PPPL PRINCETON PLASMAPHYSICS LABORATORY
PROCEDURE No. ENG-033 Rev 4
Attachment 1

PPPL Calculation Form Page 1 of 1

Calculation # **NSTXU-CALC-53-05-00.** Revision # 0_ WP # 1540
(ENG-032)

Purpose of Calculation: (Define why the calculation is being performed.)

To determine the current unbalance in the eight parallel branches if a common firing angle command is issued to all rectifiers.

References (List any source of design information including computer program titles and revision levels.)

Conversion Transformer test data

Assumptions (Identify all assumptions made as part of this calculation.)

Assume that the same firing angle command is given to all the parallel rectifiers

Calculation (Calculation is either documented here or attached)

See attached

Conclusion (Specify whether or not the purpose of the calculation was accomplished.)

All the parallel rectifiers can be issued the same firing angle command since the unbalance in the current in the branches is within acceptable limits.

Cognizant Engineer's printed name, signature, and date

S. Ramakrishnan Digitally signed by S. Ramakrishnan
DN: cn=S. Ramakrishnan, o, ou, email=raki@princeton.edu, c=US
Date: 2012.02.28 16:37:35 -05'00'

S. Ramakrishnan
01/25/2012

I have reviewed this calculation and, to my professional satisfaction, it is properly performed and correct.
Checker's printed name, signature, and date

Ronald E Hatcher Digitally signed by Ronald E Hatcher
DN: cn=Ronald E Hatcher, o=Princeton Plasma Physics Laboratory, ou=Electrical Design Branch, email=rhatcher@pppl.gov, c=US
Date: 2012.02.29 07:30:01 -05'00'

R. Hatcher
01/25/2012

TF System current unbalance calculations:

Scope:

These calculations show the unbalance at flat top between the eight parallel branches if no individual branch current control is incorporated.

Brief Background: See attached simplified schematic.

TF needs 129.8kA. This is provided by incorporating eight parallel branches of rectifiers. Each branch is fed by one 1kV, 24kA Transrex power supply section. Thyristor junction temperature calculations performed by C. Neumeyer show that each Transrex supply can deliver up to 24.3kA for the TF.

There are 3 -1/c-750mcm cables from SDS to the PSS for branches 1 through 4, and 2-1/c-1000mcm cables for branches 5 through 8. All the cables to the CLR for all branches are provided with 2-1/c-1000 mcm cables. Two branches are directly connected in parallel and fed through one SDS. All the four SDS outputs are paralleled at the Transition Area. There are 8-1/c-1000 mcm cables in each leg from the Transition area to the Test Cell.

Parallel Operation

Table 1(A&B) summarizes all the resistances in the branches for each parallel path. The current division is calculated assuming all the power supply voltages are equal. It can be seen that the maximum unbalance is +6% to -7% if frequency is 64Hz. and +5% to -6% if frequency is 74Hz. As can be seen there is better current sharing at higher frequencies. The cable conductor temperature was assumed to be at 80C (Note that the cables indifferent parts of the circuit will attain different temperature)

Table 2 shows the calculations without any rectifier drop (Kimbark resistance Zero). Note that the rectifier drop is calculated at the lowest frequency (64Hz) of the operating range which is the worst case for calculating current sharing. The unbalance is between +17% to -17%. This fictitious condition shows the rectifier regulation dominates in the sharing of the current.

Tables 3A,B show the calculation by imposing unbalanced current of +15% to -15%. Then the corresponding rectifier voltages and the associated firing angles are calculated. This shows that even if the firing angle errors due to FG performance varies 46.4 to 50.14 degrees the resultant unbalance is not exceeding +15% to -15%. Table 3C assumes a random Alpha change to 44.82 in one branch with other branches at 48 degrees.

Conclusion:

A common firing angle command can be given to all the paralleled rectifiers on a closed loop control based on the total current measured by the fiber optic DCCT positioned to measure the total current. Even with the FG not following accurately the commanded angles, the resultant unbalance is well within limits. Automatic trips can be provided if the branch current exceeds the rating of the rectifier.

