214-0105-01-01_00

R.F. Note 104

J. Vincent
June 25, 1986

AYDIN POWER SUPPLY

Contents:

1. A Brief History of the Project

The Aydin is the main RF anode power supply. It is intended to feed the anodes of three high power tetrodes (RCA 4648) with a variable bias (.6 to 20kV DC), 0 to 20 amperes each, with 1.2 megawatt maximum. The entire power supply was purchased from the now defunct Aydin Energy Systems. We have since learned not to bid for a whole supply all at once, but rather design the system and go out on bid for the standard, modular pieces. I believe we should should design and build the control portion ourselves, thus eliminating some of the "rat's nest" logic we are unfortunately becoming accustomed to. The Aydin and all other high power supplies in this Lab are taking that shape anyway. Unfortunately, this latter approach costs more time and money, neither of which we have in excess.

The following is the sequential progress of the project.

March 23, 1983

The power supply is delivered and installation begins. An RF note by J. Riedel requests that testing begin in May. Testing begins sometime in the fall of 1983.

Fall 1983

The transformer fails for the first time and is returned to Aydin for repair at their expense.

June 1984

The transformer fails again and returns to Aydin for repair, at their expense.

December 1984

The transformer fails again. In addition, during the period of testing, Aydin personnel came to the Lab to fix control problems, crowbar problems, and step-start time constant problems.

January 1985

We assume responsibility for the supply. We decide to break the transformer rectifier tank in two separate enclosures, with the rectifier and filter in one and the transformer in another. The bid process begins.

March 1985

The tank is shipped to Medsker Electric for modification.

June 1985

The new rectifier unit from Medsker and the new transformer from NWL are installed on the pad, which had recently been extended.

August 1985

The transformer fails. Both engineering and manufacturing flaws are discovered and fixed.

January 1986

Previously, whenever the transformer failed, the building breakers would drop out and/or fuses would blow. We ordered a new study of the building's short circuits and device coordination system. The Aydin system was also restudied at this time. The studies shows deficiency in breaker set points for the building and the Aydin, resulting from activation of the Aydin. The Aydin also needs a ground-fault interrupt installed. We have the hardware installed or adjusted as specified.

March 1986

The transformer fails again, but the building survives. Something is starting to go right, in a small way. The failure is due to manufacturing flaws only.

June 1986

Testing resumes. We notice a thumping noise when the crowbar is tested.

2. The Current Status

Various experts are called, who say the thumping noise is not unusual, but still undesirable. We find we need to: 1) design/install a snubber (suppressor-damping) network, and 2) decrease the interruption times.

To accomplish Item 2, we install triacs in series with the 120V AC control line for the main vacuum contactors. These are held on, with the gate signal removed at the time of a crowbar.

This decreases interruption time from 4 to 2 cycles. With the impedence of our system, the full AC current is flowing in 2.8 ms. There is no hope of interrupting anywhere near that fast -- but 2 cycles are better than 4!

To accomplish Item 1, Louis Reginato at Lawrence-Livermore sent me some information which I have expanded. Section 4 of this note describes the necessary calculations for this type of problem.

3. Comments on Protection Schemes

This section briefly describes some suggestions I received from Dr. Quentin Kerns of Fermi Lab, Dr. Warren Dexter, retired from Berkeley, and Dr. Louis Reginato of Lawrence-Livermore. The suggestions were:

1. Place series SCRs in the main power lines with the gate held on. Remove the gate signal during a crowbar. This allows interruption of the line in a maximum time of 1/2 half-line cycle.

2. Install a set of vacuum contactors which require that the coil be activated in order to interrupt the line. Install a high energy gate drive signal to force them open in less than one cycle.

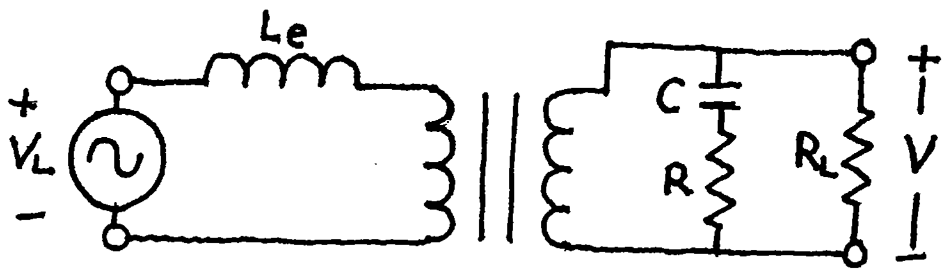
3. Install snubber circuits.

4. Transformers may last 10 years or more, or one year -- it's hard to tell under these conditions. In other words, barring premature breakdown, (transformers like to fail prematurely!), one can not reliably predict life expectancy. Therefore, have a spare system on hand.

We are implementing our version of suggestions 1-3, and are discussing implementation of suggestion 4.

4. The Design of Snubber (Suppressor, Damper, etc.) Circuits

a. Single Phase Case



The transformer is modeled as ideal, with the percent reactance or short circuit impedance, etc., modeled as a series inductance 'Le.' For rectifier transformers, the percent reactance runs about .05, but .02 to .1 is not uncommon.

Let: V_L = the necessary line voltage on the primary

V = the necessary voltage on the secondary at full normal load.

η = the short circuit impedance

ω = radian line operating frequency

ω_0 = network transfer function, natural resonant frequency

I_0 = full normal load current

I = short circuit current (RL = 0)

$$V = V_L(1 + \eta), \quad I = \frac{I_0}{\eta} \quad \text{defines } \eta$$

$$Le = \frac{\eta V_L^2}{\omega W}$$

W = full load power

The network response with RL = ∞ is:

$$\frac{V}{V_L} = \frac{K\left(s + \frac{1}{RC}\right)}{\frac{Le}{R} s^2 + s + \frac{1}{RC}}$$

The overshoot is dictated by the poles:

$$\frac{Le}{R} s^2 + s + \frac{1}{LeC} = 0$$

$$\Longrightarrow \quad s^2 + \frac{R}{Le} s + \frac{1}{LeC} = 0$$

which may be written as:

$$s^2 + 2\xi\omega_0 s + \omega_0{}^2 = 0$$

Figure 1 shows for the network to be slightly overdamped, we need $\xi \approx 1$.

