53-960906-CLN-01

TO: DISTRIBUTION
FROM: C NEUMEYER
SUBJECT: OH COIL OPTIMIZATION
REFERENCES:

1) 53-960808-CLN-01, "Preliminary Design of Monolithic OH Coil"
2) 53-960809-CLN-01, "Alternate OH Coil Design"

This memo elaborates on the procedure used to arrive at the present OH coil design point (1.0 x 1.6 cm conductor, 4.05 m height).

The story begins with the 1.4 cm conductor. This conductor is too lossy (low copper fraction) and has too many turns per unit length (high inductance for a given solenoid height). Even for short solenoids (e.g. 3.5 m total ΔZ) the available power supply (4kV no-load) is not able to drive the current to the required precharge current, even with a symmetric OH current swing. The coil "runs away" (the resistance grows and the I*R drop exceeds the power supply voltage).

Moving up to the 1.5 cm conductor, with a 355 cm coil height (ref. 1), a 24kA precharge is feasible. When supplying 24kA with the full available driving voltage (at thyristor phase control angle $\alpha = 0$, where the power factor is equal to maximum possible) the voltage drop in the grid is at the limit ($\approx$ 1% at Brunswick substation, $\approx$ 3% at PPPL 138kV bus). In addition, for this conductor size, the required current swing is 42.65kA, which is less than 2 * 24kA = 48kA. This means that a bias can be used in the current swing, precharging to 24kA (the max available current, given the grid voltage drop constraint), and then reversing to 18.65kA.

The beauty of reversing to a current smaller in magnitude than the precharge current is twofold. First, the power supply is able to (has enough voltage to) drive the coil to this current even though it is hot and its resistance has increased. Second the power demand is reduced compared to precharge so that the precharge condition can be set to the maximum grid power delivery, and after reversal there will be a power margin available to power the other loads. Recall that the grid power limit is reached at 24kA (with optimal power factor). So, at reversal currents smaller than 24kA (assuming a good power factor) a power margin exists. It is important that we retain this margin because the HHFW and outer PF coil power supply power also must come from the grid. These loads are not relevant at the end of precharge, but are relevant at the end of flat top.

Unfortunately the 355 cm coil design with the 1.5 cm conductor height was not considered a tall enough solenoid by physics (concerns about field error), so a 1.6 cm conductor height was analyzed next (ref. 2).

Because the copper fraction of the 1.6 cm conductor is a little bit higher than that of the 1.5 cm conductor, and due to fewer turns per meter (less inductance for a given solenoid height), it is possible to reach the 24kA flat top current even with a coil height of 405 cm. Thus the desired coil height is achieved. However, the total current swing required (45.3kA) is a bit higher than the 1.5 cm case. Biasing of the current is still possible but not to the same degree as the 1.5 cm case. The implication is that there is less of a power margin at the end of flat top for the other loads mentioned above.

Power demand at the end of precharge and at the end of flat top, and the difference (≈ the margin available for the other loads), for the 1.5 cm and 1.6 cm cases are given below.

Conductor Height	1.5 cm	1.6 cm
Solenoid Height	355 cm	405 cm
P, precharge (MW)	73.1	73.1
Q, precharge (MVAr)	68.3	68.3
S, precharge (MVA)	94.3	94.3
P, eoft (MW)	50.4	65.7
Q, eoft (MVAr)	53.4	52.4
S, eoft (MVA)	73.4	84.0
P, precharge-eoft (MW)	22.7	7.4
Q, precharge-eoft (MVAr)	14.9	15.9
S, precharge-eoft (MVA)*	27.2	17.5

* = sqrt of the differences in P and Q

Power requirements for the HHFW and other PF power supplies are estimated to be as follows:

	HHFW	∑ Outer PF*	∑ (HHFW + ∑ Outer PF)
P (MW)	12.0	12.7	24.7
Q (MVAr)	5.8	12.7	18.6
S (MVA)	13.3	18.0	30.9**

* Based upon all six available ESAT building power supplies operating at their rated current, with a 0.707 p.f.

** = sqrt of the sums in P and Q

From the above it can be seen that the sum of the OH eoft load (1.5 cm case) plus the estimated HHFW and outer PF load is very nearly equal to the OH precharge load, which is known to result in the permissible grid voltage drop.

The OH active power (P) load is greater in the 1.6 cm case than in the 1.5 cm case, but the reactive power load (Q) is very nearly equal. So, if the OH eoft load is added to the estimated HHFW and outer PF load in the 1.6 cm case, the total P at eoft would exceed that at precharge, but the total Q would be very nearly the same as at precharge. This fact is very important because, in an electric power system, the voltage drop is primarily caused by the reactive power (Q) demand, e.g. it depends mostly on the power factor of the load. So, even though the active power is higher in the 1.6 cm case, since the reactive power is the same in both cases, the 1.6 cm case is thought to be OK.

On the above basis, and considering the uncertainties in the grid modeling and voltage flicker limits (which are thought to be conservatively addressed in the analysis) the 1.6 cm case is considered to be acceptable from a power supply point of view.

What about a 1.7 cm coil design? As it turns out, the required current swing is 48.0 kA. Thus, asymmetric operation is not possible since the precharge limit is 24.0 kA as described above. So, it would not be possible to achieve the required volt-seconds using a 1.7 cm conductor, while at the same time allowing for the power demand of the HHFW and outer PF coil power supplies at the end of flat top.

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