IEEE802.3at Study Group

Maximum Power - System considerations

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Agenda

- Maximum current limitations (per conductor)
  - References taken from Cabling or other related Standards
  - Safety Standards (LPS)
  - Stability Criteria
  - PSE current limit design criteria
  - System efficiency and cost criteria
  - Data Integrity
  - Max operating current per conductor
- Operating voltage range
  - IEEE802.3af range
  - IEEE802.3poep suggested range
- Practical Maximum power

References taken from Cabling or other related Standards

- FCC[4,7,annex A]
  - 0.42A @ 25 deg C per conductor @ all conductors are working (8 conductors, 4pairs)
  - 0.197A @ 60 deg C per conductor (derating curves are not supplied. Instead connector derating curves were used.)

- TIA/EIA: SP-4425-AD6E_B.1-AD6DC_Draft6[10]
  - 0.42A at operating temperature range, per conductor
  - The most updated requirements for cabling manufactures.

- Mil / Nec Stds: 0.56A per conductor @ TBD deg C[5]
- NASA: 0.3A/Conductor @ 5.5 deg C rise[5]
- NASA: 0.43A/Conductor @ 11 deg C rise[5]

- Connectors[8,9,11]:
  - 0.75A per contact at 60 deg C[4,8,9].
    - Need to define margin factor of the total current permitted for two contacts in parallel.
    - Contact resistance vs current/voltage during un mating need to verified to meet the connectors reliability specifications

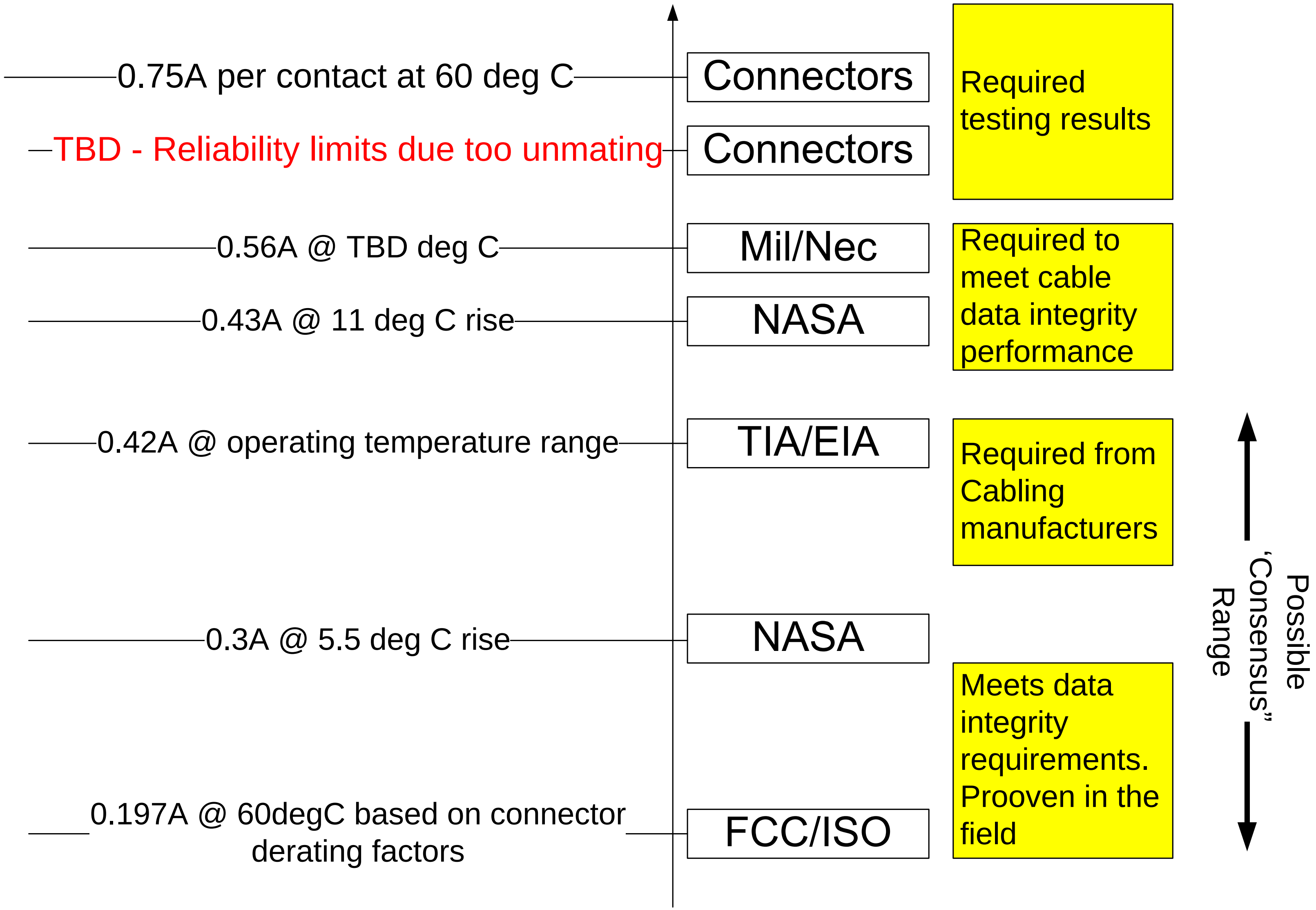
References taken from Cabling or other related Standards

