

# Arc Detection Arc Fault Circuit Interruption

Presented  
To  
**Protection Engineering Group**  
4/12/2000



**Hendry Telephone Products** Santa Barbara Research Park • Goleta, California USA

# *Agenda*

- u Standards of arc detection
- u The arc detection challenge
  - u Characteristics of arcs
  - u Characteristics of loads
  - u Electrical environment
  - u Engineering trade-offs
- u Hendry principles of arc detection
- u Summary

# *Hendry Arc Detection Technology*

- u Conducted research into arc detection for the past 15 years
- u Has domestic and international patents in the field
- u Can provide protection for DC as well as AC circuits
- u Is under contract with the ONR for development of an AFCI
  - | Development program spans 2-3 years
  - | Specification and test development is part of the program
  - | Navy will field test approximately 20 samples



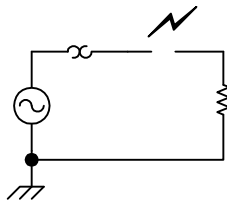
## *Standards Of Arc Detection*



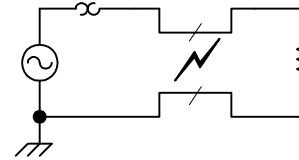
- u UL1699 - Initial commercial standard
- u First iteration
- u Key arc detection tests for a branch feeder protector:
  - u A 20 ampere breaker must clear a 75 ampere fault of certain characteristics of duration and duty cycle
  - u A piece of test cotton must not ignite when exposed to a carbonized path test
- u An outlet circuit AFCI of a 15 or 20 ampere rating must clear a 10 ampere arc within .4 sec

# Arc Fault Circuits

## u Series

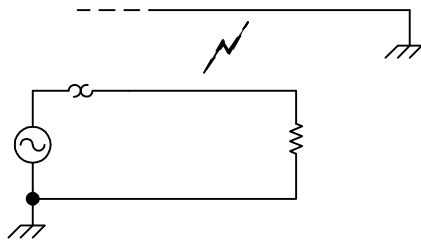


## u Parallel



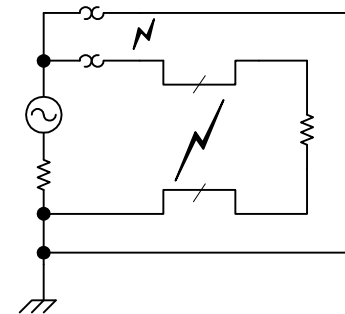
## u Ground Fault

| including arcing to adjacent active lines



## u Crosstalk

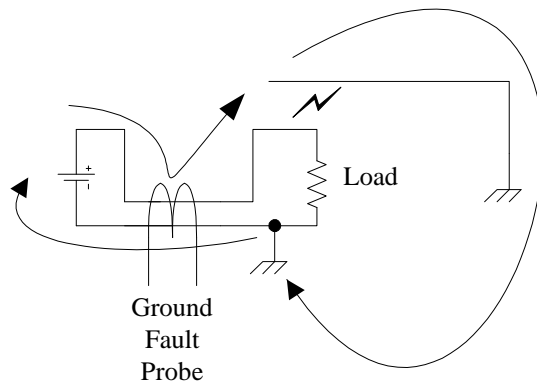
| including radiated and induced arc currents, and arc currents caused by common source impedances



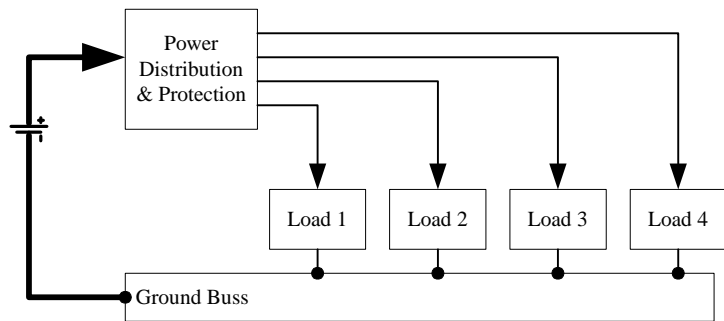
# ***Characteristics Of Reliable Arc Fault Detection***

- u Differentiate between normal load current and arc current
- u Insensitive to crosstalk signals
- u Sense small arc current in the presence of large load currents
- u Insensitive to RFI/EMI
- u Immune to startup transients
- u Fail safe
- u High reliability - no false or nuisance trips

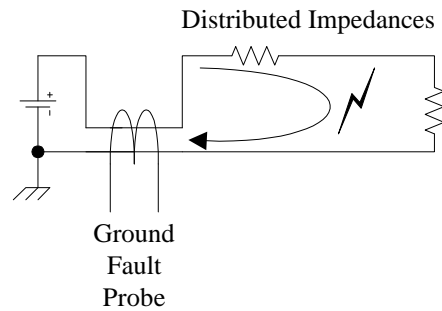
# Hendry Performance



- u Eliminates loss of protection due to ground returns past the monitoring point
- u Does not require a dedicated return line to monitor ground fault performance



# *Hendry Performance*



- u Can detect series arcs such as may be found from loose or damaged connections
- u Ground fault protection, as a separate function, may be added if desired

## *Hendry Performance*

- u Can detect arcs over considerable distances
- u Performance is not degraded by most intervening filters
- u May be augmented with time domain parameter monitoring
- u Detection is not dependent on radiated energy
- u Displays excellent crosstalk and discrimination ability
- u May be augmented with Ground Fault Detection

