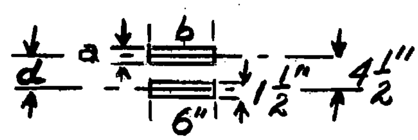
L_1 = Self Ind. of One bus cond.

$\frac{di}{dt}$ = Rate of change of current

R_2 = Resistance of grd cond.

(1) $$-M\frac{di_1}{dt} + (M + L_2)\frac{di_2}{dt} + R_2 i_2 = 0$$





Self inductance (L) of bus for 1 conductor (for check & reference value only)

(2) $$L_1 = 0.061\,\ln\left(\frac{9d}{2(a+b)} + \frac{1.2\,(b-a)}{3d+(b-a)}\right)$$ where a, b and d are in inches

$$L_1 = 0.061\,\ln\left(\frac{9 \times 9/2}{2(3/2+6)} + \frac{1.2\,(6-3/2)}{3 \times 9/2 + (6-3/2)}\right) = .061\,\ln\,(3.0)$$ micro henries per ft. of cond.

L_1 = .0672 micro h/ft of cond.

L_1 = 0.1344 micro h/ft of bus.

Assume longest bus extends entire length of C Building 100' then

$L_1 = 0.134 \times 100 = 13.4$ micro henries for bus length.

Self inductance (L) of ground conductor

Assumed - 750 MCM Cable = 0.589 square inche area. Radius therefore

$$= \sqrt{\frac{0.589}{\pi}} = 0.433 \text{ inches}$$

(3) $L_2 = .002 \times \ell \left(\ln \frac{2 \times}{r} - \frac{3}{4} \right)$ where ℓ and r are in cm.

$$L_2 = .002 \times 100 \times 30 \left(\ln \frac{2 \times 100 \times 30}{0.433 \times 2.54} - \frac{3}{4} \right) = 47.7 \text{ micro h/100 ft.}$$

Mutual Inductance (M)

(4) $M = .002 \ell \left[\ln \left(\frac{\ell}{d} + \sqrt{1 + \frac{\ell^2}{d^2}} \right) - \sqrt{1 + \frac{d^2}{\ell^2}} + \frac{d}{\ell} \right]$ when and d are in cm

d = distance of ground conductor to bus conductor = 15 inches.

$$M = .002\ (100 \times 30) \left\{ \ln \left(\frac{100 \times 12}{15} + \sqrt{1 + \left(\frac{100 \times 12^2}{15^2} \right)} - \sqrt{1 + \frac{15^2}{(100 + 12)^2} + \frac{15^2}{100^2}} \right) \right\}$$

$= 6 \ln(160) = 30.8$ micro h for 100 ft.

Resistance (R_2) of 750 MCM conductor

$$R = \rho \frac{L}{A} = 1.72 \times 10^{-6} \times \frac{100 \times 12}{0.589 \times 2.54} = 1380 \times 10^{-6} \Omega / 100 \text{ ft.}$$

from previous page.

$$- M \frac{di_1}{dt} + (M + L_2) \frac{di_2}{dt} + R_2 \, i_2 = 0$$

$$(M + L_2) \frac{di_2}{dt} + R_2 \, L_2 = M \frac{di_1}{dt}$$

(5) $\frac{di_2}{dt} + a \, i_2 = b$ and $i_2 = e^{-at}\left[\int be^{at} \, dt + c\right]$ when $c = \frac{b}{a}$

$$i_2 = \frac{b}{a} \left[1-e^{-at}\right]$$

$$a = \frac{R_2}{M + L_2} = \frac{1380 \times 10^{-6}}{(30.8 \times 47.7)10^{-6}} = 17.6$$

$$b = \frac{M \frac{di_1}{dt}}{M + L_2} = \frac{(30.8 \times 10^{-6})(45 \times 10^3)}{(30.8 + 47.7)(10^{-6})} = 17.7 \times 10^3$$

(6) $$i_2 = \frac{b}{a} \left[1 - e^{-at}\right] = \frac{17.7 \times 10^3}{17.6} \left[1 - e^{-17.7 \times \frac{1}{2}}\right] = 1000 \left[1 - \frac{1}{e^9}\right]$$