CALCULATIONS FOR SHOWING A) INTRINSIC SHARING OF CURRENTS BY BRANCHES at flat top & B) FORCED SIMULATED UNBALANCE

PROPOSED SYSTEM		**ALL FEEDER CLRS ARE 0.5 OHMS**																										
14.8	Cable resistance mOhms/1000' - 750mcm 25 C				Kimbark Lc		2.26E-05	per equip data*	2.82E-05	per actual performance**			Kimbark Lc for 0.275 fdr			1.69E-05	per performance		2.11E-05			* Calculation sheet attached.						
11.1	Cable resistance mOhms/1000' - 1000mcm 25 C				Kimbark Res. At 80Hz		1.08E-02		1.35E-02							8.11E-03			1.01E-02			** This was conveyed by Norm Fromm						
1	Resistance of the DC CLR				Kimbark Res. At 64Hz		8.68E-03		1.08E-02							6.49E-03			4.86E+00									
129800	Flattop amps																					1.23760	Multiplication factor assuming 80C conductor temp.					
0.3875	Resistance of cable runs from TA to PCTS = 0.3875 milliOhms; this is for eight cables based on measurements on existing system																											
0.125	Resistance of bus runs from PCTS to Coil terminals = 0.125 milliOhms																											
3.31	TF Coil Resistance at Tmax			3.31 milliohms																								
2.72	TF Coil Resistance at Tin			2.72 milliohhms																								
3	Assumed average TF Coil resistance during shot				3 milliohms																							
60	Assumed average cable conductor temperature degree C - however it may be noted that different section of the route will have different temperature rise - it is ignored for this calculation.																											
	For two sections - .5 ohm clr		37.86	22.6	uH																							
	For two sections - .275 ohm clr		31.956	12.43	UH																							
13800	Transformer primary:																											
750	Transformer secondary																											
1012.7029	Vd = 3*Em/Pl																											
Table 1A																												
CALCULATIONS BELOW ARE FOR FLATTOP - INTRINSIC SHARING																												
	PSS to SDS Cabling without CLR				***PSS to CLR Cabling***									**SDS to TA Cabling**														

	Cable	Cable	Length loop	Resis.	CLR Cable	Cable	Length loop	Resis.	Total loop resistance above SDS to PSS	Kimbark Resis.	Total loop resistance above SDS including Kimbark	Effective Kimbark Res + Cable Res.of two parallels	Res.from SDS to TA (P)	Res.from SDS to TA (N)	Total loop resistance SDS to TA	Eff. Loop res. From Rect. To TA	Total effective Res. Of the four parallels TA to SDS	Share of flat top amps of 129800 for each SDS	Branch Amps	PS to SDS Volt drop	SDS to TA volt drop	TA to PCTS Volt drop	Load side Volt drop at TA (includes coil)	Total voltage required at PS	Max % unbalance above required	Max % unbalance below required	External iiductance of each branch CLR + assumed cable inductance	
	kcmil	# in Parallel	feet	mOhms	mcm	# in Parallel	feet	mOhms	mOhms	Ohms	mOhms	mOhms	mOhms	mOhms	mOhms	mOhms	mOhms	Amps	Amps	Volts	Volts	Volts	Volts	Volts			uH	
Branch 1	750mcm	3	390	2.38	1000mcm	2	215	1.48	4.86	0.0087	13.536								15148	205				684			**300**	
Branch 2	750mcm	3	350	2.14	1000mcm	2	180	1.24	4.37	0.0087	13.052	6.64	0.368805	0.3762	0.745	7.390		30859	15711	205	23			684			**297**	
Branch 3	750mcm	3	330	2.01	1000mcm	2	105	0.72	3.74	0.0087	12.414								16478	205				684			**293**	
Branch 4	750mcm	3	310	1.89	1000mcm	2	145	1.00	3.89	0.0087	12.567	6.25	0.355191	0.3614	0.7166	6.962	1.757	32756	16278	205	23	**67**	**456**	684	**6**	**-7**	**294**	
Branch 5	1000mcm	2	300	2.06	1000mcm	2	160	1.10	4.16	0.0087	12.838								15997	205				684			**294**	
Branch 6	1000mcm	2	275	1.89	1000mcm	2	130	0.89	3.78	0.0087	12.460	6.32	0.34529	0.3527	0.698	7.021		32479	16482	205	23			684			**291**	
Branch 7	1000mcm	2	250	1.72	1000mcm	2	140	0.96	3.68	0.0087	12.357								16567	205				684			**291**	
Branch 8	1000mcm	2	225	1.55	1000mcm	2	105	0.72	3.27	0.0087	11.945	6.07	0.34529	0.3465	0.6918	6.766		33706	17139	205	23			684			**288**	
																		129800	129800									
Kimbark resistance is based on 64Hz																												
Table 1B (Frequency = 74)																												
CALCULATIONS BELOW ARE FOR FLATTOP - INTRINSIC SHARING																												
	PSS to SDS Cabling without CLR				***PSS to CLR Cabling***									**SDS to TA Cabling**														