# ***Texas Instruments - Klixon Circuit Breaker Technology***



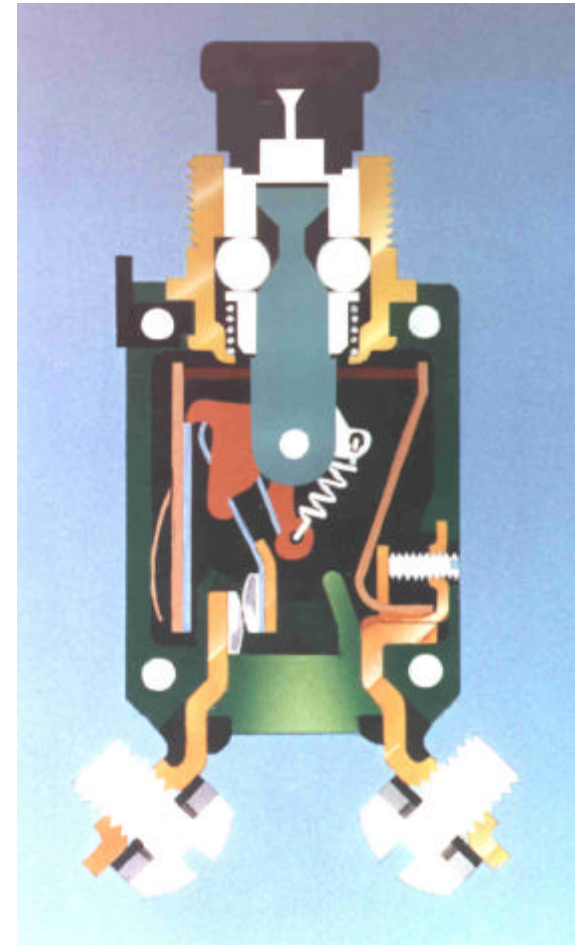
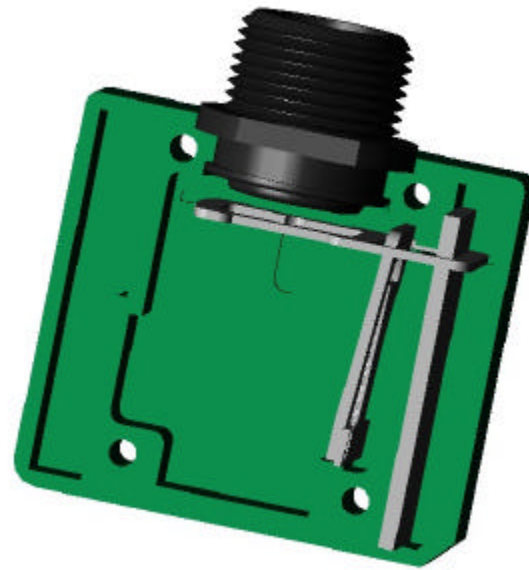
- u Dominate presence in aircraft and military circuit breakers throughout the world
- u Highly reputable

# *Circuit Breaker Technology*

- u Initial Concepts Under Evaluation For Boeing Aircraft
- u Circuit Breaker Tradeoffs

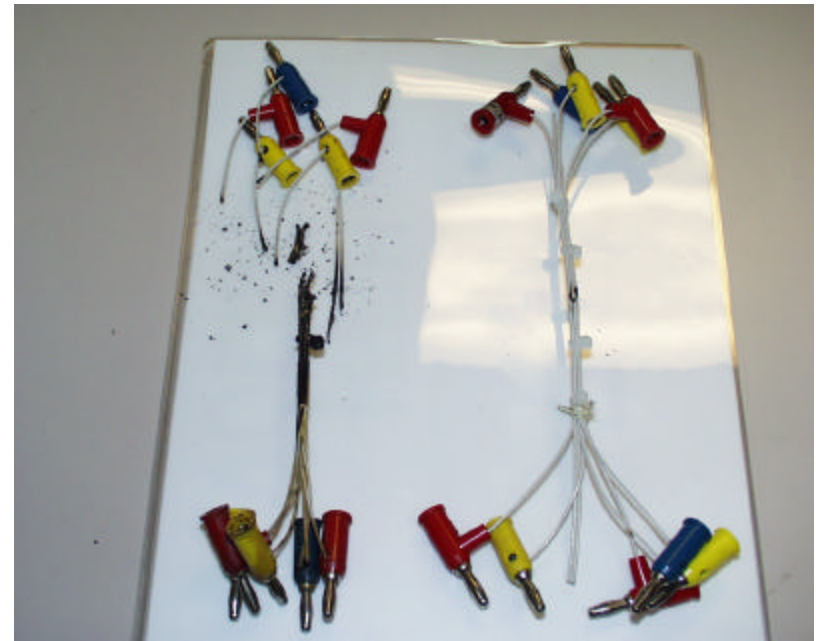
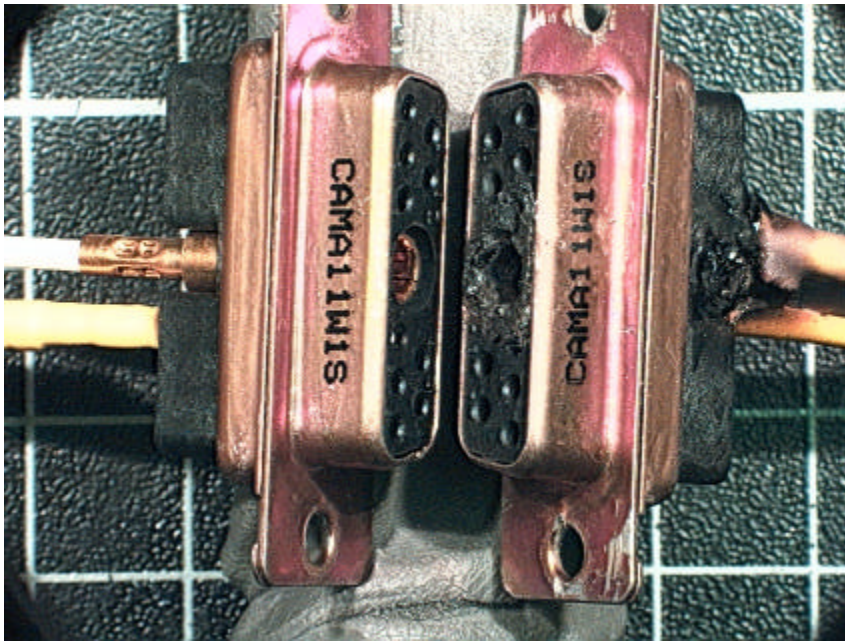