- Tested Data status

- Max current per conductor need to be tested in various cabling installations for:
  - Temperature rise vs current per conductor
  - Temperature rise effects on cabling data performance
  - Setting design margins and port operating parameters
- Connector performance during un mating
  - DC resistance
  - Other relevant performance parameters

- *Draft test procedure under development in a PoE+ ad hoc group (Chris DiMinico). Expected availability of a draft test procedure for IEEE 802.3 PoE+ Study Group review week September 26 th* .

References taken from Cabling or other related Standards



Safety Standards Requirements (LPS)

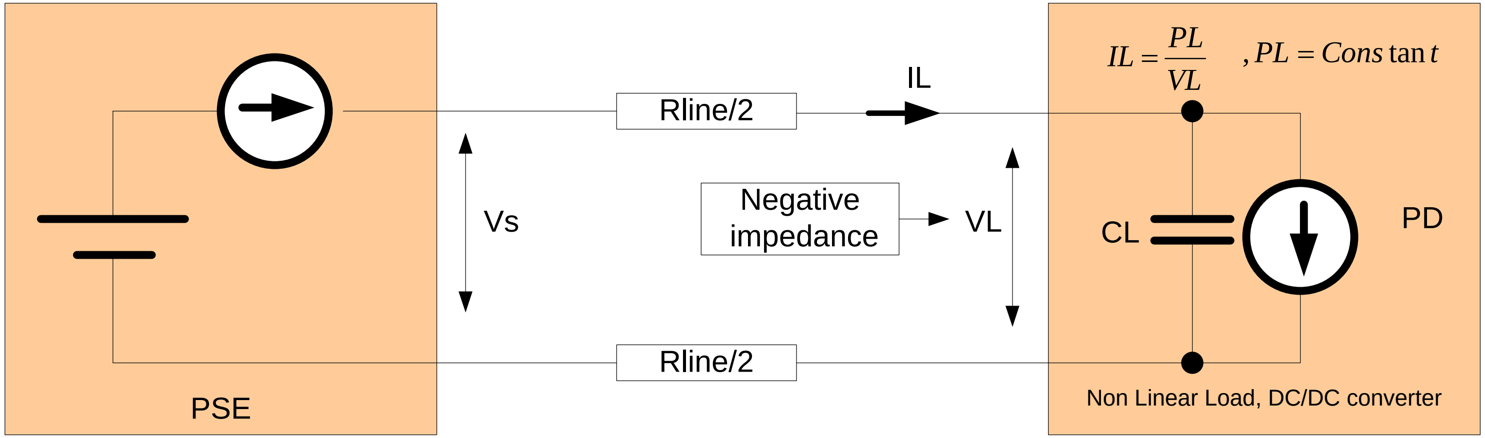
– 100VA / Vport = 100VA/44V=2.273A

- 0.568Aper conductor

– *UL permits up to 1.3A per* wire

