Voltage quality: What went wrong?

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Overview

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1. Power quality (PQ) regulation: In memoriam
2. Business risk resulting from consuming electricity
3. Compensating for poor voltage quality in shunt or in series
4. Why industry needs active voltage conditioning (self-regulation of PQ)
5. Case study on dips: How to containing business risk

What is this PQ about?

Quality of Supply Parameters

Quality of the Waveform

1. Voltage Magnitude
2. Voltage Unbalance
3. Voltage Harmonics
4. Voltage Flicker

Disturbances

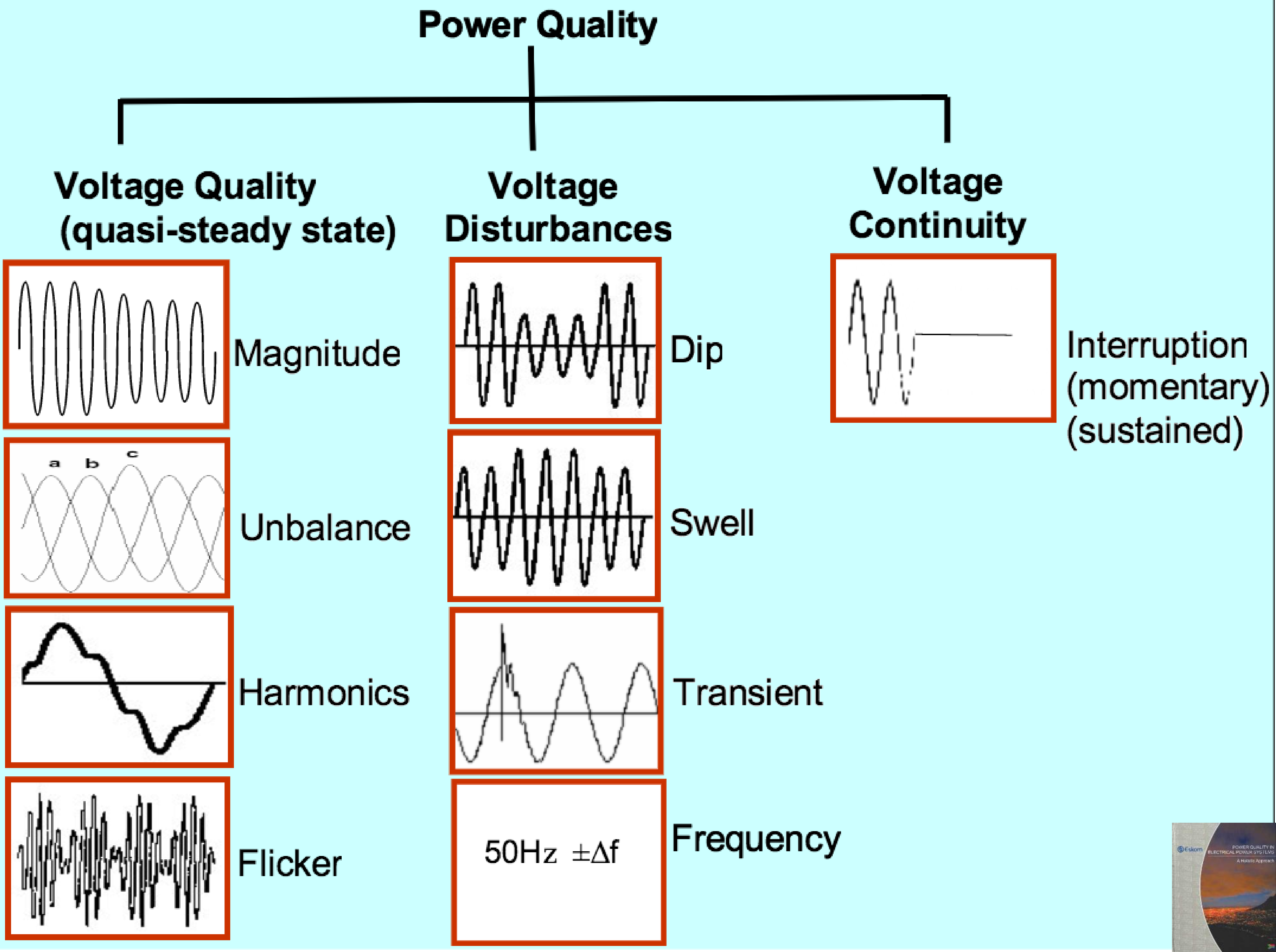
1. Voltage Dips
2. Voltage Swells
3. Voltage Transients

Reliability

1. Interruptions
2. SAIDI, SAIFI etc.

NRS 048 part 2-2007 (2015)

NRS 048 part 6 and 8


Power Quality
Voltage Quality
(quasi-steady state)
Voltage
Disturbances
Voltage
Continuity
Magnitude
Dip
Interruption
(momentary)
(sustained)
a
b
c
Unbalance
Swell
Harmonics
Transient
Flicker
50Hz ±Δf
Frequency

PQ in Southern Africa: A historical overview

- Regulating electricity in South Africa for voltage quality attempted since 1996
- A reference (benchmark) document on minimum levels in voltage quality: NRS 048 part 2 year(*n*), $n \in [1996,......2015]$
- It defined the conditions when electrical equipment should be “compatible”
- Various changes followed as better understanding developed (being pragmatic)
- Minimum “limits”, rather a statistical approach to being compatible for 95% of the time
- International respect for the NRS048 followed, even from the first world, i.e. on how dip performance of networks were categorized and managed (perceived to be managed)
- Energy Regulators would use this as part of regulating the ESI
- A Power Quality Directive was issued in 2002 referencing the NRS 048 part 2
- Regulation by setting “rules” to licensees- such as serving customers with good PQ
- That was then, and that was the plan, and now in 2019?