# *Circuit Breaker Technology*

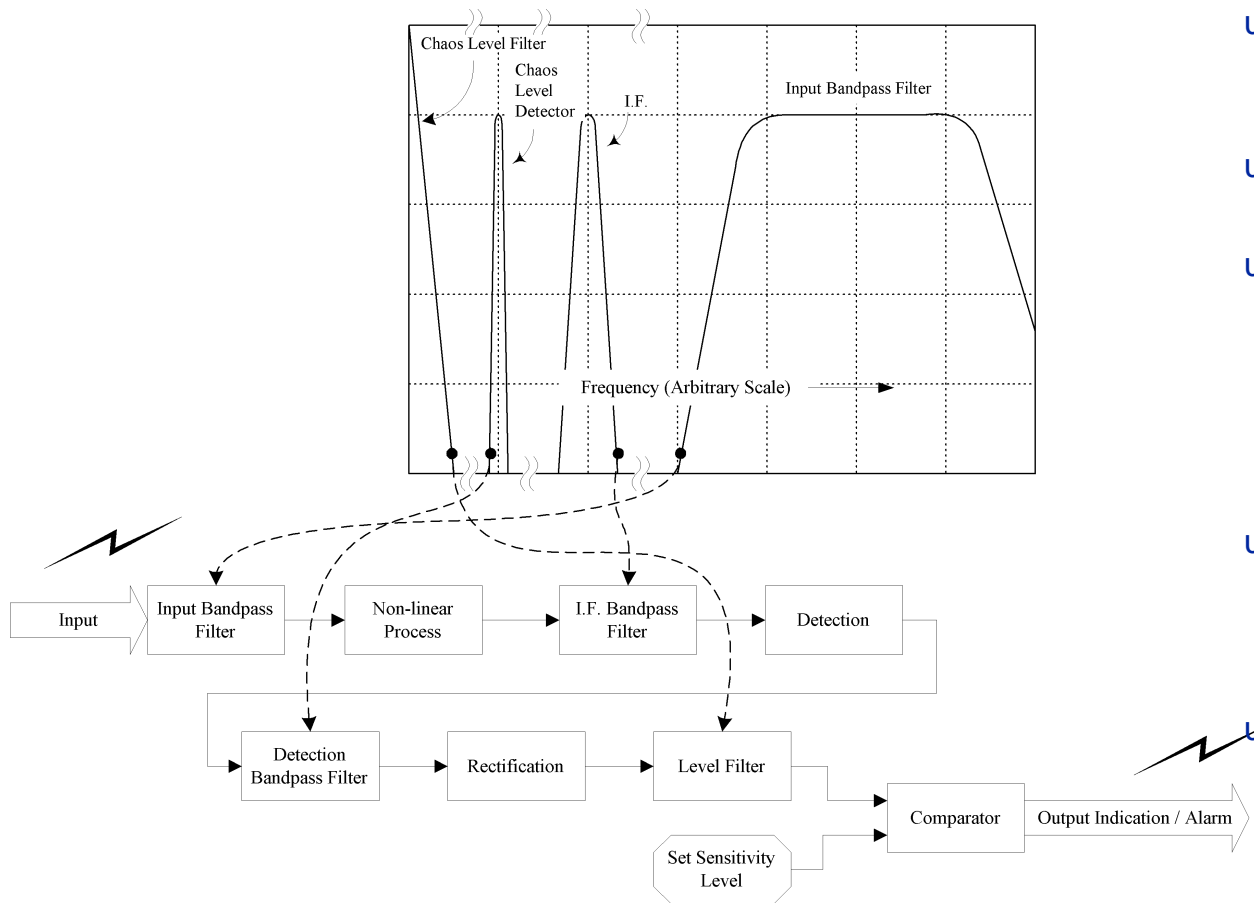


## *Concept Testing At Boeing*

Comparison of protection under arcing conditions using standard circuit breakers vs. Hendry arc detection



# Hendry's Principles Of DC Arc Detection

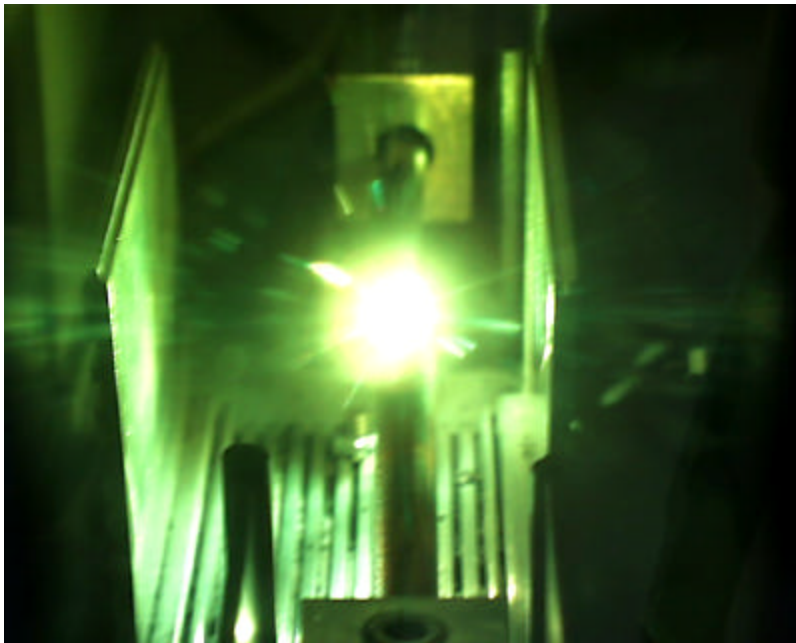


- u Responds to chaotic spectral density within a defined detection band
- u Non-linear process mixes the input signal with itself
- u Requires frequencies within the input passband that are separated by the I.F. frequency which also have frequency content around them
- u These frequencies, in turn, must also have frequency content around them
- u Domestic and international patents granted