	Cable	Cable	Length loop	Resis.	CLR Cable	Cable	Length loop	Resis.	Total loop resistance above SDS to PSS	Kimbark Resis.	Total loop resistance above SDS including Kimbark	Effective Kimbark Res + Cable Res.of two parallels	Res.from SDS to TA (P)	Res.from SDS to TA (N)	Total loop resistance SDS to TA	Eff. Loop res. From Rect. To TA	Total effective Res. Of the four parallels TA to SDS	Share of flat top amps of 129800 for each SDS	Branch Amps	PS to SDS Volt drop	SDS to TA volt drop	TA to PCTS Volt drop	Load side Volt drop at TA (includes coil)	Total voltage required at PS	Max % unbalance above required	Max % unbalance below required	External iiductance of each branch CLR + assumed cable inductance	
	kcmil	# in Parallel	feet	mOhms	mcm	# in Parallel	feet	mOhms	mOhms	Ohms	mOhms	mOhms	mOhms	mOhms	mOhms	mOhms	mOhms	Amps	Amps	Volts	Volts	Volts	Volts	Volts			uH	
Branch 1	750mcm	3	390	2.38	1000mcm	2	215	1.48	4.86	0.0100	14.892								15241	227				706			**300**	
Branch 2	750mcm	3	350	2.14	1000mcm	2	180	1.24	4.37	0.0100	14.408	7.32	0.368805	0.3762	0.745	8.068		30995	15754	227	23			706			**297**	
Branch 3	750mcm	3	330	2.01	1000mcm	2	105	0.72	3.74	0.0100	13.770								16456	227				706			**293**	
Branch 4	750mcm	3	310	1.89	1000mcm	2	145	1.00	3.89	0.0100	13.923	6.92	0.355191	0.3614	0.7166	7.640	1.927	32732	16276	227	23	**67**	**456**	706	**5**	**-6**	**294**	
Branch 5	1000mcm	2	300	2.06	1000mcm	2	160	1.10	4.16	0.0100	14.194								16021	227				706			**294**	
Branch 6	1000mcm	2	275	1.89	1000mcm	2	130	0.89	3.78	0.0100	13.816	7.00	0.34529	0.3527	0.698	7.699		32479	16459	227	23			706			**291**	
Branch 7	1000mcm	2	250	1.72	1000mcm	2	140	0.96	3.68	0.0100	13.713								16541	227				706			**291**	
Branch 8	1000mcm	2	225	1.55	1000mcm	2	105	0.72	3.27	0.0100	13.301	6.75	0.34529	0.3465	0.6918	7.444		33594	17053	227	23			706			**288**	
																		129800	129800									
Kimbark resistance is based on 64Hz																												

Table 2

Lead effective resistances without Kimbark - SHOWS Rectifier drop helps sharing This is a fictitious assumption but shows rectifier drop helps in current sharing