Le can be transformed to the secondary.

$$Le_s = (1 + \eta)^2 Le = \frac{(1 + \eta)^2 \eta V_L^2}{\omega W} = \frac{\eta V^2}{\omega W} = Le$$

$$Le = \frac{\eta V^2}{\omega W}$$

$$2\xi\omega_0 = \frac{R}{Le} \qquad Le = \frac{\eta V^2}{\omega W} \qquad \xi = 1.0$$

$$2\omega_0 = \frac{R\omega W}{\eta V_L^2}$$

$$\Longrightarrow \quad R = 2\frac{\omega_0}{\omega} \eta \frac{V^2}{W} = \frac{2F_0}{F} \eta \frac{V^2}{W}$$

$$\text{also,} \quad C = \frac{1}{\omega_0^2 Le} = \frac{\omega W}{\omega_0^2 \eta V^2}$$

$$R = \frac{2F_0}{F} \eta \frac{V^2}{W} \qquad \xi = 1.0$$

$$C = \frac{\omega W}{\omega_0^2 \eta V^2}$$

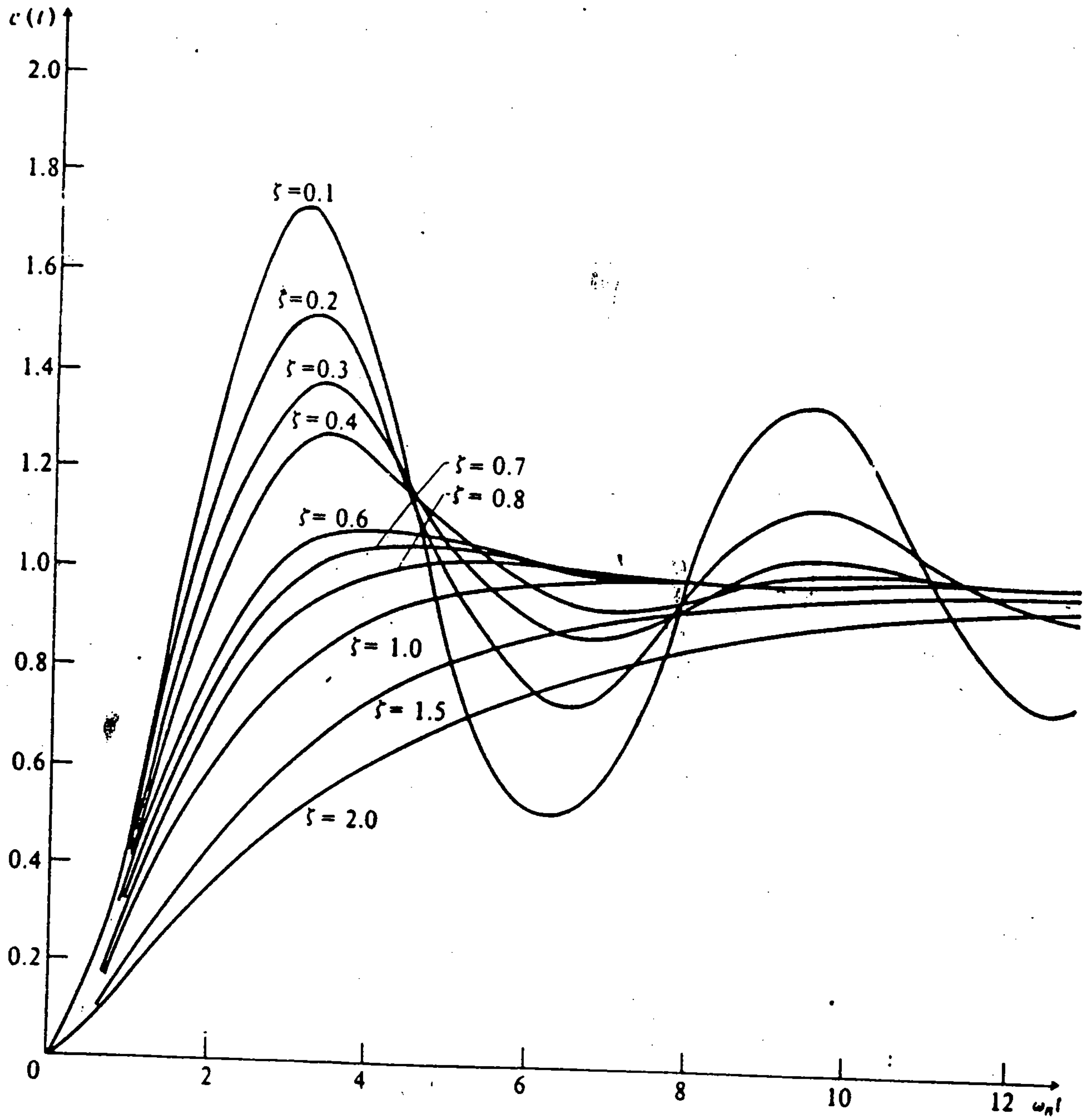

c(t)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
ζ =0.1
ζ=0.2
ζ =0.3
ζ = 0.4
ζ = 0.6
ζ = 0.7
ζ = 0.8
ζ = 1.0
ζ = 1.5
ζ = 2.0
2
4
6
8
10
12
$\omega_n t$

Figure 1

Everything in the equations is known except for F_0. We pick F_0, such that we dissipate an acceptable amount of energy in the snubber resistor (R) at steady state. Empirically, this appears to be $W_R = (4 \times 10^{-4})W$. Also, we must insure that the pole frequency (F_0) is not any known operating frequency (such as a close known multiple of 60 Hz!).

$$W_R = \frac{V^2}{R\left[1 + \left(\frac{1}{\omega RC}\right)^2\right]} \qquad \frac{1}{\omega RC} >> 1$$

$$\Longrightarrow \quad W_R \approx \frac{V^2}{R\left(\frac{1}{\omega RC}\right)^2} = RV^2\omega^2C^2$$

$$\tau_c = RC$$

$$W_R = V^2\omega^2\tau_c C$$

$$\tau_c = \frac{2\omega_0}{\omega}\eta\frac{V^2}{W} \cdot \frac{\omega W}{\omega_0^2\eta V^2}$$

$$\tau_c = \frac{2}{\omega_0} \quad \Longrightarrow \quad F_0 = \frac{1}{\pi\tau_c}$$

$$W_R = \frac{V^2\omega^2C}{\pi F_0} \quad \Longrightarrow \quad F_0 = \frac{V^2\omega^2C}{\pi W_R} \quad \text{or}$$

$$F_0 = \left[\frac{2}{\eta}\left(\frac{W}{W_R}\right)\right]^{1/3}$$

So for the single phase case:

$$R = \frac{2F_0}{F}\eta\frac{V^2}{W}$$

$$C = \frac{\omega W}{\omega_0^2\eta V^2}$$

$$F_0 = \frac{V^2\omega^2C}{\pi W_R} = \left[\frac{2}{\eta}\left(\frac{W}{W_R}\right)\right]^{1/3}$$

$$V = (1 + \eta)V_L$$

$$W_R = (4 \times 10^{-4})W$$

Example:

We need a 20kV DC power supply to deliver 1.2 MW at full load. We desire a short circuit impedance of 7 percent. The primary voltage is 10kV.

$$\eta = .07 \qquad V_{DC} = 20\text{kV @ full load}$$

$$V = \frac{\pi V_{DC}}{2\sqrt{2}} = 22.21\text{kV AC}$$

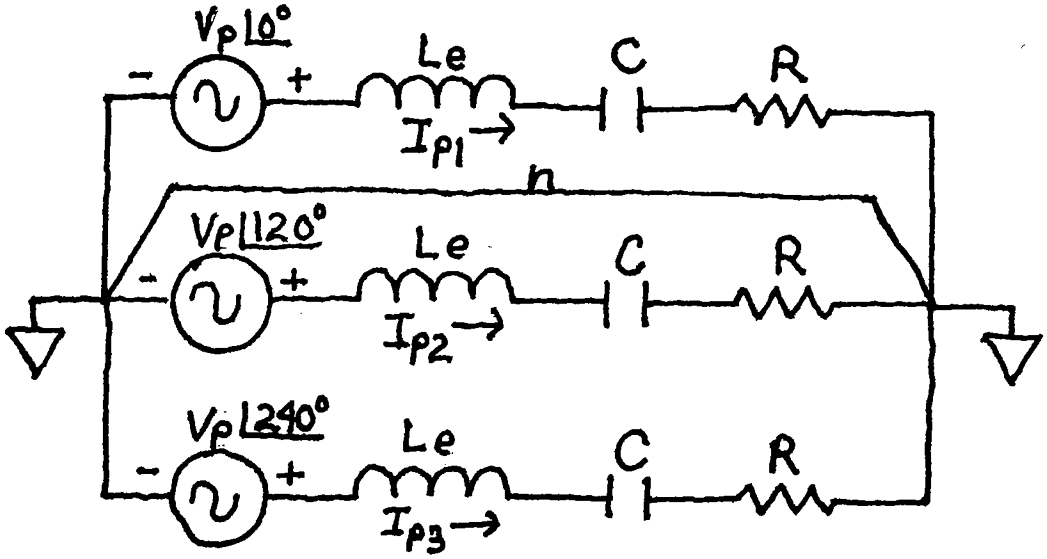
But this must be increased from the ideal value above, due to the short circuit impedance:

$$V = \frac{(1 + \eta)\pi V_{DC}}{2\sqrt{2}} = 23.8\text{kV AC (rms)}$$

The turns ratio must therefore be:

$$\frac{N_s}{N_p} = \frac{23.8}{10} = 2.38$$

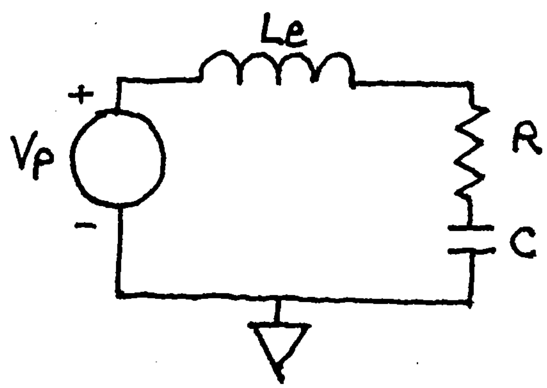
b. Three Phase Case



The excitations and loads are balanced. Therefore:

$$I_{p1} + I_{p2} + I_{p3} = I_p\angle 0^\circ + I_p\angle 120^\circ + I_p\angle 240^\circ = 0$$

Since no current flows in the neutral, and this point is common to all three, a solution to the following circuit solves the problem.



$$V_p = \frac{V_L}{\sqrt{3}} \qquad W_p = \frac{W}{3}$$

$$I_p = I_L = \frac{W_p}{V_p} = \frac{W}{3V_p}$$

$$\omega Le = \frac{nV_p}{I_p}$$

; again, the entire potential drops across Le during a short. $\frac{I_p}{\eta}$ is the short circuit current.

$$\omega Le = \frac{3\eta V_p^2}{W} \implies Le = \left[\frac{3\eta V_p^2}{\omega W}\right]$$

$$2\omega_0 = \frac{R}{Le} = \frac{R\omega W}{3\eta V_p^2}$$

$$\implies R = \frac{2\omega_0}{\omega} 3\eta \frac{V_p^2}{W}$$

$$C = \frac{1}{\omega^2{}_0 Le} = \frac{\omega W}{3\eta V_p^2 \omega_0^2}$$

$$\tau = RC \qquad W_R = RV_p^2\omega^2C^2 = V_p^2\omega^2\tau C$$

$$\tau = \frac{\omega W}{3\eta V_p^2\omega_0^2} \cdot \frac{2\omega_0}{\omega} 3\eta \frac{V_p^2}{W}$$

$$= \frac{2}{\omega_0}$$

$$\implies F_0 = \frac{1}{\pi\tau} \qquad \tau = \frac{W_R}{V_p^2\omega^2 C}$$

$$F_0 = \frac{V_p^2\omega^2 C}{\pi W_R} = \frac{V_p^2\omega^2}{\pi W_R} \cdot \frac{\omega W}{3\eta V_p^2\omega^2}$$

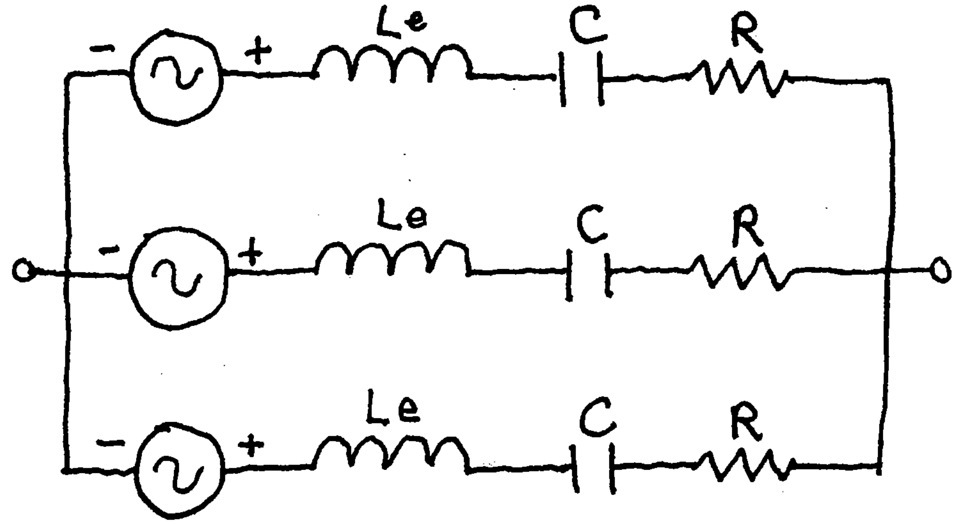
$$F_0 = \left(\frac{\omega}{\omega_0^2}\right)^3 \cdot \frac{W}{\pi W_R} \cdot \frac{1}{3\eta}$$

$$\omega_0^3 = \frac{2\omega^3}{3\eta} \cdot \frac{W}{W_R}$$

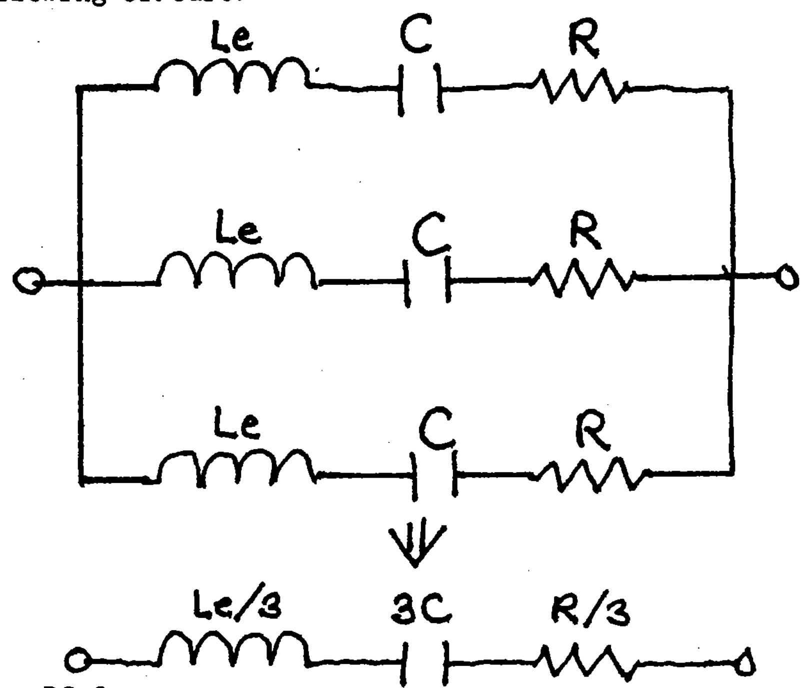
$$F_0 = F\left[\frac{2}{3\eta}\left(\frac{W}{W_R}\right)\right]^{1/3} \qquad W_R = \frac{W_R}{3}$$

$$F_0 = F\left[\frac{2}{\eta}\left(\frac{W}{W_R}\right)\right]^{1/3}$$

This is the resonant frequency of each leg of the Y. To inspect the resonant frequency of the structure, consider:



Notice no neutral connection and each voltage source can be considered ideal, which leaves the following circuit:



$$\tau = \frac{RC \cdot 3}{3} = RC; \quad \text{no change}$$

$$F_0 = \frac{V_p^2 \omega^2 C \cdot 3}{\pi W_R} = \frac{V_p^2 \omega^2 \cdot 3C}{\pi W_R} \cdot \frac{\omega W}{3\eta V_p^2 \omega_0^2}$$

$$F_0 = F\left[\frac{2}{\eta}\left(\frac{W}{W_R}\right)\right]^{1/3}; \quad \text{no change}$$

To recapitulate:

$$R = \frac{2\omega_0}{\omega} \eta \frac{V_L^2}{W}$$

$$C = \frac{\omega W}{\eta V_L^2 \omega_0^2}$$

$$F_0 = F \left[\frac{2}{\eta}\left(\frac{W}{W_R}\right)\right]^{1/3}$$

$$V_L = \sqrt{3}\, V_p$$

$$I_L = I_p = \frac{W}{3V_p} = \frac{\sqrt{3}W}{3V_L}$$

$$Le = \frac{3\eta V_p^2}{\omega W} = \frac{\eta V_L^2}{\omega W}$$

Example: The Aydin Power Supply

$$V_{LY} = 15.8\text{kV} \qquad W = 1.2 \times 10^{6}\text{W}$$

$$W_R = 4 \times 10^{-4} W = 480 \text{ watts}$$

$$\eta = .07$$

$$F_0 = F\left[\frac{2}{\eta}\left(\frac{W}{W_R}\right)\right]^{1/3} = 2.489 \times 10^{3}\text{Hz}$$

$$R_Y = \frac{2F_0}{F}\,\eta\,\frac{V_L^2}{W} = 1.208 \times 10^{3}\,\Omega$$

$$C_Y = \frac{\omega W}{\eta V_L^2 \omega_0^2} = .10585\,\mu\text{F}$$

(Y)

$$R_\Delta = 3R_Y = 3.624\text{k}\Omega$$

$$C_\Delta = \frac{C_Y}{3} = .0353\,\mu\text{F}$$

$$V_{\Delta L} = V_L = 15.8\text{kV}$$

(Δ)

$$V'_{\Delta L} = 13.2\text{kV} \implies \frac{V'_{\Delta L}}{V_{\Delta L}} = \frac{13.2\text{kV}}{15.8\text{kV}}$$

$$R'_\Delta = \left(\frac{V'_{\Delta L}}{V_{\Delta L}}\right)^2 R_\Delta = 2.529\text{k}\Omega$$

$$C'_\Delta = \frac{C_\Delta}{\left(\frac{V'_{\Delta L}}{V_{\Delta L}}\right)^2} = .0506\,\mu\text{F}$$

$$W_{R'_\Delta} \approx R'_\Delta (V'_{\Delta L})^2 \omega^2 C^2$$

$$= 160 \text{ watts}$$

$$3W_{R'_\Delta} = 481 \text{ watts}$$

5. Conclusion

I am enclosing in Appendix A the charts sent to me by Louis Reginato. These charts are for a transformer impedance of 5 percent. The power is 4×10^{-4}W, which is where my figure came from. Also, the frequency F_0 is 4kHz, which disagrees with my formula; anyone who can explain the discrepancies please do. In Appendix B, I am including various memos and bid specifications for this power supply -- just for future reference.

The Aydin example lists values for the delta side of the transformer of .0506μF and 2.529kΩ. These are now scaled to .047μF and 2.7kΩ. These are more standard and the power dissipated in each network, or the response, doesn't change much. These components will be mounted in the step-start cabinet, which is in the building and on the primary (delta) side of the transformer.

The inclusion of the triac did not cause the thump noise to go away. At this point, we are waiting for parts. We will design the mounting apparatus for the snubber before parts arrive, so installation and testing should begin almost concurrently with parts arrival. We will be waiting for probably in excess of three weeks. The specifications for the capacitor are as follows:

$$I_C = \frac{13.2\text{kV}}{\sqrt{R^2 + (\frac{1}{\omega C})}} \approx 240\text{mA}$$

$$V_C = \frac{I_C}{\omega C} \implies \text{kVA} = \frac{I_C^2}{\omega C(10^3)} = 3.25$$

Specifications:

V_{rms} steady state ==> 15kV @ 60Hz

kVA = ≥ 6kVA

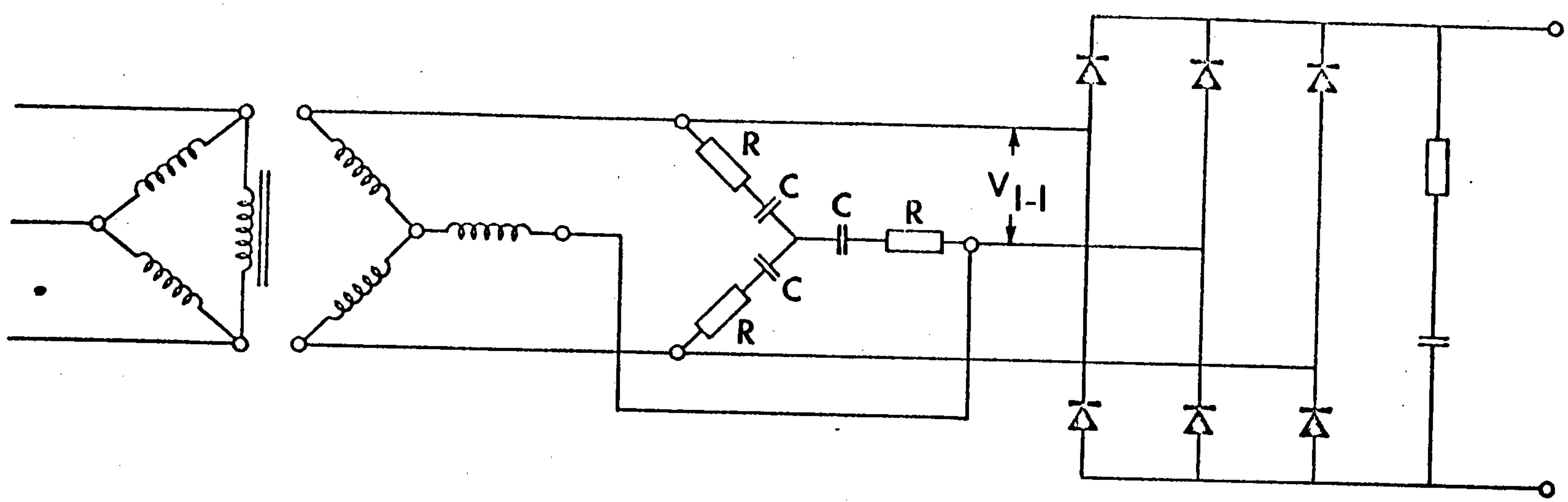
Peak pulse = 40kV

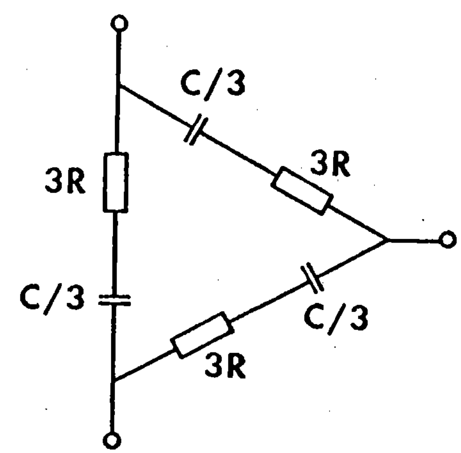
Value = .047μF

The resistors should have a dielectric coating to allow them to survive large transients without arcing over. I am expecting none to occur, but we don't want to go down because of one. They should be picked to dissipate at least twice as much as their steady state value of 160W for each network. Any combination of resistances is acceptable to achieve 2.7kΩ or thereabouts, with money, availability, and time of delivery carrying the weight for the decision.