## *Engineering Trade-Offs*

- u Sensitivity
- u Rejection of false alarms
- u Speed of response
- u Detection distance
- u Crosstalk - discrimination
- u Complexity - cost

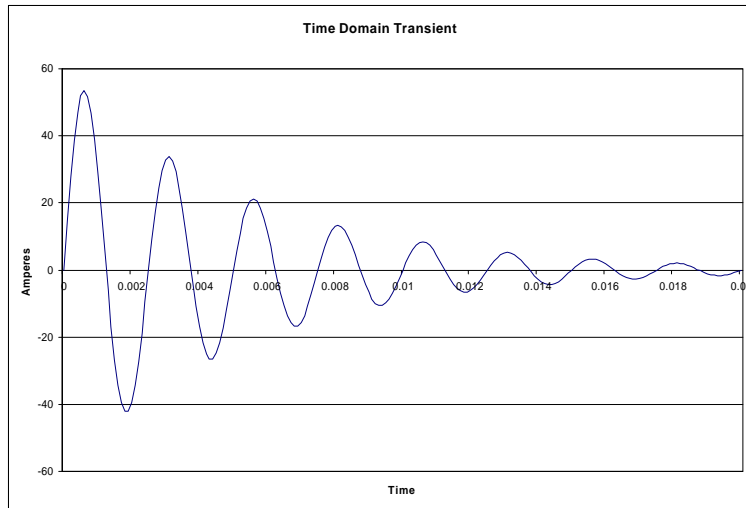
## *Spectral Plots*



- u Motor Generator voltage, unloaded
- u Motor Generator voltage, loaded
- u Current, linear
- u Arcing current, 7 A
- u Motor Generator voltage, 7 A arc
- u Arcing current, 13 A
- u Motor Generator voltage, 13 A arc

# Spectral Splatter From Transients

u Exponentially decaying sinusoid



$$f(t) = \begin{cases} A \sin \omega_0 t e^{-at} & \text{for } t \geq 0 \\ 0 & \text{for } t < 0 \end{cases}$$

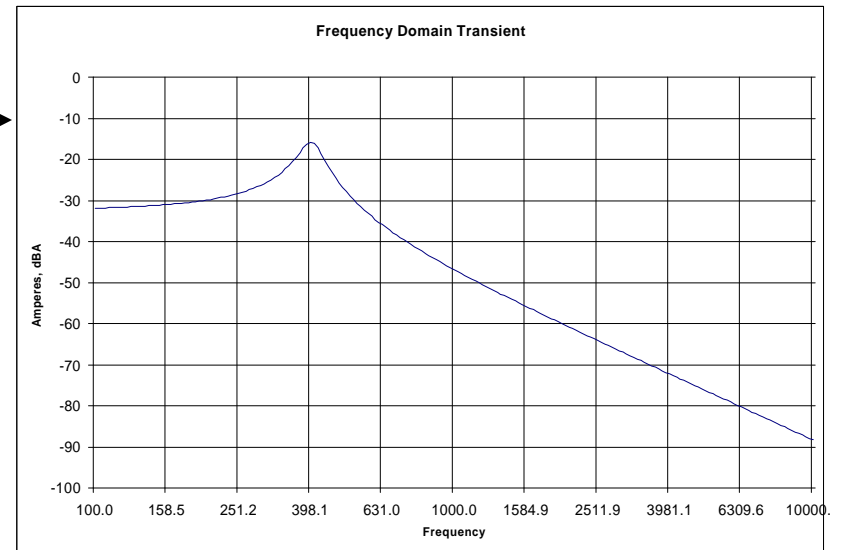
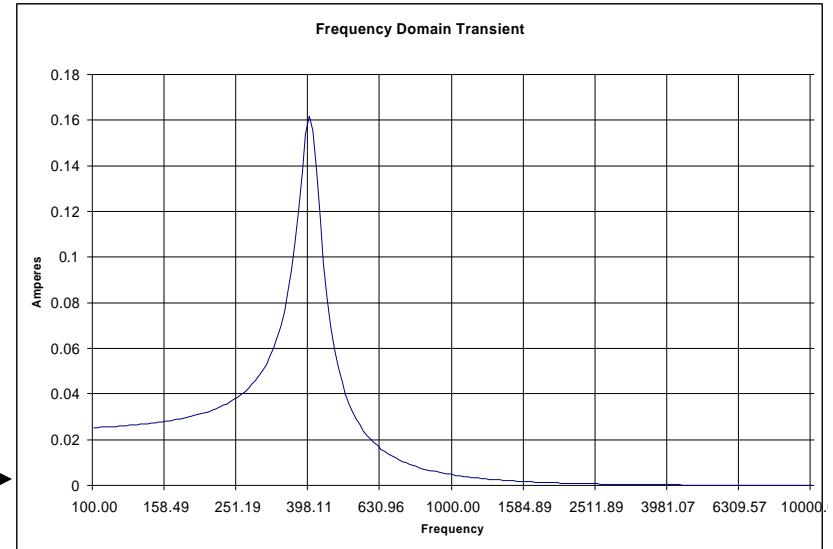
$$A = 60$$

$$\omega_0 = 2\pi \cdot 400$$

In example:

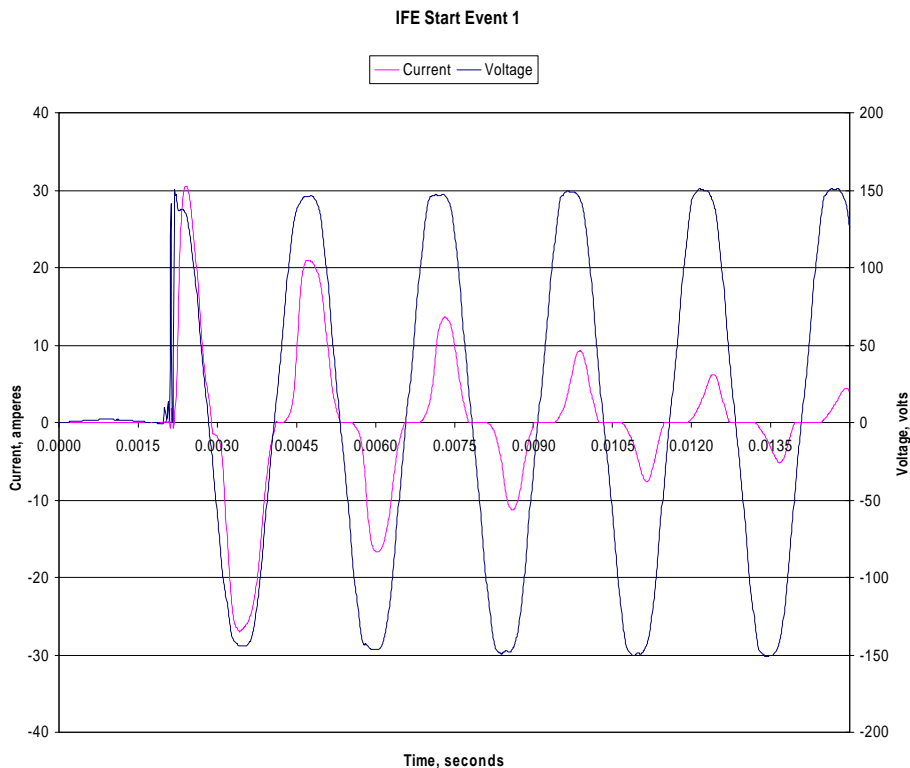
$$a = 1 / .0054$$

$$F(\omega) = \frac{A \omega_0}{(a + j\omega)^2 + \omega_0^2}$$



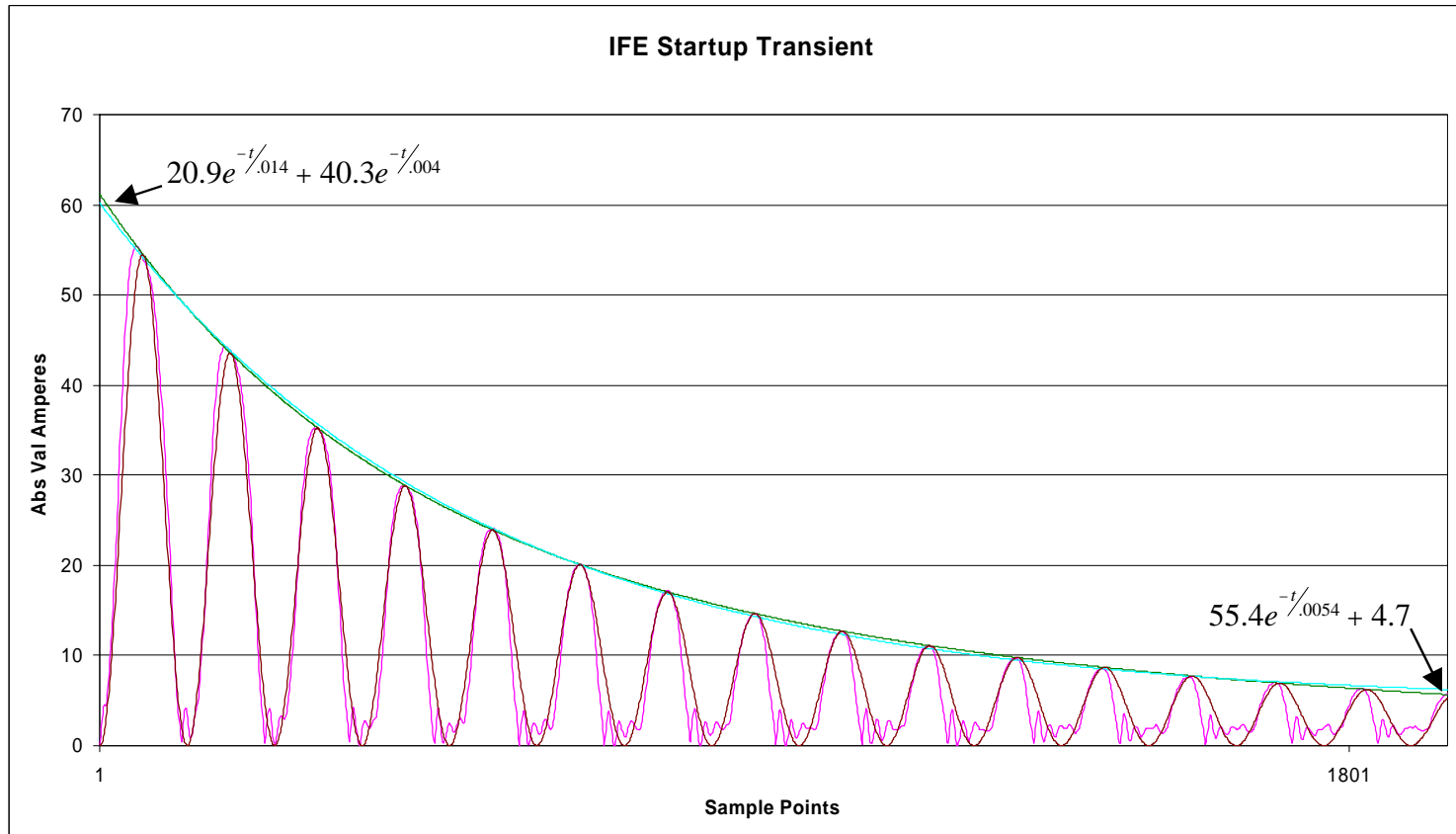
# Load Current Characteristics

(partially excerpted from NAVAIR Electrical Power Systems Div.)