– Safety requirements are not the limiting factors

Stability[13] Criteria at Startup



Rline=25Ω/round loop conductor
Rline=12.5Ω / 2P
Rline=6.25Ω / 4P

$$\frac{Vs - VL}{Rline} = IL = \frac{PL}{VL}$$

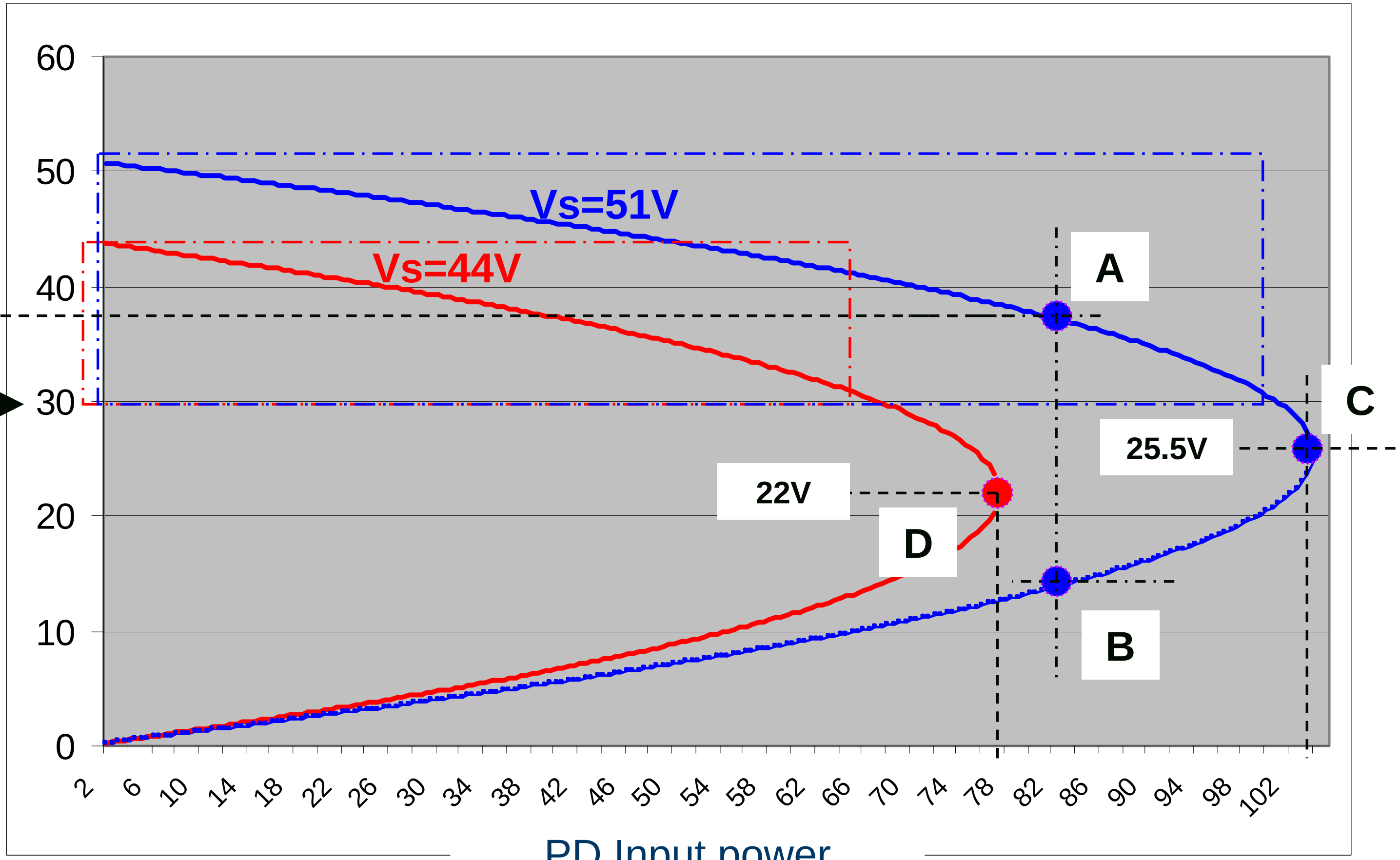
- PD load is constant hence generating negative impedance.
- Model Equation: $VL1, VL2 = \frac{Vs \pm \sqrt{Vs^2 - 4 \cdot PL \cdot RLine}}{2}$
- Stability at startup mode: $Vs^2 - 4 \cdot PL \cdot RLine \geq 0$

Stability Criteria at Startup – Operating Zone

PD Input Voltage

37V

30V



Notes:

1. For the same power level, Vpd has two values **A and B** hence instable operation
2. PD max power always at Vs/2. See points **C and D**
3. IEEE802.3af minimum operating region = 30V. Preventing working below **C and D**.