APPENDIX A

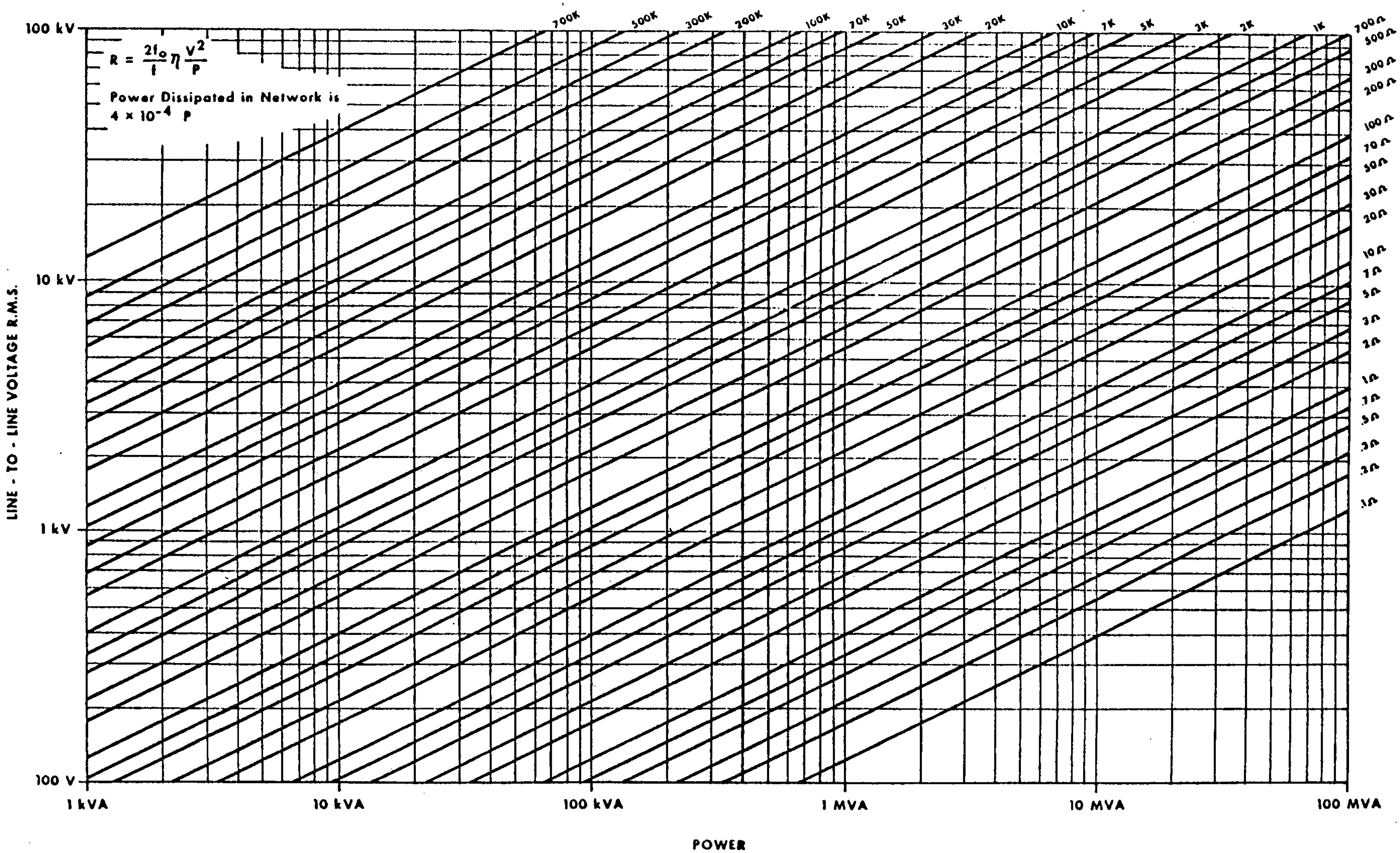
Snubber Design Charts





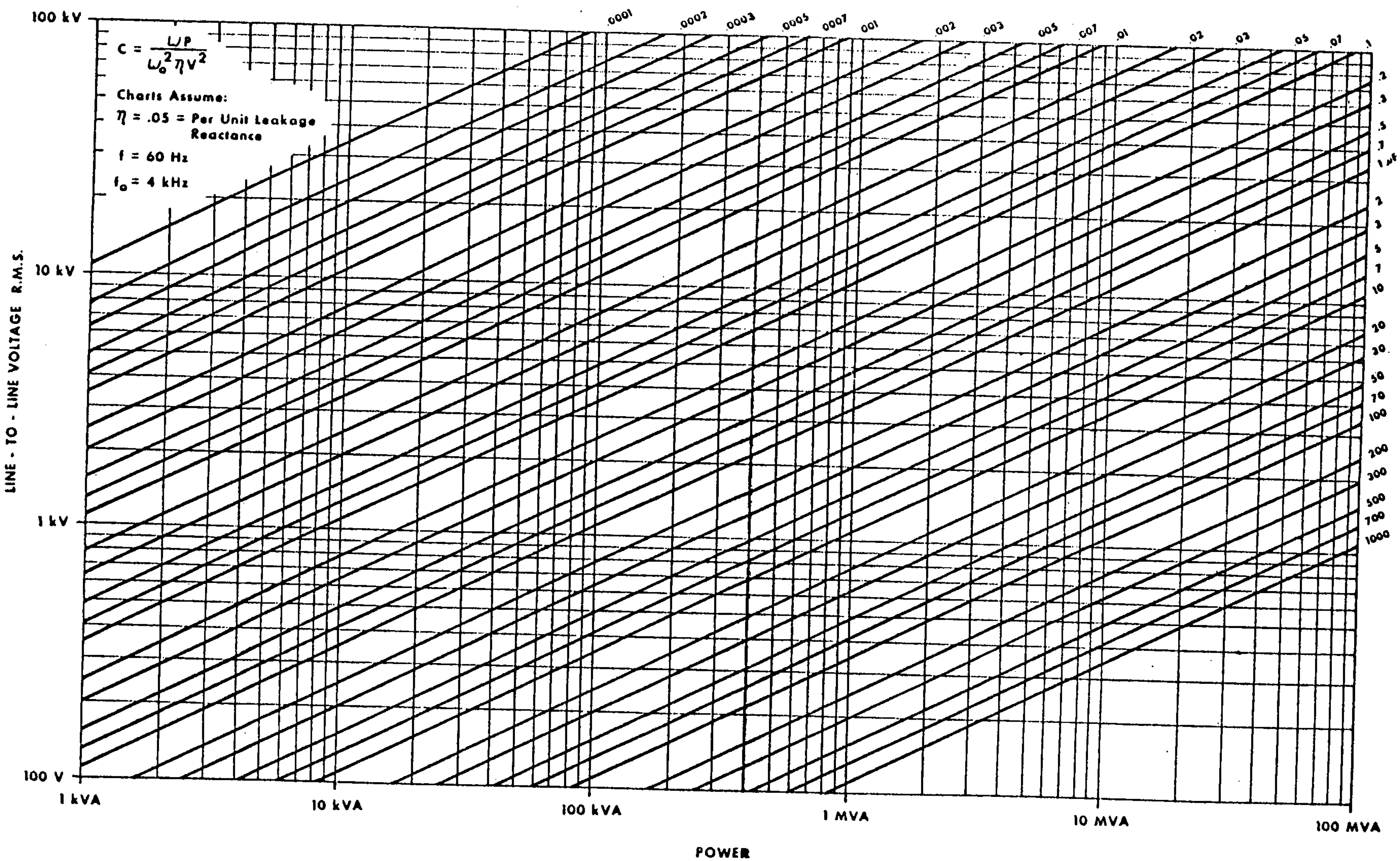
DELTA EQUIVALENT TO THE ABOVE 'WYE'

SCR POWER SUPPLY SURGE NETWORK
RESISTOR CHART



Lou Reginato

SCR POWER SUPPLY SURGE NETWORK
CAPACITOR CHART



APPENDIX B

Miscellaneous Power Supply Memos and RF Qs

M E M O R A N D U M

Date: January 7, 1985

To: H. Blosser, L. Tharp, D. Au

From: J. Vincent

Re: Aydin Power Supply

This supply consists of 5 major cubicles as follows:

1. Tap changer (G.E.)
2. Transformer/Rectifier/Filter (Aydin)
3. Breakers (G.E.)
4. Step Start resistors, caps, etc. (Aydin)
5. Crowbar, control, monitor electronics (Aydin)
   (This last item also contains the remote control box)

We are proposing to take charge of item 2 above. This would involve purchasing a transformer and enclosure from NWL, along with cleaning this tank or manufacturing a new tank (Medsker or NWL) to house the rectifier/filter/snubber.

This would of course make us liable for a great portion of this supply whether Aydin stuck with us or not.

The only other major components left are items 1, 3. Should we break relations with Aydin, I suggest we get as much of the following as possible.

Items 1 & 3

Aydin may still hold warranties from G.E. for these. If they do, we want them, if not we would at least want the names, phone numbers, addresses of the particular supplier.

Items 4 & 5

We would normally assume maintenance for these components anyway. They are much, much less expensive than all others and are maintained or replaced in a small piecewise process anyway.

Aydin also supplied us with a bundle of drawings for this supply. These are blueprints which are not directly copiable. I want the original drafted copies from Aydin. This will certainly save us much documentation time in the future.

I am also enclosing Jack's final words on this subject from his last r.f. note.

JV/mi

Fingers. Whereas previously I have recommended that we use the same pressurized door spring design for the stem short, I now am recommending that we use our new carbonized silver fingers. Previously we had tested a finger at 60 Hz and found that with a little air blowing on it, it could carry 100 amps with a temperature rise of less than 100°C. Since then we have tested a finger using 30 MHz R.F. and find that with no air it can carry 42 amps with a temperature rise of only 40°C. During the next week we will increase this current to 55 amps I suspect it will do fine, especially if we blow a little air by it.

Now even using Superfish's value of 4954 amps for the stem current, this results in only 39.5 amps per finger (there will be 125 fingers per inner short). Using these fingers for both the inner and outer stem will result in much greater simplicity of short fabrication. I think, however, that we should still sprinkle six or eight photosensitive transistors about the inner stem short, and 12 about the outer shorts.

Aydin Testing. For a while, on Friday, 11/2/84, it seemed like the Aydin 1.2 MW P.S. was going to be O.K. There were some idiosynchrisies about the controls, but it did run for two hours delivering, 800 KW into our two dummy loads. On Monday morning we found that the spark gap across the filter choke was melted down and shorted out. So we wasted a day making a new spark gap and installing closed circuit TV to watch it. On Tuesday, 11/6/84, we again came on, but this time with provision to instantly cut off the output current.

We were now also monitoring the output voltage. At 10 KV, with the total current approximately 20 amps, the peak to peak voltage ripple was 10% at 60 Hz, and about 3% at 720 Hz. This is a puzzle. The supply has no business producing 60 Hz ripple. On suddenly removing the current the voltage rose by 20%, which is to be expected from the increased leakage inductance of the supply.

Above 17.5K.V. we would get unaccounted for overcurrents which shut us off, but with perserverence, especially if we came on with no load and then applied the load, we could get on. AT 20 KV we were drawing 800 KW (40 amps) and the tap changer was all the way up. It is obvious that at 1.2 MW the supply would not be able to deliver 20 KV.

Everytime we shut the current off we would get a crowbar. ------ I see that I am entering excessive detail into this r.f. note. So, suffice it to say that soon the rectifier transformer developed shorted turns, and thus failed! Again we are out of business with our K800 r.f. system final power supply, and the odds are that three or four months will elapse before we can try again. C'est la vie.

JR/as

REQUEST FOR PROPOSAL

1.2 Megawatt Anode Power Supply Transformer Replacement/Repair

The National Superconducting Cyclotron Laboratory desires to purchase a transformer to replace a transformer which has twice burned out in an existing power supply. Desirably the replacement transformer would be one that could be mounted in the existing outdoor-transformer-rectifier-filter cubicle. A dimensional and schematic electrical drawing of this cubicle is attached, the inside of the tank is available for visual inspection, and a photo is attached. The existing transformer core may be reused if desired. (If a new transformer core is used the old transformer is to be forwarded to Aydin Energy Division, Palo Alto, California.) We believe the rectifier stack is undamaged. The quotation should provide for carefully cleaning the entire interior of the tank including the rectifier stack, with an option covering pricing of a replacement rectifier stack. Specifications are as follows:

Input: 13 kilovolt 3 phase line, of 1% source impedance with overload protection via a set of 3 cycle vacuum switches, backed up by a 5 cycle GE thermal and magnetic breaker.

Output: 60 amperes at 20 kilovolts

Transformer Impedance: Impedance built into the transformer should be between 8 and 10% where impedance is defined as the percentage by which the output voltage rises from full load to no load.

Load: The transformer rectifier feeds a cluster of rf amplifiers protected by a fast acting crowbar (short circuit). Load impedance will frequently change from full load to short circuit to no load on a rapid time scale. The transformer must be capable of withstanding these changes on an indefinite basis including all transient forces and voltages.