i_2 = 1000 amperes induced from 15" single bus conductor

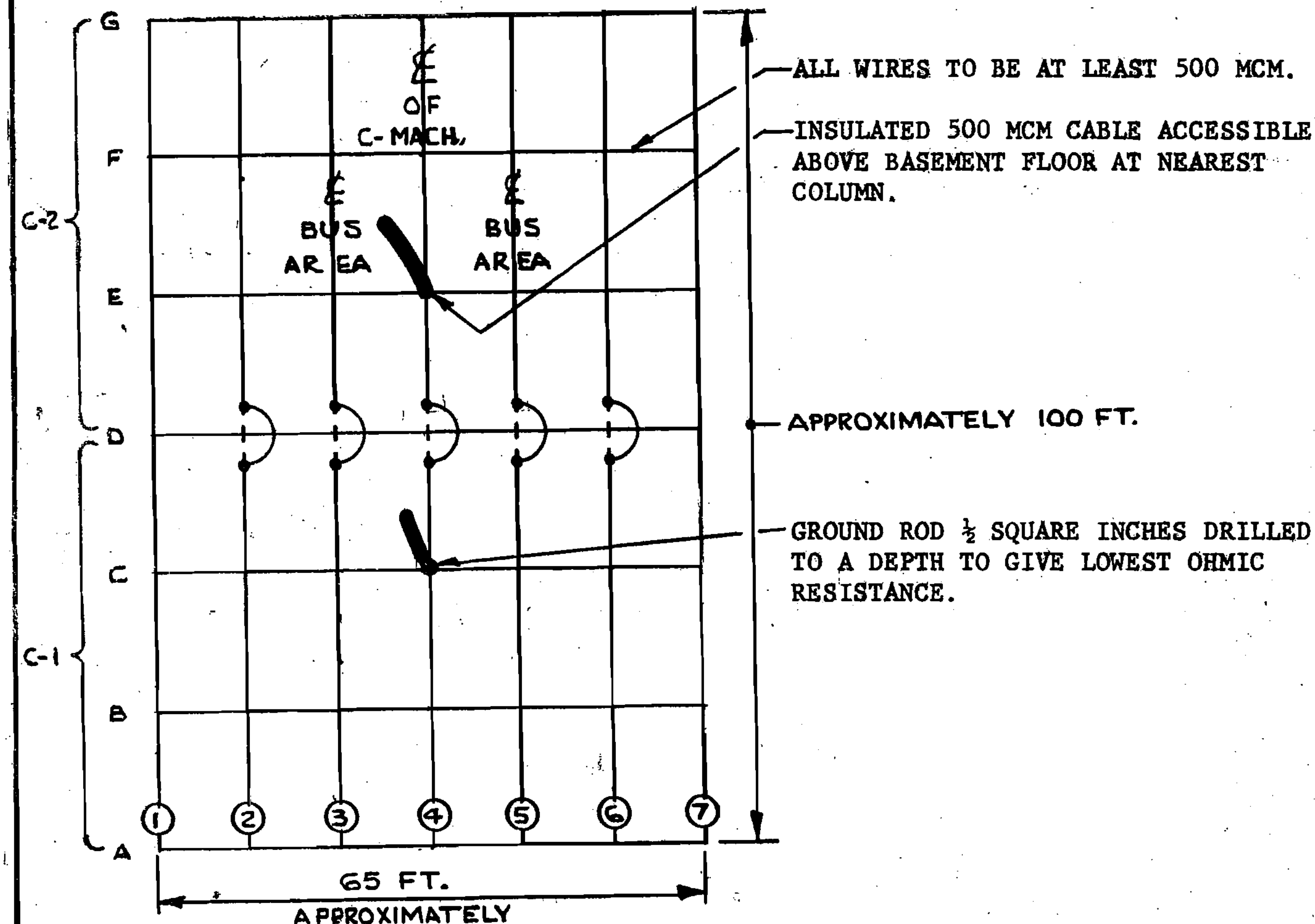
In a like manner the bus of opposite polarity $4\frac{1}{2}$" higher than the 15" bus was calculated.

The induced current i_2' is 943 amperes.

This induced current (i_2') is in opposition to the induced current (i_2) with the result current being

$$i_2 - i_2' = 1000 - 943 = 57 \text{ amperes}$$

SUGGESTED GROUND GRID
C-ROOM



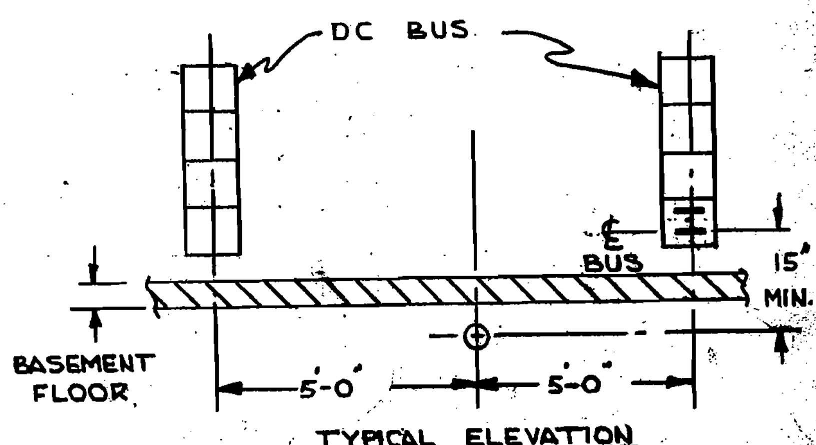
3 & 5 GROUND WIRES TO BE CENTERED BELOW GENERATOR BUS.

4 GROUND WIRE TO BE ON CENTERLINE OF C-MACHINE.

1, 2, 6, 7 EQUALLY SPACED TO PERIMETER.

A, B, C, D, E, F, G EQUALLY SPACED TO PERIMETER.

FIGURE 1



TYPICAL ELEVATION

C-STELLARATOR ASSOCIATES PRINCETON, N. J.	DRN. RGE. 7-29-58 APPV. [signature] 8/5/58	SHEET OF SK58210-2	ISSUE