Why voltage is not always perfect

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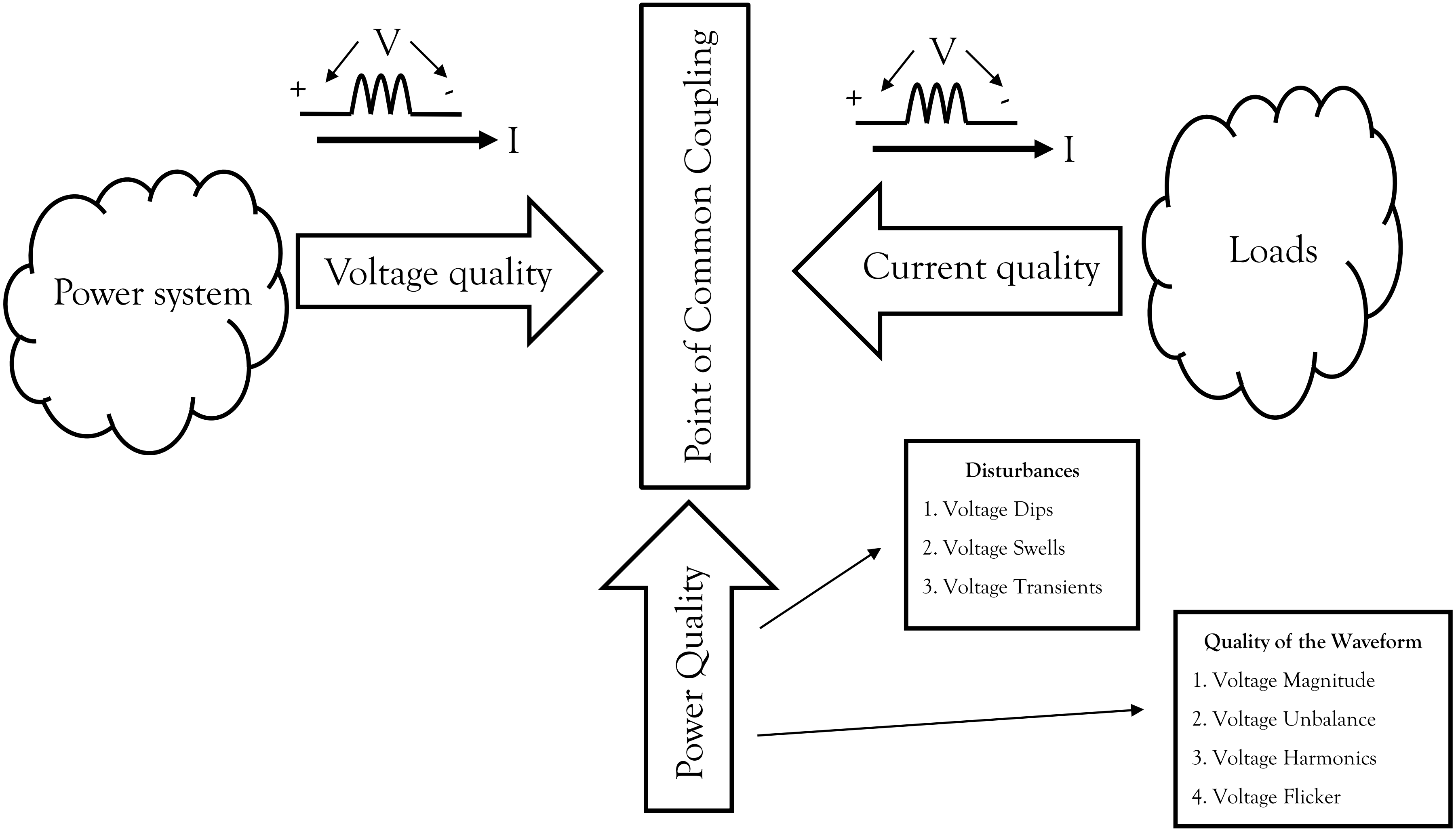
The law of constant misery in power systems - Ohm's law: V=IxZ



PQ has financial consequences

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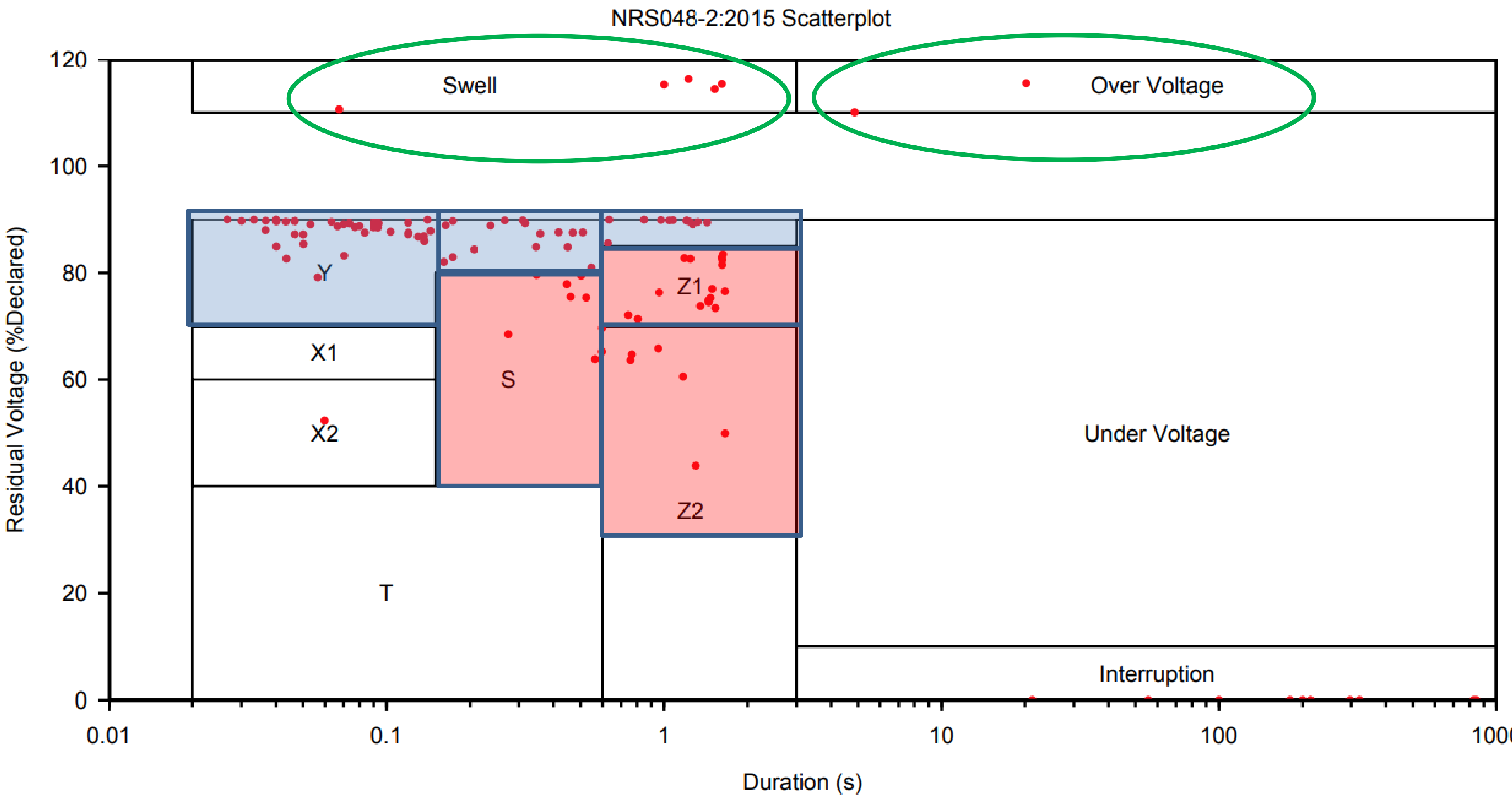