Guarantee: The replacement/repaired transformer is to be guaranteed to function properly for a period of one year from date of delivery and likewise for the rectifier stack if replacement of the rectifier stack is included in the order.

Testing: Within 30 days of receipt at NSCL the transformer-rectifier-filter unit will be tested by operating at full voltage and current for a period of 12 hours and by subjecting it to 50 successive full output crowbars at a rate of 1 per minute. If the transformer (and rectifier if new rectifiers are a part of the order) performs properly throughout this test it will be accepted.

Payment Schedule: 80% of the replacement/repair price will be paid on receipt of the unit at NSCL. 20% will be paid upon satisfactory completion of the acceptance test.

Shipping: The transformer-rectifier-filter cubicle will be shipped to the selected vendor as is, i.e. with oil removed, F.O.B. vendor's plant. The unit is to be returned to NSCL filled with oil and ready for use F.O.B. NSCL. The old transformer if not reused is to be shipped F.O.B. vendors plant to Aydin Energy Systems.

Information to be included with proposal. Expected schedule, brief work plan, cost for transformer repair, cost for rectifier replacement. Proposals due December 10.

January 22, 1985

MEMORANDUM

To: H. Blosser, R. Au, W. Nurnberger, L. Tharp, J. Brandon

From: J. Vincent

Subject: Aydin Power Supply

A formal agreement has been reached with Aydin Energy Systems concerning our 1.2 MW power supply. Knowing this; we must now begin to move rapidly to get a workable supply running in a reasonable time frame. I believe the first step has already been initiated. This step involved accepting the bid from NWL for a transformer, tank, encloser. I request the following personnel be assigned to this project.

J. Easley

W. Nurnberger

J. Brandon

Jim Easley will arrange for cranes to remove and install all tanks as needed. He should also arrange for the cement pad to be extended and fence's re-engineered to hold the incoming equipment. This pad should be ready by mid-June or earlier.

Bill Nurnberger will immediately be requested to inspect the rectifier tank we now have. He will take whatever steps he deems necessary to insure the survival of this equipment until further action is taken. He should also get in touch with Aydin to inquire as to whether or not they want the transformer shipped back to them at their expense. Following the above, he must assemble specifications for a bid package to go out as quickly as possible. This package should have basically two options.

1. Clean, modify, re-assemble, test, etc., the current tank. Refill and ship back to us.

2. Build a new tank specifically designed by them to house our rectifier, filter, circuits. Clean, assemble, test, fill, etc., and ship back to us.

Both of the above bids will include shipping charges in their quotes. These bids should go to NWL and Medsker Electric. Also confer with Bod Rodgers at Texas A & M University to get the High Power Test Apparatus back here by the time we need it.

J. Brandon will quickly insure all interior components are in working order. He will make minor modifications as I specify and will low level test these.

I will assist anyone in any way I can and will supervise and assist in the testing and verification of the final product. I would like all this to be done and the supply up and running by mid-July.

J. Vincent

JV/mi

January 31, 1985

REQUEST FOR PROPOSAL

1.2 Megawatt Anode Power Supply
Rectifier and Filter Circuit Refurbishing//Rehousing

The National Superconducting Cyclotron Laboratory (NSCL) desires to purchase a housing to contain the rectifier stacks, a snubber network, and the filter input inductor of an existing power supply. These components are currently housed in a large outdoor oil tank which also contains the supply's original rectifier transformer. After the original transformer failed twice during acceptance tests a new transformer in its own tank was purchased. NSCL solicits proposals on basically two options:

1. Modification of existing tank - Clean and modify the existing tank containing the original transformer, rectifier, snubber, and inductor to reduce its volume and cooling capacity to that required by the rectifier, snubber and inductor alone. Install these components in the modified tank, fill, test, and ship the assembly back to us.

2. Construction of a new tank - Design and construct a new tank specifically to house the existing rectifier, snubber, and inductor. Install these components in the new tank, fill, test, and ship the assembly back to us.

Although we believe the existing rectifiers, snubber components, inductor, and high voltage bushings are undamaged the quotation should provide for a careful cleaning, inspection and test of these and all other existing components and material which can be reused in the final assembly. Options covering replacement pricing for the major components, if they prove defective, should be included. Note that the vendor will retain possession of any components in the existing assembly which can not be used in the new or modified tank assembly and will deduct their reasonable salvage value from the cost for the proposed work. This will include the tank itself if option 2 above is selected.

A dimensional and schematic electrical drawing of the existing tank assembly is attached. In addition, the inside of the tank is available for visual inspection if desired. The existing rectifier assembly consists of six(6) Westinghouse No. HH1B6D2312 half-wave rectifier stacks connected in a three phase full-wave bridge. The existing filter inductor is a 0.27 Hy. unit built by the original vendor. Other pertinent information is as follows:

Input: 15,700V, open circuit @ 49 Amps, wye connected; supplied by a new transformer designed to allow delivery of 20KV @ 60 Amps DC when used with the existing rectifier and filter combination. The transformer has electrostatic shields between the primary and secondary windings and a short circuit impedance of 8 to 10%. The primary of the transformer is delta connected and is supplied by a 13.2KV, three phase line of 1% source impedance with overload protection via a set of 3 cycle vacuum switches backed up by a 5 cycle thermal and magnetic breaker.

Load: The output of the filter feeds a cluster of RF amplifiers protected by a fast acting electronic crowbar circuit (short circuit). Load impedance will frequently change from full load to short circuit to no load on a rapid time scale. The rectifier/filter assembly must be capable of withstanding these changes including all transient forces and voltages on an indefinite basis.

Guarantee: All equipment supplied by the vendor is to be guaranteed to function properly for a period of one year from date of delivery.

Documentation: The following information shall be supplied with the equipment as built:

a. Parts list of all component parts to enable purchase of replacement parts if necessary.
b. One print and one reproducible copy of the electrical schematic and/or the wiring diagram.
c. One print and one reproducible copy of the overall dimensional outline drawing showing outline dimensions, required mounting pad dimensions, and locations of electrical connections.
d. Any other information necessary to assure proper operation and maintenance of the assembly. Drawings should include one print and one reproducible copy.

Access: NSCL's designated representative(s) shall be allowed reasonable access to the production and test area of the vendor's facility at any time during the progress of the work called for in this RFP.

Payments: 80% of the accepted proposal price will be paid upon receipt of the unit at NSCL. 20% will be paid upon satisfactory completion of the acceptance test.

Shipping: The transformer-rectifier-filter tank will be shipped to the selected vendor as is (the oil has been removed) F.O.B. vendor's plant. The new unit is to be shipped to NSCL filled with oil and ready for use, F.O.B. NSCL.

Information to be included with proposal: Expected schedule; brief work plan; cost for proposed work; cost for major component replacement; and a proposed overall dimensional outline drawing showing outline dimensions, required mounting pad dimensions, and locations of electrical connections.

Proposals are due February 22, 1985.