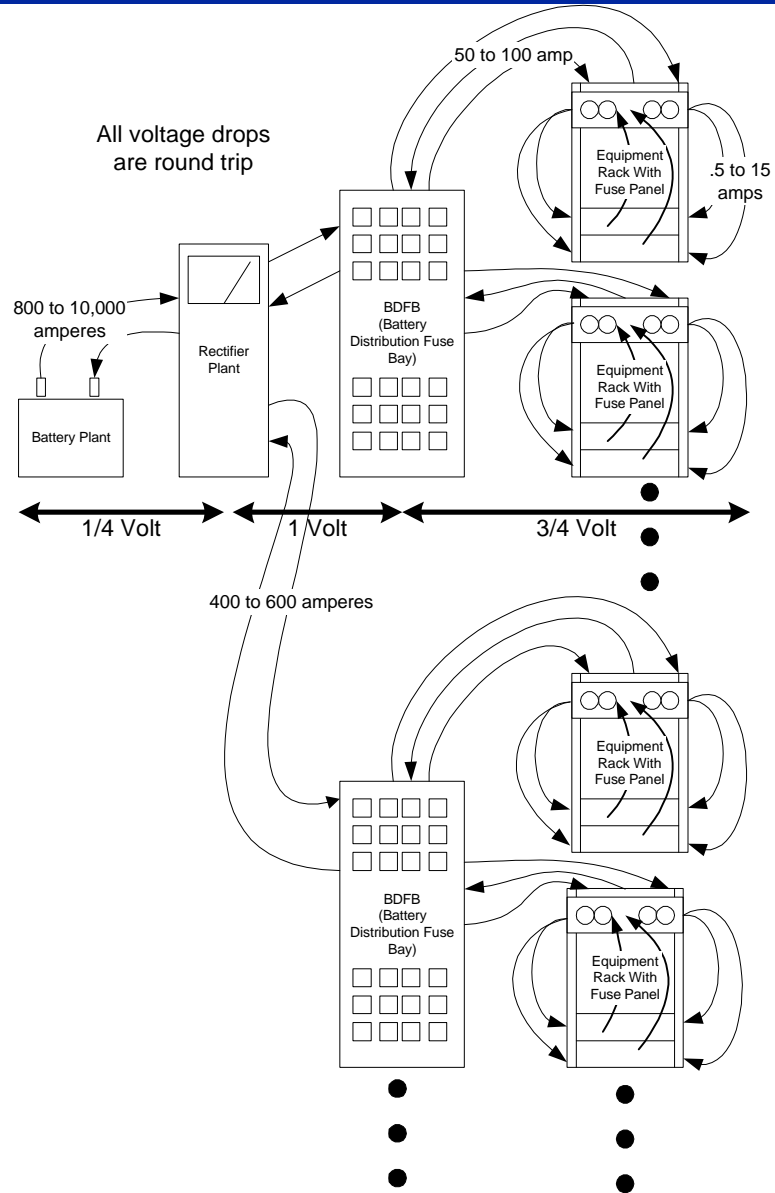


- u Linear loads with various power factors
- u Non-linear constant loads
- u Transient loads, linear and non-linear including pulsed loads
- u Loads which use a common structure as a return path
- u Loads which have a natural arcing characteristic (i.e. contactors).