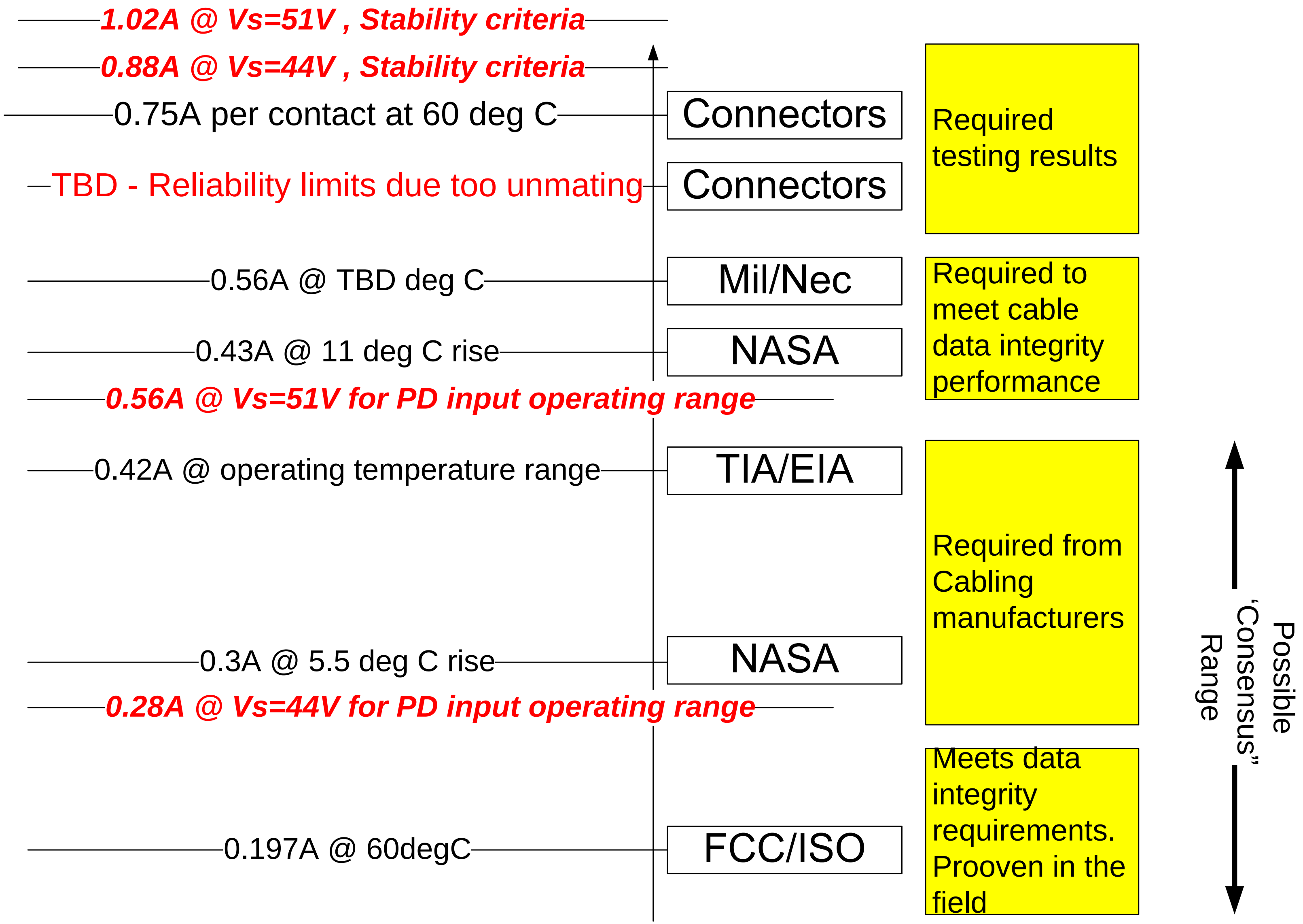
Stability Criteria at Startup and Normal powering mode

- Max values per conductor:
  - Max power ……..:
    $$PL < Vs^2/(4\cdot Rline) = \begin{Bmatrix} 44^2/100 = 19.36W @ 44V \\ 51^2/100 = 26W @ 51V \end{Bmatrix}$$
  - Max current ….:
    $$ILp < \frac{Vs}{2\cdot Rline} = \begin{Bmatrix} \frac{44}{2\cdot 25} = 0.88A @ Vs = 44V \\ \frac{51}{2\cdot 25} = 1.02A @ Vs = 51V \end{Bmatrix}$$
- However:
- Max current for meeting 802.3af PD input operating voltage range…..