	Cable	Cable	Length loop	Resis.	CLR Cable	Cable	Length loop	Resis.	Total loop resistance above SDS to PSS	Kimbark Resis.	Total loop resistance above SDS including Kimbark	Effective Kimbark Res + Cable Res.of two parallels	Res.from SDS to TA (P)	Res.from SDS to TA (N)	Total loop resistance SDS to TA	Eff. Loop res. From Rect. To TA	Total effective Res. Of the four parallels TA to SDS	Share of flat top amps of 129800 for each SDS	Branch Amps	PS to SDS Volt drop	SDS to TA volt drop	TA to PCTS Volt drop	Load side Volt drop at TA (includes coil)	Total voltage required at PS	Max % unbalance above required	Max % unbalance below required		
	kcmil	# in Parallel	feet	mOhms	1000mcm	# in Parallel	feet	mOhms	mOhms	Ohms	mOhms	mOhms	mOhms	mOhms	mOhms	mOhms	mOhms	Amps	Amps	Volts	Volts	Volts	Volts	Volts				
Branch 1	750mcm	3	390	2.38	1000mcm	2	215	1.48	4.86	0.0000	4.858								13494	66				543				
Branch 2	750mcm	3	350	2.14	1000mcm	2	180	1.24	4.37	0.0000	4.373	2.30	0.368805	0.3762	0.745	3.046		28484	14990	66	21			543				
Branch 3	750mcm	3	330	2.01	1000mcm	2	105	0.72	3.74	0.0000	3.736								16879	63				543				
Branch 4	750mcm	3	310	1.89	1000mcm	2	145	1.00	3.89	0.0000	3.889	1.91	0.355191	0.3614	0.7166	2.622	0.669	33096	16217	63	24	**67**	**456**	543	**17**	**-17**		
Branch 5	1000mcm	2	300	2.06	1000mcm	2	160	1.10	4.16	0.0000	4.160								15426	64				543				
Branch 6	1000mcm	2	275	1.89	1000mcm	2	130	0.89	3.78	0.0000	3.782	1.98	0.34529	0.3527	0.698	2.679		32393	16967	64	23			543				
Branch 7	1000mcm	2	250	1.72	1000mcm	2	140	0.96	3.68	0.0000	3.679								16851	62				543				
Branch 8	1000mcm	2	225	1.55	1000mcm	2	105	0.72	3.27	0.0000	3.267	1.73	0.34529	0.3465	0.6918	2.422		35827	18977	62	25			543				
																		129800	129800	129800								

Table 3A FORCED UNBALANCE ON BRANCHES SHOWING ALPHA VARIATIONS THAT CAN BE TOLERATED.

CALCULATIONS BELOW ARE FOR FLATTOP - assume unbalance as indicated in each branch

	PSS to SDS Cabling without CLR				*PSS to CLR Cabling*												SDS to TA Cabling										
	Cable	**Cable**	**Length loop**	**Resis.**	**CLR Cable**	**Cable**	**Length loop**	**Resis.**	**Total loop resistance above SDS to PSS**	**Kimbark Resis.**	**Total loop resistance above SDS including Kimbark**	**Effective Kimbark Res + Cable Res.of two parallels**	**Res.from SDS to TA (P)**	**Res.from SDS to TA (N)**	**Total loop resistance SDS to TA**	**Eff. Loop res. From Rect. To TA**	**Total effective Res. Of the four parallels TA to SDS**	**Share of flat top amps of 129800 for each SDS**	**Branch Amps**	**PS to SDS Volt drop**	**SDS to TA volt drop**	**TA to PCTS Volt drop**	**Load side Volt drop at TA (includes coil)**	**Total voltage required at PS**	**Max % unbalance above required**	**Max % unbalance below required**	**COS (Alpha) reqd.**	**Alpha reqd.**
	kcmil	# in Parallel	feet	mOhms	1000mcm	# in Parallel	feet	mOhms	mOhms	Ohms	mOhms	mOhms	mOhms	mOhms	mOhms	mOhms	mOhms	Amps	Amps	Volts	Volts	Volts	Volts	Volts				Degrees
Branch 1	750mcm	3	390	2.38	1000mcm	2	215	1.48	4.86	0.0087	13.536								**17848**	242				722			0.71323	44.50147
Branch 2	750mcm	3	350	2.14	1000mcm	2	180	1.24	4.37	0.0087	13.052	6.64	0.368805	0.3762	0.745	7.390		**33261**	**15414**	201	25			682			0.67333	47.67575
Branch 3	750mcm	3	330	2.01	1000mcm	2	105	0.72	3.74	0.0087	12.414								**14603**	181				660			0.65160	49.33778
Branch 4	750mcm	3	310	1.89	1000mcm	2	145	1.00	3.89	0.0087	12.567	6.25	0.355191	0.3614	0.7166	6.962	1.757	**31639**	**17036**	214	23	**67**	**456**	693	**15**	**-15**	0.68400	46.84293
Branch 5	1000mcm	2	300	2.06	1000mcm	2	160	1.10	4.16	0.0087	12.838								**18659**	240				718			0.70911	44.83778
Branch 6	1000mcm	2	275	1.89	1000mcm	2	130	0.89	3.78	0.0087	12.460	6.32	0.34529	0.3527	0.698	7.021		**32450**	**13791**	172	23			650			0.64226	50.03973
Branch 7	1000mcm	2	250	1.72	1000mcm	2	140	0.96	3.68	0.0087	12.357								**15414**	190				669			0.66045	48.66558
Branch 8	1000mcm	2	225	1.55	1000mcm	2	105	0.72	3.27	0.0087	11.945	6.07	0.34529	0.3465	0.6918	6.766		**32450**	**17036**	203	22			682			0.67332	47.67633
																		129800	**129800**	129800								