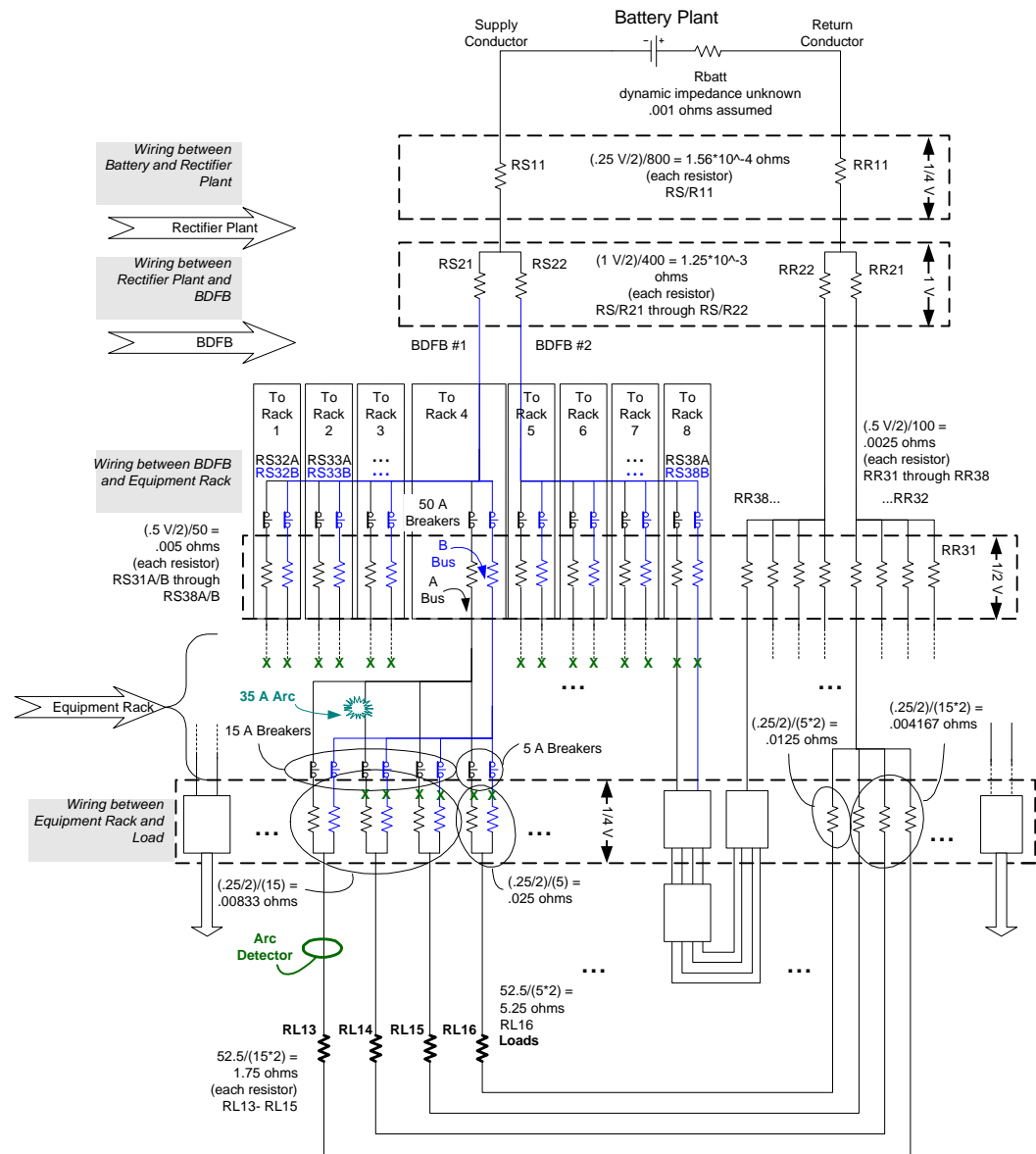
# Characterization Of Startup Transient



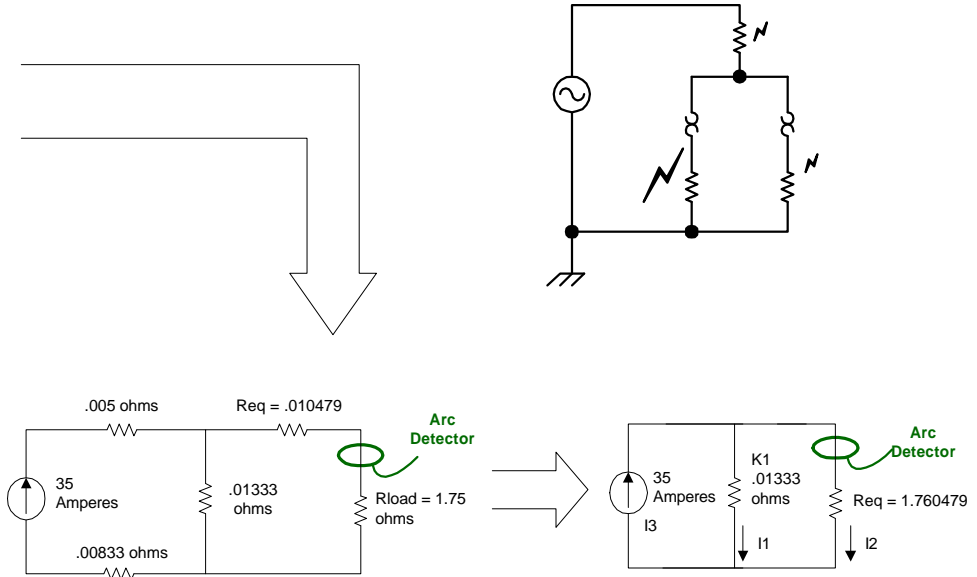
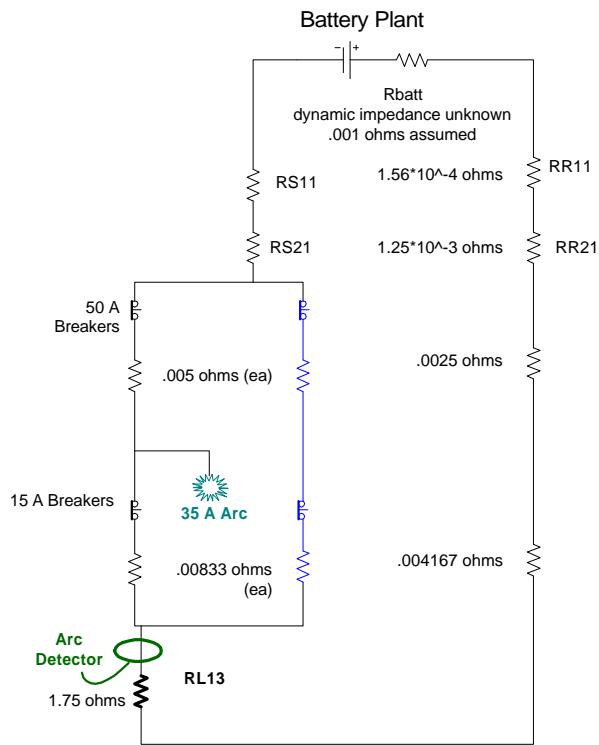
# *Discrimination Of Arcs In Parallel Power Buses*