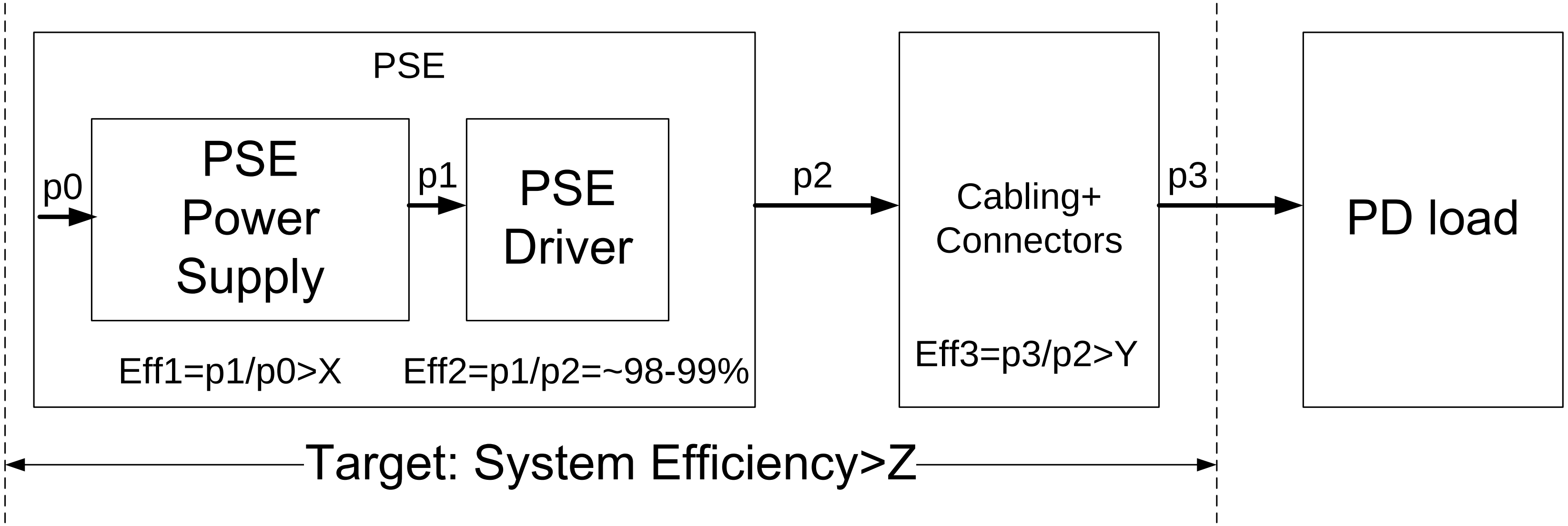
$$IL < \frac{Vs - VL}{Rline} = \begin{Bmatrix} \frac{44-37V}{25} = 0.28A @ Vs = 44V \\ \frac{51-37V}{25} = 0.56A @ Vs = 51V \end{Bmatrix}$$ Per conductor

$$Max\_power < VL\cdot IL = \begin{Bmatrix} 37V\cdot 0.28A = 10.36W @ Vs = 44V \\ 37V\cdot 0.56A = 20.72W @ Vs = 51V \end{Bmatrix}$$ Per conductor

Updated limitations list



System[13] cost effective efficiency criteria



$$Example\_1:$$

$$Eff1 =\sim 0.85, Eff2 = 0.98, Z = 0.8, Ppd = p3 = ?$$

$$Eff1 \cdot Eff2 \cdot Eff3 > Z$$

$$Eff3 > \frac{0.8}{0.85 \cdot 0.98} = 0.96$$

$$Eff3 = \frac{Ppd}{Ppd + \left(0.5 \cdot Vs - 0.5 \cdot \sqrt{Vs^2 - 4 \cdot Ppd \cdot Rline}\right)^2 \cdot \frac{1}{Rline}}$$

$$IL\_per\_conductor = \frac{Vs - \sqrt{Vs^2 - 4 \cdot Ppd \cdot RLine}}{4 \cdot 2 \cdot RLine}$$

$$@\ Rline = 6.25\Omega$$

Example for showing how system efficiency requirements limits PD input power, Ppd.

Solving Eff3[13] for getting Ppd:

Ppd=16W @ Eff3=0.96

System cost effective efficiency criteria

- <u>In the next example:</u>
  - Target efficiency=75%
  - Eff2=98%
  - The objective is to find cost effective Eff1 and Eff3 combinations that satisfies Eff1*Eff2*Eff3>75%
- <u>Method</u>
- Running Eff1 from 0 to 100% and Eff3 from 0 to 100% and keeping all results that satisfies all the following constrains:
  - Eff1*Eff3>0.75/0.98=76.5%
  - Eff1*Eff3<100%
  - Eff3 allows supporting 30W (=160mA per conductor at Vs=51V) by using the following equation (See annex B):

$$Eff3 = \frac{Ppd}{Ppd + \left(0.5 \cdot Vs - 0.5 \cdot \sqrt{Vs^2 - 4 \cdot Ppd \cdot Rline}\right)^2 \cdot \frac{1}{Rline}}$$

System cost effective efficiency criteria @ Vs=51V

Target Eff	Eff3	Eff2	Eff1
0.75	1.034	0.98	0.74
0.75	1.020	0.98	0.75
0.75	1.007	0.98	0.76
0.75	0.994	0.98	0.77
0.75	0.981	0.98	0.78
0.75	0.969	0.98	0.79
0.75	0.957	0.98	0.8
0.75	0.945	0.98	0.81
0.75	0.933	0.98	0.82
0.75	0.922	0.98	0.83
0.75	0.911	0.98	0.84
0.75	0.900	0.98	0.85
0.75	0.890	0.98	0.86
0.75	0.880	0.98	0.87
0.75	0.870	0.98	0.88
0.75	0.860	0.98	0.89
0.75	0.850	0.98	0.9
0.75	0.841	0.98	0.91
0.75	0.832	0.98	0.92
0.75	0.823	0.98	0.93
0.75	0.814	0.98	0.94
0.75	0.806	0.98	0.95
0.75	0.797	0.98	0.96
0.75	0.789	0.98	0.97
0.75	0.781	0.98	0.98
0.75	0.773	0.98	0.99
	0.000	0.98	1

Non physical solution

Less then 30W min

Feasible solution

May not be cost effective during the next 100years..