Dip Y	Dip X1	Dip X2	Dip S	Dip T	Dip Z1	Dip Z2
67	0	1	9	0	16	6

The impact of PQ can now be quantified

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- This is a dip diagram of a large cement factory over a period of 76 days
- Y dip area constitute compatibility, but today not always true, some equipment fail: under Y dip conditions, a voltage sag down to 70% for near 100 ms is strictly a Y dip!
- Observe dip events in S, Z1 and Z2: most equipment will fail
- 32 Total dips from X2, S, T Z1 and Z2: An event that affect production every 2.4 days!
- And, even some Y dips could have affected production

Dip Y	Dip X1	Dip X2	Dip S	Dip T	Dip Z1	Dip Z2
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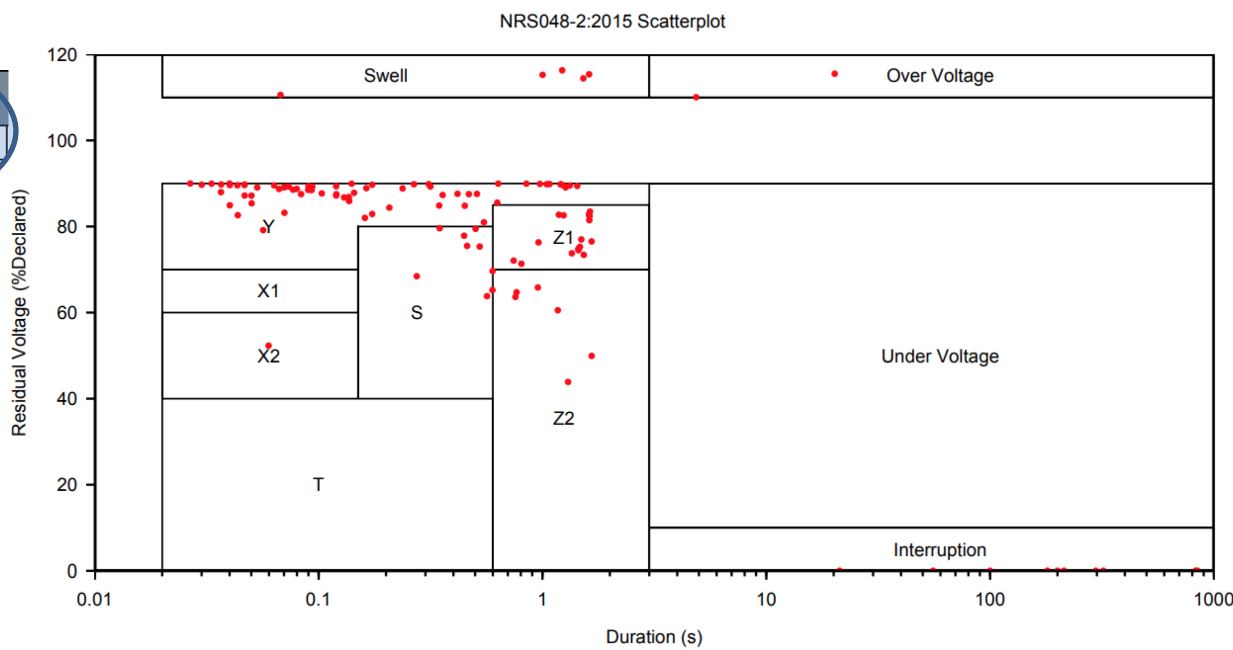

What can be done?

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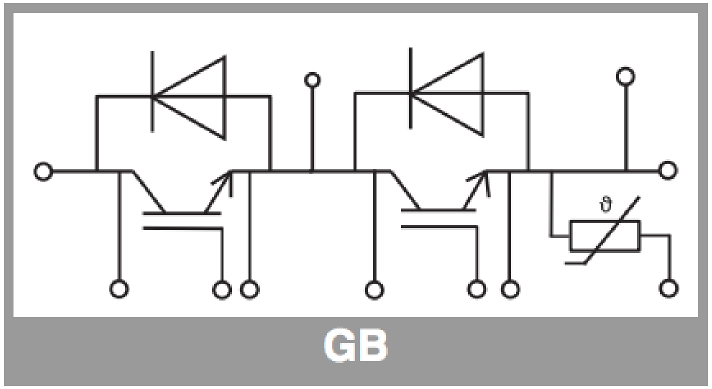
- Voltage dips for the user of electricity realise as business risk (profitability)
- PQ regulation will not (can not) protect users in a non-competitive ESI
- Litigation will recover damages of the past, litigation will not change the future (soon)
- Not all root-causes of voltage dips are under the “control” of the local utility
- Financial condition of the national (and local) utility realise at the user of electricity in voltage quality being poor – causing financial losses
- Users of electricity will have to contain the operational risk on-site
- Active voltage conditioning is an interesting solution
- This can be done by a parallel device, or by a series device
- Let’s investigate……