Table 3B UNBALANCE ON BRANCHES BASED ON FORCED ALPHA VARIATIONS Alpha chosen same as Table 3

CALCULATIONS BELOW ARE FOR FLATTOP - assume unbalance as indicated in each branch

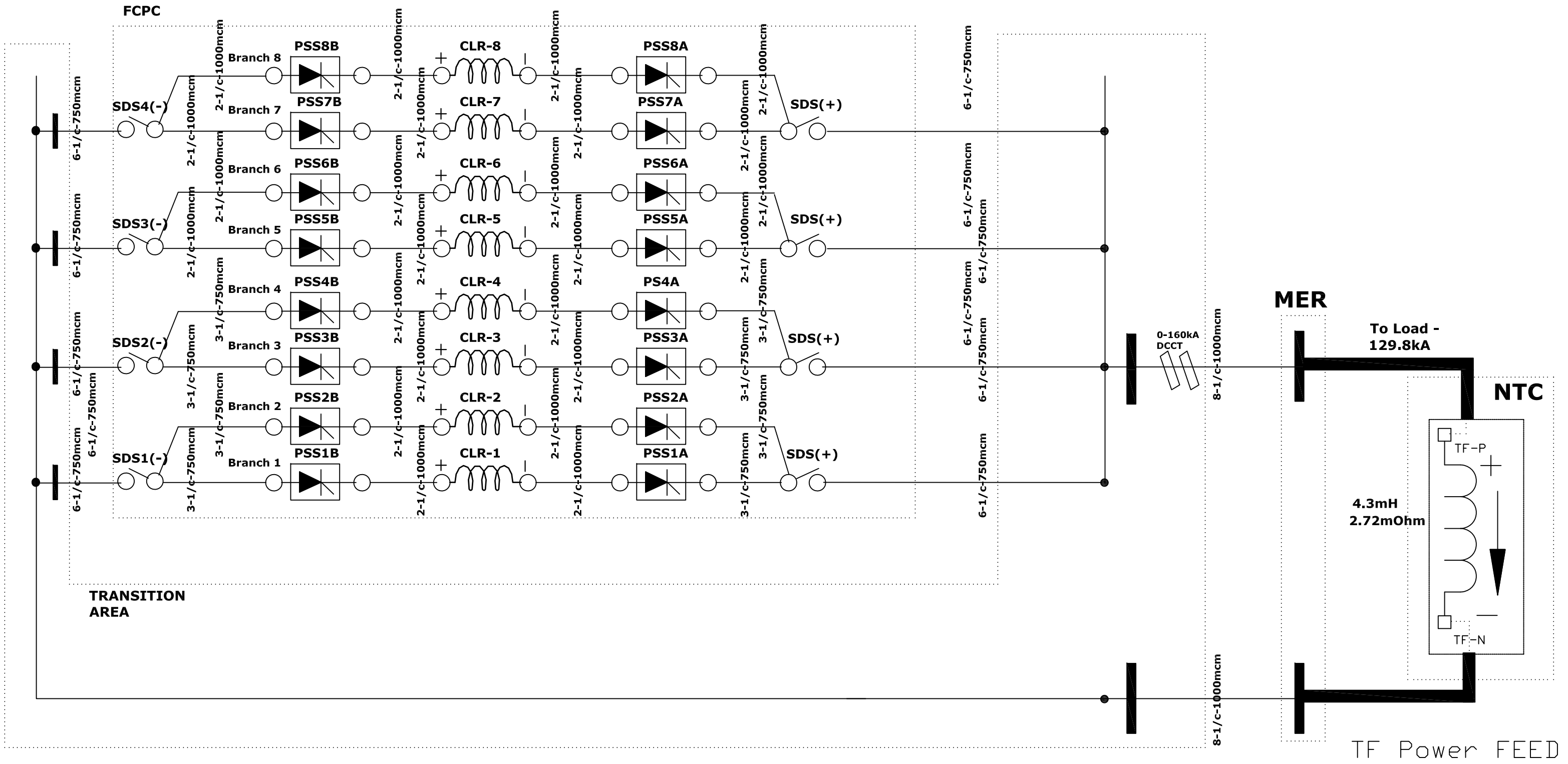
	PSS to SDS Cabling without CLR				*PSS to CLR Cabling*												SDS to TA Cabling										
	Cable	**Cable**	**Length loop**	**Resis.**	**CLR Cable**	**Cable**	**Length loop**	**Resis.**	**Total loop resistance above SDS to PSS**	**Kimbark Resis.**	**Total loop resistance above SDS including Kimbark**	**Effective Kimbark Res + Cable Res.of two parallels**	**Res.from SDS to TA (P)**	**Res.from SDS to TA (N)**	**Total loop resistance SDS to TA**	**Eff. Loop res. From Rect. To TA**	**Total effective Res. Of the four parallels TA to SDS**	**Share of flat top amps of 129800 for each SDS**	**Branch Amps**	**PS to SDS Volt drop**	**SDS to TA volt drop**	**TA to PCTS Volt drop**	**Load side Volt drop at TA (includes coil)**	**Total voltage required at PS**	**Max % unbalance above required**	**Max % unbalance below required**	**COS (Alpha) reqd.**	**Alpha reqd.**
	kcmil	# in Parallel	feet	mOhms	1000mcm	# in Parallel	feet	mOhms	mOhms	Ohms	mOhms	mOhms	mOhms	mOhms	mOhms	mOhms	mOhms	Amps	Amps	Volts	Volts	Volts	Volts	Volts				Degrees