System cost effective efficiency criteria @ Vs=51V

- Analysis the results for the above example
  - Valid Eff3 range: 80%-91%
  - Valid Eff1 range: 84% -95%
  - Eff1 lower limit can be reduced by setting Target efficiency to lower value such 70%.
    - In this case Eff3 is 75% to 91% and Eff1 range is 78% - 95% (See annex C for complete table results)

- Once Eff3 is determined, Ppd can be derived and the current per conductor is calculated per example_1

System cost effective efficiency criteria

- **Conclusions:**

- Max current per conductor that allows flexible allocation of system components efficiencies (PSE PS, PSE driver and infrastructure and yet is still cost effective is:

Current per conductor for Target Efficiency=75%		Vs	
		44V	51V
Eff3	80%	0.35A	0.4A
	91%	0.16A	0.18A

Current per conductor for Target Efficiency=70%		Vs	
		44V	51V
Eff3	75%	0.44A	0.51A
	91%	0.16A	0.18A

Cost effective region

Updated limitations list

1.02A @ Vs=51V , Stability criteria

0.88A @ Vs=44V , Stability criteria

0.75A per contact at 60 deg C — Connectors

TBD - Reliability limits due too unmating — Connectors

Required testing results

0.56A @ TBD deg C — Mil/Nec

0.43A @ 11 deg C rise — NASA

0.56A @ Vs=51V for PD input operating range

Required to meet cable data integrity performance

0.42A @ operating temperature range — TIA/EIA

~0.4A @ Eff3~80%, Vs=51V

~0.35A @ Eff3~80%, Vs=44V

0.3A @ 5.5 deg C rise — NASA

0.28A @ Vs=44V for PD input operating range

Required from Cabling manufacturers

0.197A @ 60degC — FCC/ISO

~0.18A @ Eff3~90%, Vs=51V

~0.16A @ Eff3~90%, Vs=44V

Meets data integrity requirements. Prooven in the field

Possible 'Consensus" Range

Data Integrity – Temperature rise on the cabling

- Data parameters vs temp rise for I >175mA -200mA per conductor need to be tested
  - (350mA per 802.3af at steady state and 400mA in overload).

- Current below 175mA-200mA per conductor are already supported by current standards (IEEE802.3af, ISO, TIA/EIA and FCC)
  - No risks are expected.

Data Integrity – Data Transformer Current balance

- Effects of data transformers on max power limit are cost, system (4P vs 2P) and size issues.
  - Currently (per IEEE802.3af) 400mA should be supported.
    - 350mA at steady state, 33W (0.35A, 51V)
    - 400mA for 50mS min should be supported during overload, 37W (0.4A, 51V)
    - Any power below these power levels doesn't need current balancing circuit for the data transformer in the PD.
    - Above 33-37W PD specification should contains a requirements to limit the unbalanced current to the 802.3af levels. (~10mA)

PSE current limit design criteria

- If we keep the same maximum duty cycle and peak current duration as in 802.3af for Inrush and ILIM, the effect on DC current or RMS current will be negligible hence no effects on the limitations (proven in 802.3af)

- The important effects are thermal issues on the PSE driver and PD input current limit circuits however they are not infrastructure related.

- Conclusion: I_{LIM} and I_{INRUSH} are not a limiting factor for the infrastructure components

PSE OVLD current design criteria

- During Over load Vport stays at normal operating range.
- In 802.3af we allowed for 5% duty, 400mAp and 50ms duration.

- Keeping similar ratios for PoEp need to be accounted hence the following margins need to be taken;
  - Ip/Iavg=400mA/350mA ➔ ~15%
  - Duty cycle = ~5% (flexible, Cost related)
  - Ip time duration =~50mS (flexible, Cost related)

- Bottom line: Steady state maximum current per conductor should be ~15% lower then the final value of the max current per conductor that will be decided.