<u>Request for Bid</u>

1.2 Megawatt Anode Power Supply
Short Circuit and Protective Device Coordination
Study

The National Superconducting Cyclotron Laboratory (NSCL) requires a Short Circuit and Device Coordination Study be done for a 1.2 Megawatt anode power supply. This study will begin at the building incoming feeder and include all equipment from that point to the extremes of the 1.2 Megawatt power supply. The rest of the building will be placed in parallel with this power supply and assumed running under full load as specified in the original short circuit and device coordination study. The vendor should include in the bid any funds necessary for a plant visit to inspect NSCL equipment, acquire any necessary information or specifications not included in this request, and confer with NSCL personel.

The power supply for which this study is basically intended feeds the anodes of three high power tetrodes in three class c rf amplifiers. These amplifiers supply power to three high Q rf cavities on the K800 Superconducting Cyclotron. These cavities are tightly toleranced and are prone to repeated arcing during initial suface conditioning and hydrogen outgasing. The high power tetrodes in the amplifiers also may occasionally spark internally and are protected against damage by a fast acting crowbar circuit in the 1.2 Megawatt supply. The crowbar circuit shorts the output of the 1.2 Megawatt supply to ground within 2 microsecounds of the occurance of a large dI/dT. The same pulse which triggers the crowbar to fire also initiates normal opening of the output ~~De~~ ac vacuum contactors. We predict the maximum time for these contactors to open (removing the fault condition) after the firing pulse is received to be 60 ms. Hence, the impedance seen by this supply may go from full load (20 KVDC @ 60 ADC) to short circuit to no load on a rapid time scale. The breakers, fuses, etc. time constants and duties must be able to withstand this behavior without disrupting service to the power supply under normal circumstances.

<u>Desired 1.2 Megawatt power supply
Protective Device Coordination Philosophy</u>

In addition to the requirements mentioned elsewhere in this request, the fuses, breakers, system reactance, etc. must conform with the following points. By "abnormal transients" in the following, we mean "any electrical transient condition which exceeds what industrial equipment and electronics are designed to tolerate and does not comply with the most rigid standards or laws".

1. During the normal occurance of crowbars (when normal power supply shutdown sequences are

operating properly), no breakers or fuses open and no other equipment in the building experiences any abnormal transients.

2. Should the normal shut down sequence fail after the occurance of a crowbar, or a fault occur anywhere on the power supply circuit not covered by the crowbar; the power supply breakers would open before any unnecessary damage to fuses, transformer, rectifiers, or lines would occur. No other equipment in the building experiences any abnormal transients.

3. Should the breakers fail to respond, the fuses would open before any unnecessary damage occurs. No other equipment in the building experiences any abnormal transients.

Basic Short Circuit Study Requirements

A short~circuit current study shall be performed and documented in a bound report form with all short~circuit current calculations made in accordance with the latest standards adopted by the American National Standards Institute. The following short~circuit calculating standards shall be used where appropriate in the study:

ANSI~C37.010	~ Standard Application guide for AC High~Voltage Circuit Breakers.
ANSI~C37.5	~ Calculation of Fault Currents for Application of Power Circuit Brea~kers Rated on a total Current Basis.
ANSI~C37.13	~ Low~voltage AC Power Circuit Brea~kers (600~volt Insulation class).
ANSI/IEEE~399~1980	~IEEE Recommended Practice for Power System Analysis.

The short~circuit calculations shall be accompanied by a bus~to~bus listing of all the system impedances calculated on a common 10 MVA base. A complete one~line diagram shall be furnished that will identify the bus locations in the system. The base MVA used for calculating all impedances will be included in the report. The short~circuit calculations shall be made with the aid of a digital computer. The computer printout for each study condition shall accompany the report with a written explanation of how to interpret the printout sheets. The one~line impedance diagram shall be indexed to the computer printout for complete interpretation of short~circuit duties. Calculations shall include all buses specifically identified for study on the one~line diagram. The following additional requirements will also be included:

1. A complete engineering discussion with an analysis of the results of the short~circuit study shall be included in the report.

2. A tabulated comparison between the calculated short~circuit duties and ratings of all medium~ and high~voltage fuses and circuit breakers shall be included in the report.

3. The short~circuit analysis shall include a phase~to~ground (zero sequence) short~circuit current calculation for the solidly grounded medium and/or high voltage portions of the power system. This will be used for coordinating phase~to~ground fault protection devices in these portions of the system.

Basic Protective Device Coordination Report Requirements

A complete protective device coordination study of the power system shall be performed and documented in a bound report form to prescribe settings for defined adjustable protective devices. The prescribed settings shall be determined based on a practical compromise between protection of electrical equipment and coordination between devices for downstream faults. The criteria for protection shall be in accordance with the latest requirements that are set forth by the National Electrical Code (NEC) and the American National Standards Institute (ANSI).

The study report shall include a complete one-line diagram that represents the parts of the system with the protective devices being studied. The diagram shall identify the devices involved in the study, all current and potential transformer ratios, and protective relaying functionally identified by ANSI device numbers.

The tabulation of recommended relay settings shall be identified by location, device number, adjustable range, and proposed settings. The following additional requirements will also be included:

1. A complete engineering evaluation shall be made of the protective devices in the system from an application standpoint. Where existing devices are inadequate to protect electrical equipment, the report shall reflect these deficiencies and make recommendations for improvement.

2. Time-current coordination curve plots shall be inluded in the report that represent suggested settings for the system protective devices. The coordination curves shall reflect the following information where applicable:
   a. Appropriate NEC protection points

b. Appropriate ANSI protection points
c. Magnetizing inrush points of transformers
d. One-line diagram of the system identifying the devices plotted
e. Short-circuit current levels used for coordination

3. The study shall prescribe (where necessary) new settings for all medium- and high-voltage applied switchgear relays in the system. The settings shall be prescribed based on existing settings for any low-voltage circuit breakers or fuses in the system.

4. The report shall include a discussion of each type protective relay in the system with respect to application and limitation of protection.

Technical Items Included with this Request for Bid

1. One copy of the most current Short Circuit and Device Coordination Study for the building.

2. One copy of the most current One Line Diagram for the building

3. One diagram displaying component values, electrical placement, and model types for the 1.2 Megawatt Power Supply.

Work to be Performed

1. The vendor shall perform a Short Circuit Study as specified in this request.

2. The vendor shall perform a Protective Device Coordination Study as specified in this request.

3. The vendor shall draft a copy of the current one line diagram of the building adding the one line diagram of the 1.2 Megawatt power supply as appropriate at K800 anode supply.

4. The vendor shall supply two certified bound copies of all results of the studies as specified in this request, and two copies of the One Line Diagram as described in (3).

5. The vendor shall supply a list of any additional devices recommended along with part numbers, model numbers, and total cost of each.

6. The vendor shall estimate the total cost for his service dept. to implement the study results both with and without any recomended additional hard~ ware. This portion is not to include any hardware costs.

The above items under the title of "Work to be Performed" fall into three basic groups (A,B,C) as follows:

A. Items 1,2,3 and 4.
B. Item 5.
C. Item 6.

The vendor is expected to bid on group A only since we believe the study results are necessary to accomplish groups B and C. NSCL reseves the right to choose any vendor to implement the results of this study.

This power supply is currently behind schedule for completion so time is a important consideration. The complete bid package will include (beyond any normal requirements):

1. The job starting time

2. The latest possible completion date

3. Any requirements for the plant visit

4. The total job cost

Any technical problems or questions about these specifications may be directed to:

John Vincent (517)355-7587
RF Engineer
NSCL
Michigan State University
East Lansing, Michigan 48824