# Discrimination Of Arcs In Parallel Power Buses



# Discrimination Of Arcs In Parallel Buses



# Geometry Of Current Flow

x	K1	K2	x	K1	K2	x	K1	K2	x	K1	K2
0.0	1.00000	1.00000	2.9	1.28644	0.86012	6.6	2.60313	0.42389	17	6.26817	0.16614
0.1	1.00000	1.00000	3.0	1.31809	0.84517	6.8	2.67312	0.41171	18	6.62129	0.15694
0.2	1.00001	1.00000	3.1	1.35102	0.82975	7.0	2.74319	0.40021	19	6.97446	0.14870
0.3	1.00004	0.99998	3.2	1.38504	0.81397	7.2	2.81334	0.38933	20	7.32767	0.14128
0.4	1.00013	0.99993	3.3	1.41999	0.79794	7.4	2.88355	0.37902	21	7.68091	0.13456
0.5	1.00032	0.99984	3.4	1.45570	0.78175	7.6	2.95380	0.36923	22	8.03418	0.12846
0.6	1.00067	0.99966	3.5	1.49202	0.76550	7.8	3.02411	0.35992	23	8.38748	0.12288
0.7	1.00124	0.99937	3.6	1.52879	0.74929	8.0	3.09445	0.35107	24	8.74079	0.11777
0.8	1.00212	0.99894	3.7	1.56587	0.73320	8.2	3.16480	0.34263	25	9.09412	0.11307
0.9	1.00340	0.99830	3.8	1.60314	0.71729	8.4	3.23518	0.33460	26	9.44748	0.10872
1.0	1.00519	0.99741	3.9	1.64051	0.70165	8.6	3.30557	0.32692	28	10.15422	0.10096
1.1	1.00758	0.99621	4.0	1.67787	0.68632	8.8	3.37597	0.31958	30	10.86101	0.09424
1.2	1.01071	0.99465	4.1	1.71516	0.67135	9.0	3.44638	0.31257	32	11.56785	0.08835
1.3	1.01470	0.99266	4.2	1.75233	0.65677	9.2	3.51680	0.30585	34	12.27471	0.08316
1.4	1.01969	0.99017	4.3	1.78933	0.64262	9.4	3.58723	0.29941	36	12.98160	0.07854
1.5	1.02582	0.98711	4.4	1.82614	0.62890	9.6	3.65766	0.29324	38	13.68852	0.07441
1.6	1.03323	0.98342	4.5	1.86275	0.61563	9.8	3.72812	0.28731	40	14.39545	0.07069
1.7	1.04205	0.97904	4.6	1.89914	0.60281	10.0	3.79857	0.28162	42	15.10240	0.06733
1.8	1.05240	0.97390	4.7	1.93533	0.59044	10.5	3.97477	0.26832	44	15.80936	0.06427
1.9	1.06440	0.96795	4.8	1.97131	0.57852	11.0	4.15100	0.25622	46	16.51634	0.06148
2.0	1.07816	0.96113	4.9	2.00710	0.56703	11.5	4.32727	0.24516	48	17.22333	0.05892
2.1	1.09375	0.95343	5.0	2.04272	0.55597	12.0	4.50358	0.23501	50	17.93032	0.05656
2.2	1.11126	0.94482	5.2	2.11353	0.53506	12.5	4.67993	0.22567	60	21.46541	0.04713
2.3	1.13069	0.93527	5.4	2.18389	0.51566	13.0	4.85631	0.21703	70	25.00063	0.04040
2.4	1.15207	0.92482	5.6	2.25393	0.49764	13.5	5.03272	0.20903	80	28.53593	0.03535
2.5	1.17538	0.91347	5.8	2.32380	0.48086	14.0	5.20915	0.20160	90	32.07127	0.03142
2.6	1.20056	0.90126	6.0	2.39359	0.46521	14.5	5.38560	0.19468	100	35.60666	0.02828
2.7	1.22753	0.88825	6.2	2.46338	0.45056	15.0	5.56208	0.18822			
2.8	1.25620	0.87451	6.4	2.53321	0.43682	16.0	5.91509	0.17649			

u Effect of conductors on current flow geometry

$$R' = K_1 R$$

$$x = 2\pi a \sqrt{\frac{2f\mu}{\rho}}$$

$$x = 0.063598 \left( \sqrt{\frac{f}{R}} \right)$$

$$L' = 2 \left( \ln \left( \frac{d}{a} \right) \right) + K_2 \left( \frac{\mu}{2} \right)$$

# Geometry Of Current Flow

- u The nature of the power source, loads, and wiring (including wire size and conductor spacing) can have a significant impact on where arc currents flow

Frequency	0	100	1000
Ohms per mile, Mcm300	0.1926	0.1926	0.1926
x	<b>0.00</b>	<b>1.45</b>	<b>4.58</b>
K1 (interpolated)	<b>1</b>	<b>1.0227</b>	<b>1.8928</b>
K2 (interpolated)	<b>1</b>	<b>0.9887</b>	<b>0.6051</b>
d/a	10	10	10
abhenries per centimeter	<b>5.1052</b>	<b>5.0995</b>	<b>4.9077</b>
DC Resistance	0.01333	0.01333	0.01333
Length of conductor, round trip	365.4	365.4	365.4
Henries per foot	<b>1.56E-07</b>	<b>1.55E-07</b>	<b>1.50E-07</b>
Resistance of Z1 at frequency	<b>0.0133</b>	<b>0.0136</b>	<b>0.0252</b>
Inductive reactance of Z1 at frequency	<b>0.0000</b>	<b>0.0357</b>	<b>0.3434</b>
Z2	1.7605	1.7605	1.7605
Abs[Z1/(Z1 + Z2)]	<b>0.75%</b>	<b>2.15%</b>	<b>18.94%</b>
Arc required to give a false reading	<b>133.1</b>	<b>46.5</b>	<b>5.3</b>

# ***Hendry Telephone Products***

- Your Total Solution -