Updated limitations list

- ***1.02A @ Vs=51V , Stability criteria***
- ***0.88A @ Vs=44V , Stability criteria***
- 0.75A per contact at 60 deg C — **Connectors**
- **TBD - Reliability limits due too unmating** — **Connectors**

Required testing results

- 0.56A @ TBD deg C — **Mil/Nec**
- 0.43A @ 11 deg C rise — **NASA**
- ***0.56A @ Vs=51V for PD input operating range***

Required to meet cable data integrity performance

- 0.42A @ operating temperature range — **TIA/EIA**
- **~0.4A @ Eff3~80%, Vs=51V**
- **~0.35A @ Eff3~80%, Vs=44V**
- 0.3A @ 5.5 deg C rise — **NASA**
- ***0.28A @ Vs=44V for PD input operating range***
- **TBD – Temperature rise limits of 60deg C cables – Testing results**

Required from Cabling manufacturers

- 0.197A @ 60degC — **FCC/ISO**
- **~0.18A @ Eff3~90%, Vs=51V**
- **~0.16A @ Eff3~90%, Vs=44V**
- **~0.1A @ Eff3~90%, Vs=44V**

Meets data integrity requirements. Prooven in the field

Possible 'Consensus" Range

Summary of max operating current per conductor

- No risks at cabling level: 197mA/Conductor
- Connectors
  - Connector during un mating: TBD. We need test results
    - Connector specifications: 750mA/Contact at 60 degC
    - Hence 197mA/Conductor <<750mA should be OK?
- Data transformers
  - Need to be supported by 802.3af up to 200mA/Conductor
  - For higher currents (above 36W @51V, 200mA) PD should balance the current.
- TIA/EIA specifications
  - Requires 420mA per conductor at all operating temperature (per cable grade).
  - Needs testing to verify data integrity

Operating voltage range

– IEEE802.3af range

– 44VDC to 57VDC at the PSE

– 37VDC to 57VDC at the PD

– IEEE802.3poep suggested range at PSE

– 51V to 57V

- For increased power
- Still leaves reasonable ±5% tolerance
- Co exist with different legacy PoE voltages due to diode bridge presence in the PD

Practical Maximum power

- No risks: 36W @ 51V, 200mA per conductor at PD/4P
- Higher power possible:
  - Depends on temperature rise limitations vs data integrity performance.
  - Max ABS power per TIA/EIA document: 68W.
  - Derating factors:
    - Maintain system (PSE + Cabling) efficiency (not lower than 80%):65W
    - 15% margin to support overload function: ~55W
  - Hence max practical power *assuming the following:*
    - *no temperature rise issues*
    - *No connectors un mating degraded reliability issues*
    - *Not additional design margin is required*

55W max.

Summary

- System aspects as possible limiting factors were analyzed.
- There is sufficient power to meet objective (max practical power) without risks. (36W)
- Higher power possible per connector and cabling specifications.
  - Tests are required to verify effects on connector reliability during un mating and temperature rise on the cabling for higher power then 36W/4P

Annex A:FCC limits

- CAT5, CAT 6 wire size: worst case ➔AWG 24
- AWG 24 Max current capacity per conductor=2.1A
- Max current capacity of 8 conductor cable: 8*2.1A=16.8A
- Derating 80% if <u>all conductors</u> are carrying current in the cable: I_cable =16.8*(1-0.8)=3.36A ➔3.36A/8=0.42A per conductor
- Temperature derating curve for cable: Not exist
  - Assuming the same derating curve as connectors:
- Derating by 53% from 25C to 60C: 0.42A*(1-0.53)=0.197A per conductor

Annex B[13]- How to calculate Eff3

$$VL1, VL2 = \frac{Vs \pm \sqrt{Vs^2 - 4 \cdot Ppd \cdot RLine}}{2}$$

$$Stable\_solution:$$

$$VL1 = VL = \frac{Vs + \sqrt{Vs^2 - 4 \cdot Ppd \cdot RLine}}{2}$$

$$IL = \frac{Vs - VL}{Rline}$$

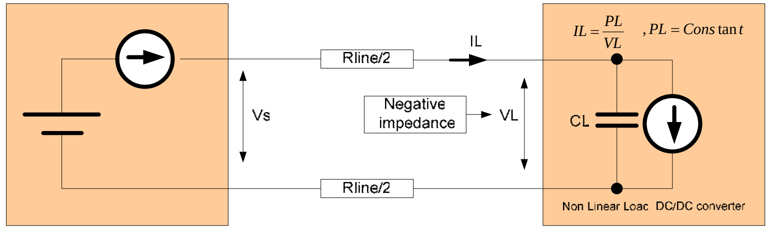
$$Pcable = IL^2 \cdot Rline$$

$$Eff3 = \frac{Ppd}{Ppse} = \frac{Ppd}{Ppd + Pcable} = \frac{Ppd}{Ppd + IL^2 \cdot Rline}$$