First, let the power transistor be

- By means of fast solid-state power switches AND fast control, a host of solutions

i.e. Semikron module

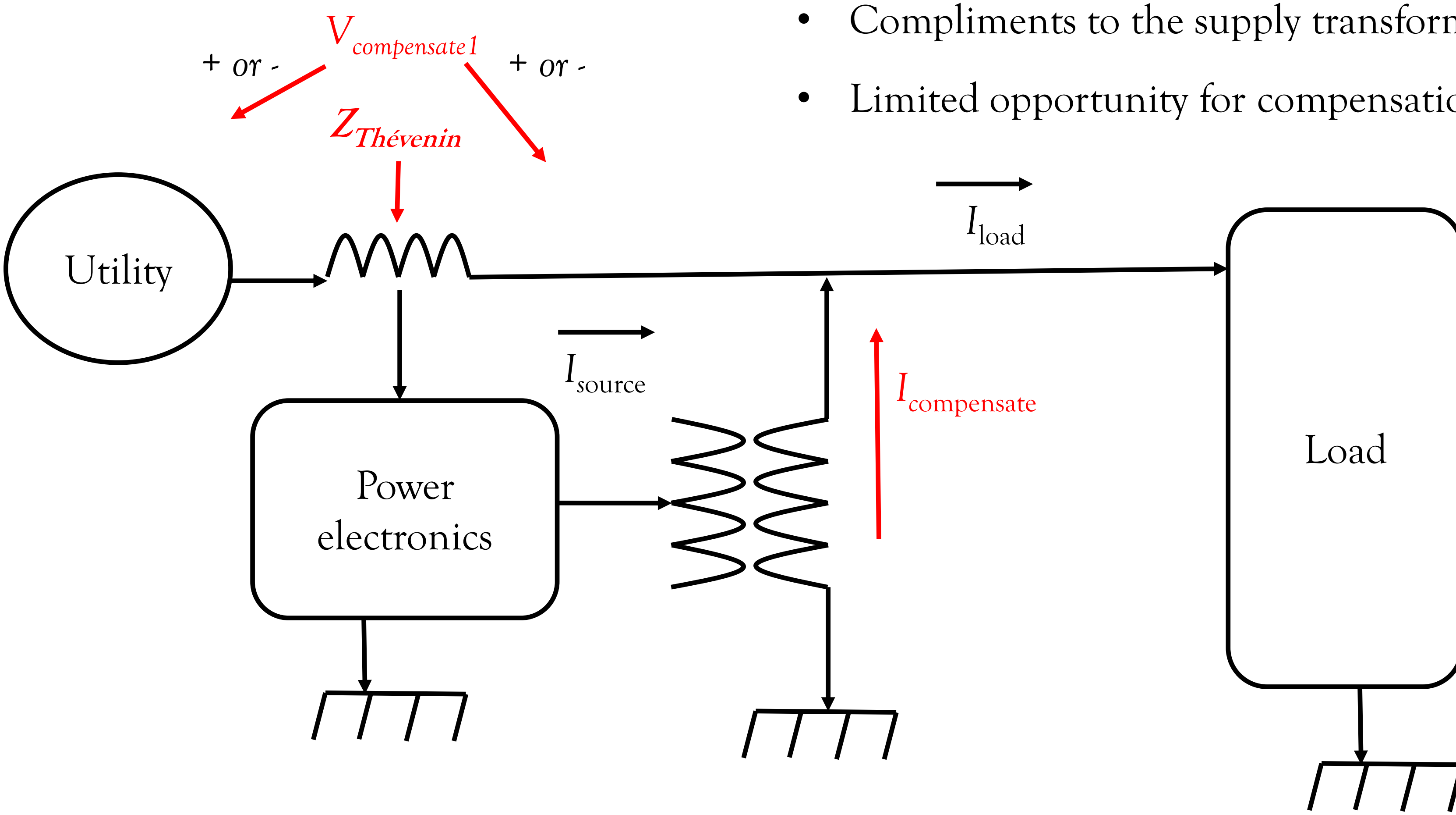
Absolute Maximum Ratings				
Symbol	**Conditions**		**Values**	**Unit**
IGBT				
V_{CES}	$T_j = 25$ °C		3300	V
I_C	$T_j = 150$ °C	$T_c = 25$ °C	760	A
		$T_c = 80$ °C	542	A
I_{Cnom}			450	A
I_{CRM}	$I_{CRM} = 2xI_{Cnom}$		900	A
V_{GES}			-20 ... 20	V
t_{psc}	$V_{CC} = 2200$ V, $L_s = 40$ nH, $R_{Gon} = 6.8\ \Omega$, $R_{Goff} = 68\ \Omega$, $V_{GE} \pm 15$, $T_j = 150$ °C, $V_{CES} \leq 3300$		10	µs
T_j	Operation		-50 ... 150	°C