Branch 1	750mcm	3	390	2.38	1000mcm	2	215	1.48	4.86	0.0087	13.536								**17728**	240				721			0.71147	44.64512
Branch 2	750mcm	3	350	2.14	1000mcm	2	180	1.24	4.37	0.0087	13.052	6.64	0.368805	0.3762	0.74504	7.38983		**33037**	**15309**	200	25			680			0.67181	47.7934
Branch 3	750mcm	3	330	2.01	1000mcm	2	105	0.72	3.74	0.0087	12.414								**14498**	180				658			0.65016	49.44643
Branch 4	750mcm	3	310	1.89	1000mcm	2	145	1.00	3.89	0.0087	12.567	6.25	0.355191	0.3614	0.71657	6.96171	1.75686	**31412**	**16914**	213	23	**67**	**456**	691	**14**	**-16**	0.68232	46.97491
Branch 5	1000mcm	2	300	2.06	1000mcm	2	160	1.10	4.16	0.0087	12.838								**18526**	238				716			0.70727	44.98706
Branch 6	1000mcm	2	275	1.89	1000mcm	2	130	0.89	3.78	0.0087	12.460	6.32	0.34529	0.3527	0.69801	7.02115		**32220**	**13694**	171	22			649			0.64090	50.14129
Branch 7	1000mcm	2	250	1.72	1000mcm	2	140	0.96	3.68	0.0087	12.357								**15303**	189				667			0.65893	48.78143
Branch 8	1000mcm	2	225	1.55	1000mcm	2	105	0.72	3.27	0.0087	11.945	6.07	0.34529	0.3465	0.69182	6.76563		**32210**	**16908**	202	22			680			0.67164	47.80635
																		128879	**128879**									