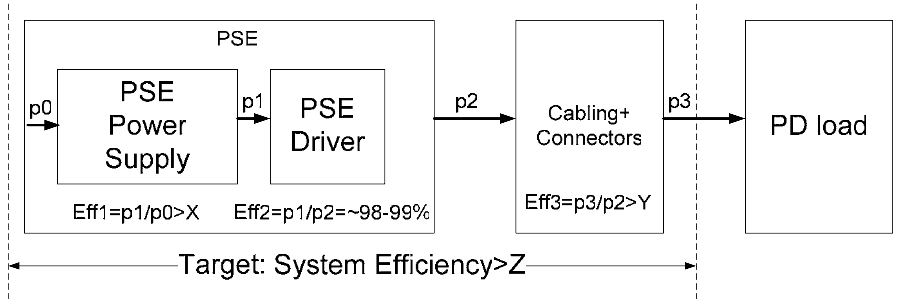
$$= \frac{Ppd}{Ppd + \left(\frac{Vs - VL}{Rline}\right)^2 \cdot Rline} =$$

$$= \frac{Ppd}{Ppd + \left(Vs - \frac{Vs + \sqrt{Vs^2 - 4 \cdot Ppd \cdot Rline}}{2}\right)^2 \cdot \frac{1}{Rline}} =$$

$$= \frac{Ppd}{Ppd + \left(0.5 \cdot Vs - 0.5 \cdot \sqrt{Vs^2 - 4 \cdot Ppd \cdot Rline}\right)^2 \cdot \frac{1}{Rline}}$$



Rline=25Ω/round loop conductor
Rline=12.5Ω / 2P
Rline=6.25Ω / 4P



Annex C[13] – Running Eff3 for target efficiency of 70%

Target Eff	Eff3	Eff2	Eff1
0.7	1.020	0.98	0.7
0.7	1.006	0.98	0.71
0.7	0.992	0.98	0.72
0.7	0.978	0.98	0.73
0.7	0.965	0.98	0.74
0.7	0.952	0.98	0.75
0.7	0.940	0.98	0.76
0.7	0.928	0.98	0.77
0.7	0.916	0.98	0.78
0.7	0.904	0.98	0.79
0.7	0.893	0.98	0.8
0.7	0.882	0.98	0.81
0.7	0.871	0.98	0.82
0.7	0.861	0.98	0.83
0.7	0.850	0.98	0.84
0.7	0.840	0.98	0.85
0.7	0.831	0.98	0.86
0.7	0.821	0.98	0.87
0.7	0.812	0.98	0.88
0.7	0.803	0.98	0.89
0.7	0.794	0.98	0.9
0.7	0.785	0.98	0.91
0.7	0.776	0.98	0.92
0.7	0.768	0.98	0.93
0.7	0.760	0.98	0.94
0.7	0.752	0.98	0.95
0.7	0.744	0.98	0.96
0.7	0.736	0.98	0.97
0.7	0.729	0.98	0.98
0.7	0.722	0.98	0.99
0.7	0.714	0.98	1

Non physical solution

Less then 30W min

Feasible and cost effective solution

May not be cost effective during the next 100 years..

References

- 1. ANSI/TIA/EIA-568-A, Section 10.4.4.4, DC Resistance
- 2. ANSI/TIA/EIA-568-B.2
- 3. CSA C22.2 No. 950/UL1950 (CEI/IEC 60950) - Safety Extra-Low Voltage (SELV) Circuit
- 4. Chris Diminico – CFI presentation. http://groups.yahoo.com/group/PoEplus/files/
- 5. Derek Knooce, July 2005 San Francisco, 802.3 PoEPlus maximum Power,
- 6. IEC60950, Equipment classified as a Limited Power Source in accordance with IEC publication.
- 7. FCC PART 68—CONNECTION OF TERMINAL EQUIPMENT TO THE TELEPHONE NETWORK
- 8. IEC 60603-7 TEMPERATURE DERATING FACTOR FOR CONNECTOR.
- 9. IEC 60603-7 - current capacity for connectors
- 10. SP-4425-AD6E_B.1-AD6DC_Draft6 Commercial Building Telecommunications Cabling Standard Part 1: General Requirements. Addendum 6: Additional Cabling Requirements for DC Power May 5, 2005
- 11. UL 1863 – connector voltage
- 12. Yair Darshan, Consideration in selecting voltage/current, IEEE802.3 DTE power via MDI, http://www.ieee802.org/3/af/public/may00/lehr_1_0500.pdf
- 13. Yair Darshan, System Stability and Efficiency analysis, data calculations excel file. Sep 2005