Compensation can be done in shunt

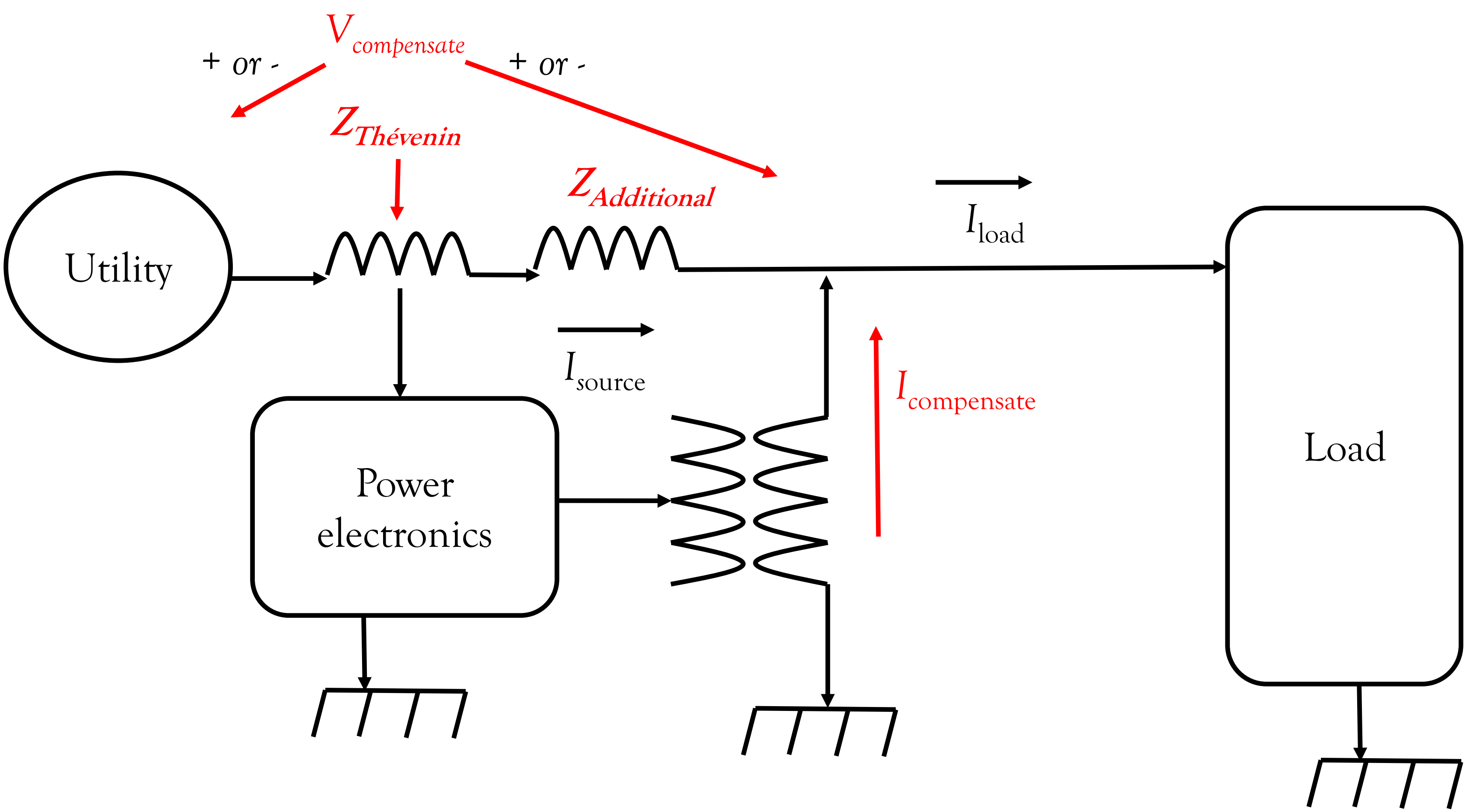
- STATCOM: Emulating a reactive current
- To be injected by the shunt transformer
- Mostly capacitive

- Compensation by Ohm's law
- $V_{compensate} = I_{compensate} \times Z_{Thévenin}$
- $Z_{Thévenin}$ is the fault impedance, upstream
- Compliments to the supply transformer
- Limited opportunity for compensation



Compensation can need additional Z

- Compensation by Ohm's law
- $V_{Compensate2} = I_{\text{compensate}} \times (Z_{Thévenin} + Z_{additional})$
- $V_{Compensate2} > V_{Compensate1}$
- Voltage THD >> before
- Protection now compromised
- I do not like too much.....



Why use a STATCOM?

STATCOM an attractive solution for:

- Improving voltage regulation,
- For fast control of power factor,
- Improving steady state power transfer capacity in long lines,
- Improving transient stability margins.
- Damping sub-synchronous power system oscillations,
- Controlling voltage flicker

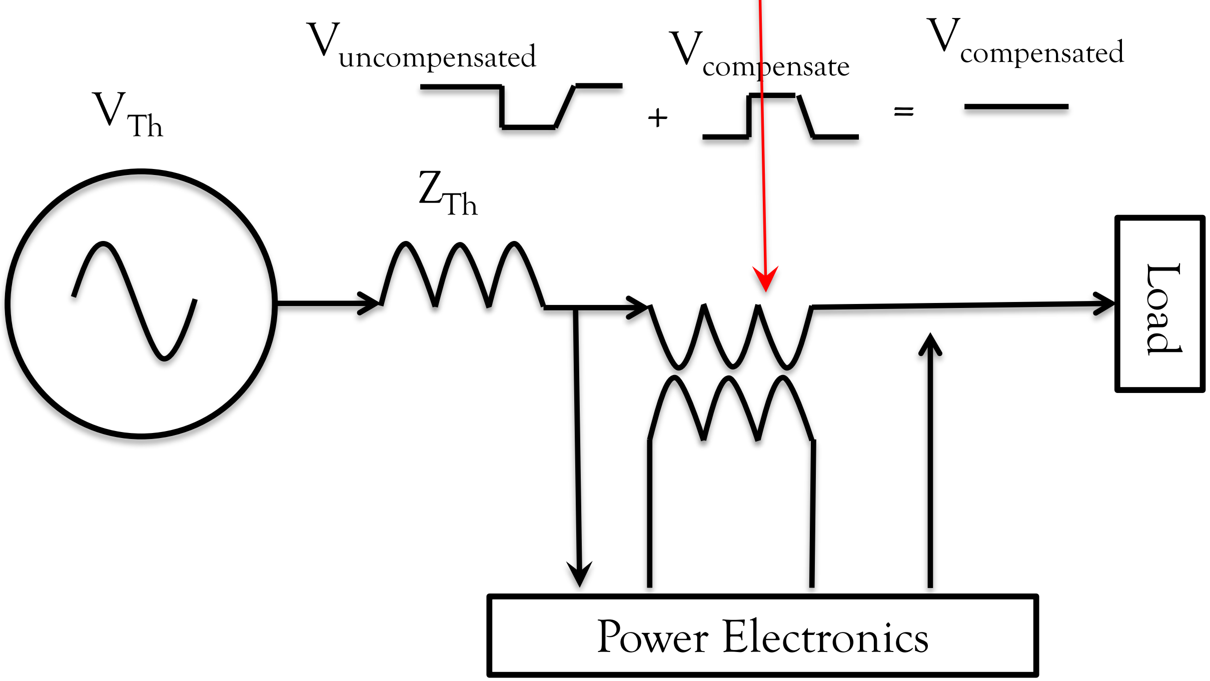
STATCOM a less attractive solution for compensating voltage dips:

- Performance when mitigating voltage dips and magnitude and unbalance depends on fault impedance upstream ($Z_{thévenin}$) – when it change, compensation change
- Adding impedance to ($Z_{thévenin}$) increase the upstream fault level, requiring changes to protection
- Increase voltage Total Harmonic Distortion: current harmonics remain same magnitude, adding impedance, the law of constant misery dictate an increase in voltage THD
- Mostly too slow: 2 cycles = 40 ms, the load has already stopped making money!
- Dip compensation requires operation in overloaded (2x) condition = abnormal operation

Rather consider a series solution

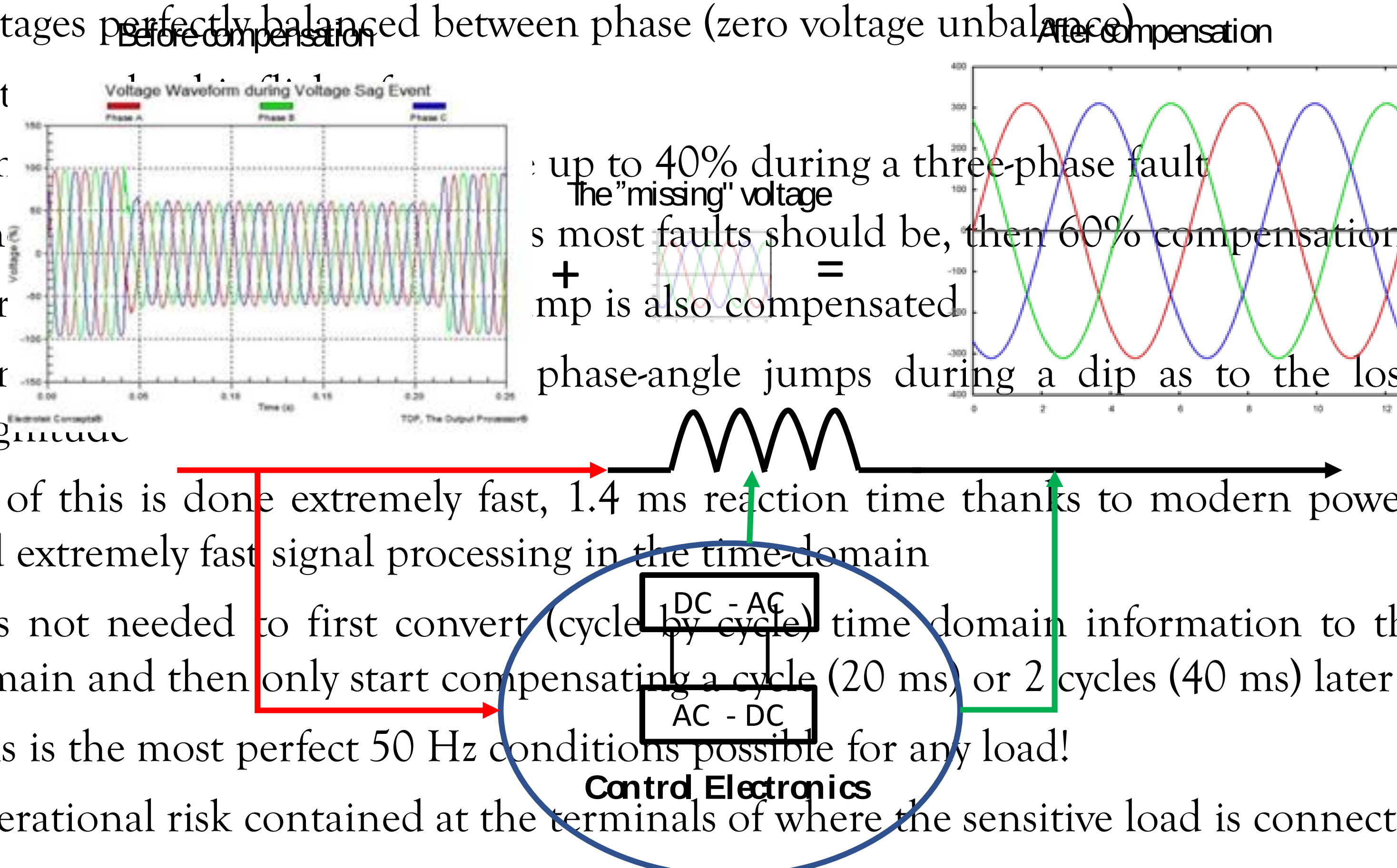
It seems like a STATCOM now connected in series?

- Indeed, in series with only an additional 2% impedance between source and load
- No changes needed to protection settings
- Secondary side is disconnected during faulted (or startup) conditions
- No increase in voltage THD
- Rated for compensation and used within design values (no overloading needed)
- Extremely fast: compensate within 1.4 ms



Active conditioning of supply voltage

- Continuous conditioning of source voltage variations
- Voltages at load terminals remain at 1.0 per unit, per phase
- Voltages perfectly balanced between phase (zero voltage unbalance)
- Volt
- Cor up to 40% during a three-phase fault
- Wh s most faults should be, then 60% compensation
- Dur mp is also compensated
- Mar phase-angle jumps during a dip as to the loss of voltage magnitude
- All of this is done extremely fast, 1.4 ms reaction time thanks to modern power electronics and extremely fast signal processing in the time-domain
- It is not needed to first convert (cycle by cycle) time domain information to the frequency domain and then only start compensating a cycle (20 ms) or 2 cycles (40 ms) later
- This is the most perfect 50 Hz conditions possible for any load!
- Operational risk contained at the terminals of where the sensitive load is connected
- Plant owner take responsibility for compatibility between supply and load conditions