Table 3C UNBALANCE ON BRANCHES BASED ON FORCED ALPHA VARIATIONS - Alpha randomly chosen

CALCULATIONS BELOW ARE FOR FLATTOP - assume unbalance as indicated in each branch

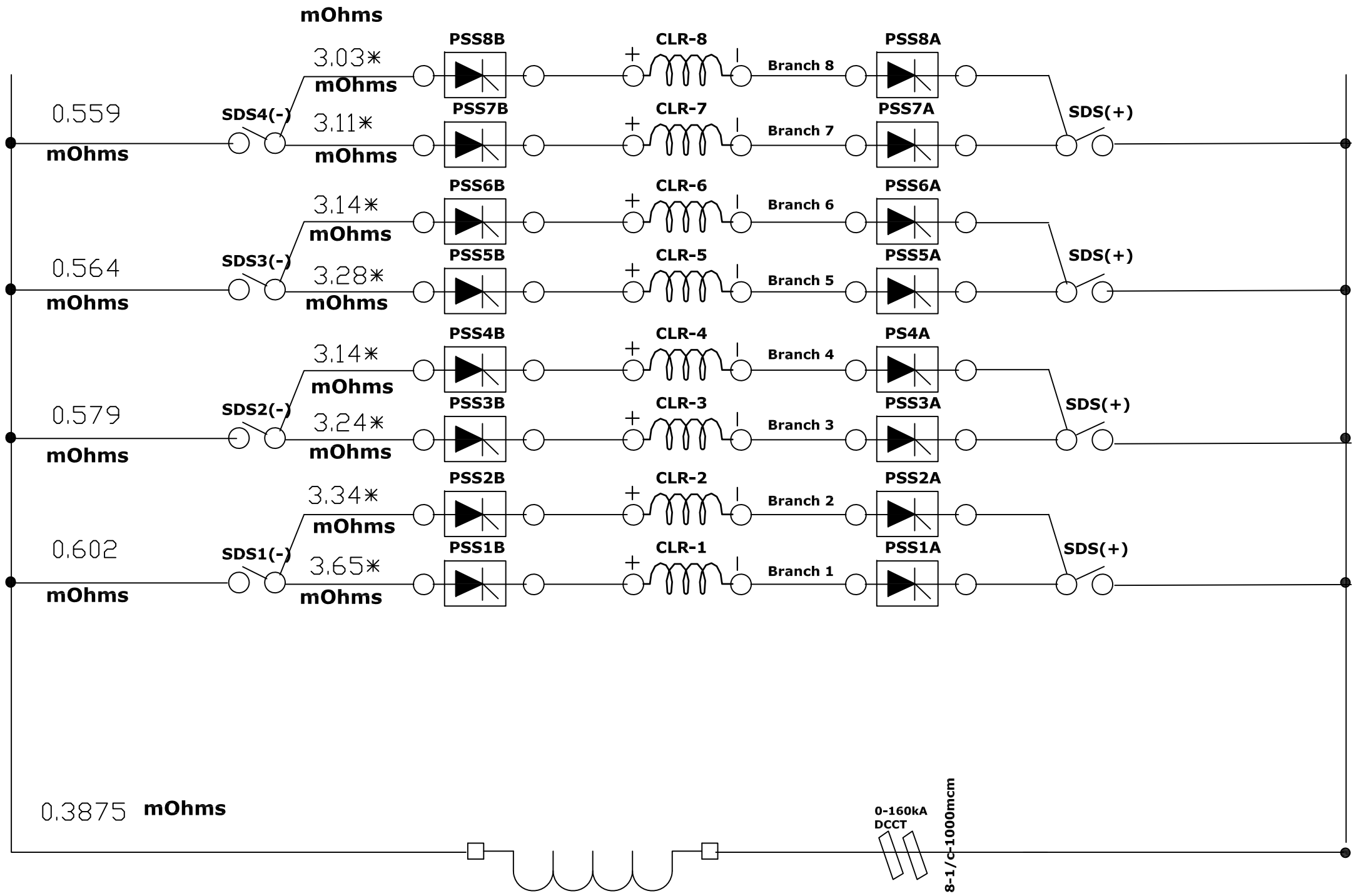
	PSS to SDS Cabling without CLR				*PSS to CLR Cabling*												SDS to TA Cabling										
	Cable	**Cable**	**Length loop**	**Resis.**	**CLR Cable**	**Cable**	**Length loop**	**Resis.**	**Total loop resistance above SDS to PSS**	**Kimbark Resis.**	**Total loop resistance above SDS including Kimbark**	**Effective Kimbark Res + Cable Res.of two parallels**	**Res.from SDS to TA (P)**	**Res.from SDS to TA (N)**	**Total loop resistance SDS to TA**	**Eff. Loop res. From Rect. To TA**	**Total effective Res. Of the four parallels TA to SDS**	**Share of flat top amps of 129800 for each SDS**	**Branch Amps**	**PS to SDS Volt drop**	**SDS to TA volt drop**	**TA to PCTS Volt drop**	**Load side Volt drop at TA (includes coil)**	**Total voltage required at PS**	**Max % unbalance above required**	**Max % unbalance below required**	**COS (Alpha) reqd.**	**Alpha reqd.**
	kcmil	# in Parallel	feet	mOhms	1000mcm	# in Parallel	feet	mOhms	mOhms	Ohms	mOhms	mOhms	mOhms	mOhms	mOhms	mOhms	mOhms	Amps	Amps	Volts	Volts	Volts	Volts	Volts				Degrees
Branch 1	750mcm	3	390	2.38	1000mcm	2	215	1.48	4.86	0.0087	13.536								**17586**	238				718			0.70932	44.82000