A case study

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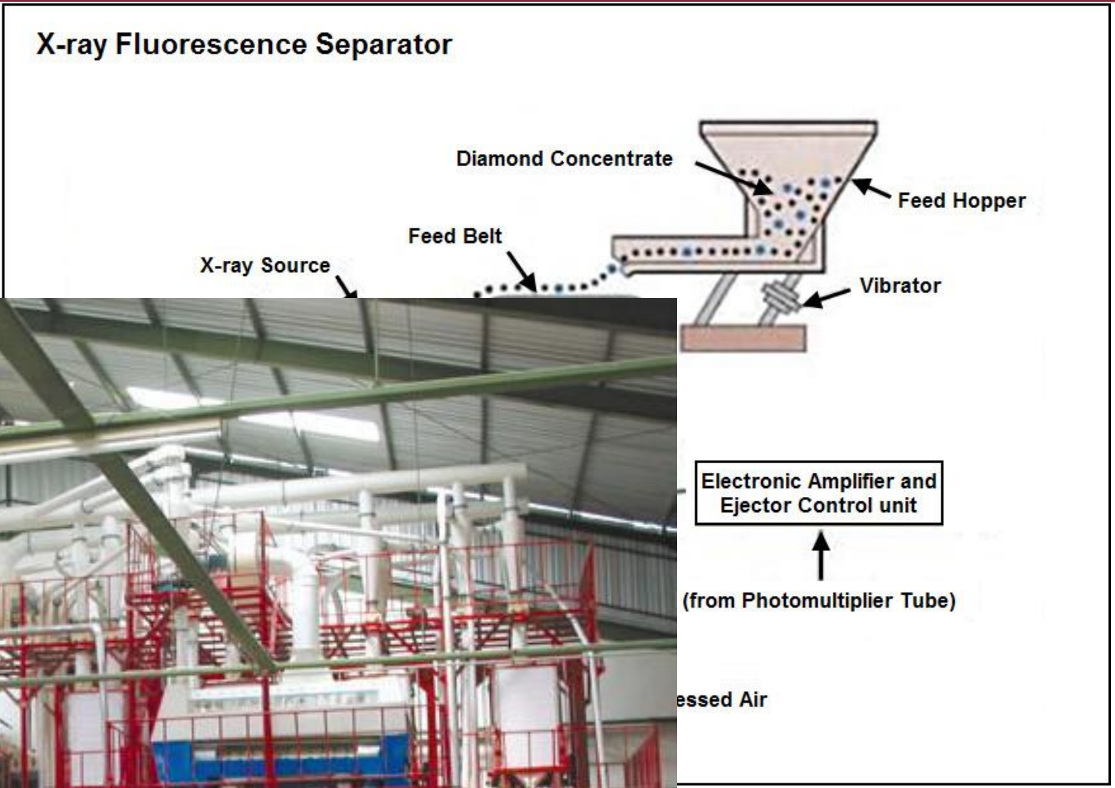
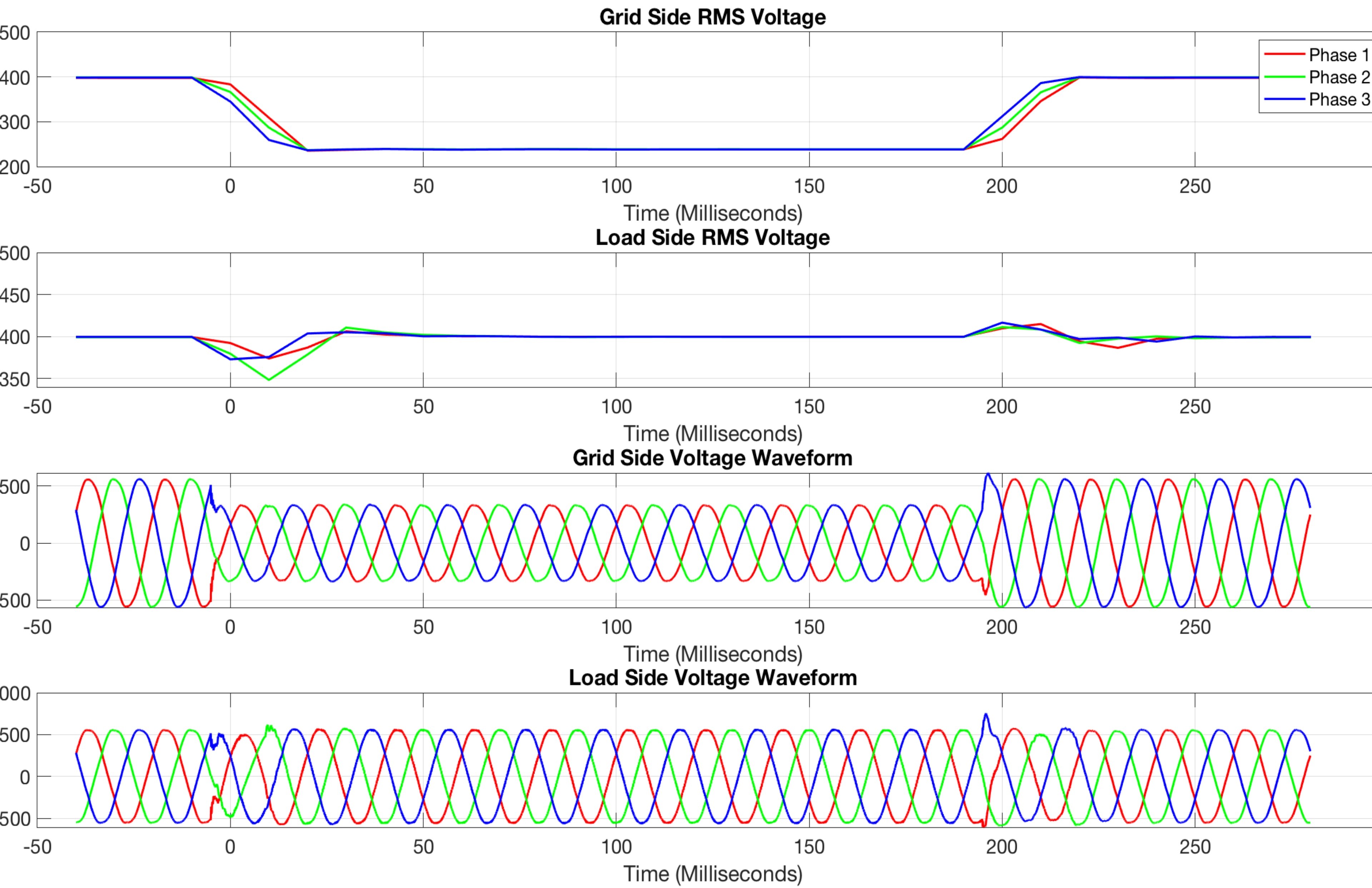
- A long (LONG) serial production pr
- **Financial**: Product loss and opportu operations
- **Reputational**: Promises made to cli