Branch 2	750mcm	3	350	2.14	1000mcm	2	180	1.24	4.37	0.0087	13.052	6.64	0.368805	0.3762	0.74504	7.38983		**32706**	**15120**	197	24			678			0.66913	48.00000
Branch 3	750mcm	3	330	2.01	1000mcm	2	105	0.72	3.74	0.0087	12.414								**16021**	199				678			0.66913	48.00000
Branch 4	750mcm	3	310	1.89	1000mcm	2	145	1.00	3.89	0.0087	12.567	6.25	0.355191	0.3614	0.71657	6.96171	1.75686	**31847**	**15826**	199	23	**67**	**456**	678	**8**	**-7**	0.66913	48.00000
Branch 5	1000mcm	2	300	2.06	1000mcm	2	160	1.10	4.16	0.0087	12.838								**15553**	200				678			0.66913	48.00000
Branch 6	1000mcm	2	275	1.89	1000mcm	2	130	0.89	3.78	0.0087	12.460	6.32	0.34529	0.3527	0.69801	7.02115		**31577**	**16024**	200	22			678			0.66913	48.00000
Branch 7	1000mcm	2	250	1.72	1000mcm	2	140	0.96	3.68	0.0087	12.357								**16107**	199				678			0.66913	48.00000
Branch 8	1000mcm	2	225	1.55	1000mcm	2	105	0.72	3.27	0.0087	11.945	6.07	0.34529	0.3465	0.69182	6.76563		**32770**	**16663**	199	23			678			0.66913	48.00000
																		128899	**128899**									

2kV - 24kA, 6.6s every 300s
Typical of each of 8 parallels



1kV - 24kA each PSS pulsed
Typical of each of 8 parallels

*** Includes all cables & CLR**
Kimbark resis at 64Hz: 8.8 mOhms
All AC CLRs are 0.5 Ohms



TF Power FEED