Grid Side RMS Voltage
Phase 1
Phase 2
Phase 3
Time (Milliseconds)
Load Side RMS Voltage
Time (Milliseconds)
Grid Side Voltage Waveform
Time (Milliseconds)
Load Side Voltage Waveform
Time (Milliseconds)

How the difference look (6 months)

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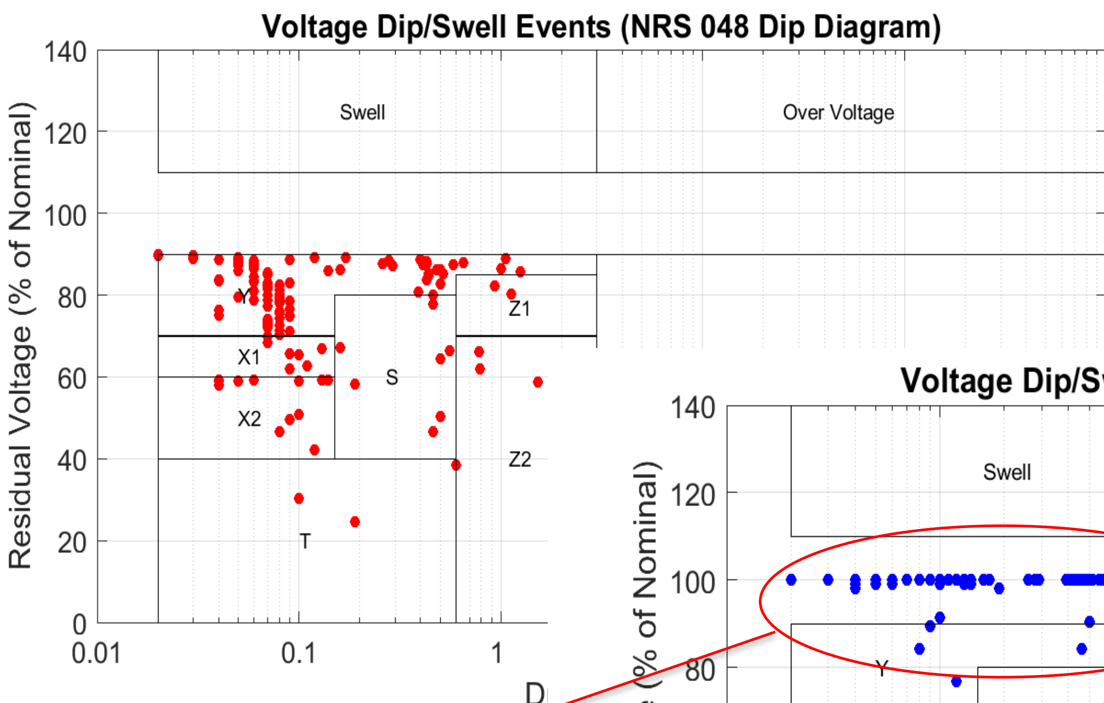
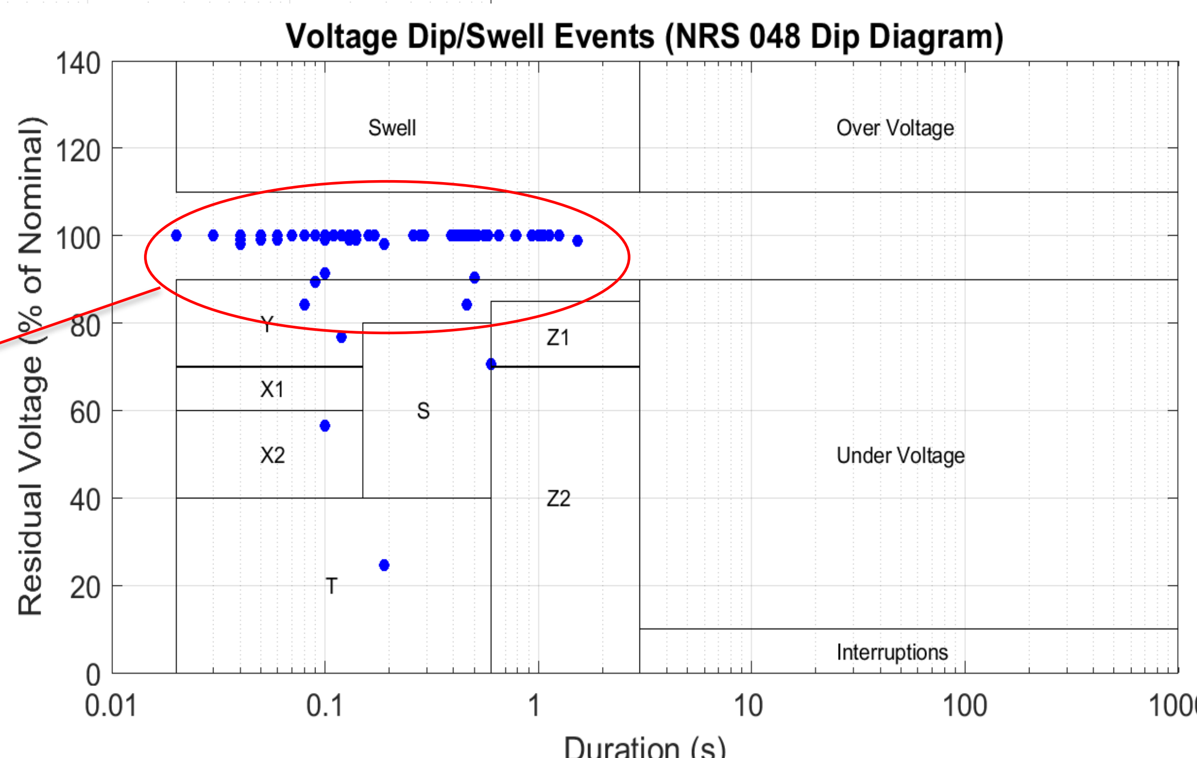
NRS048 dips without compensation

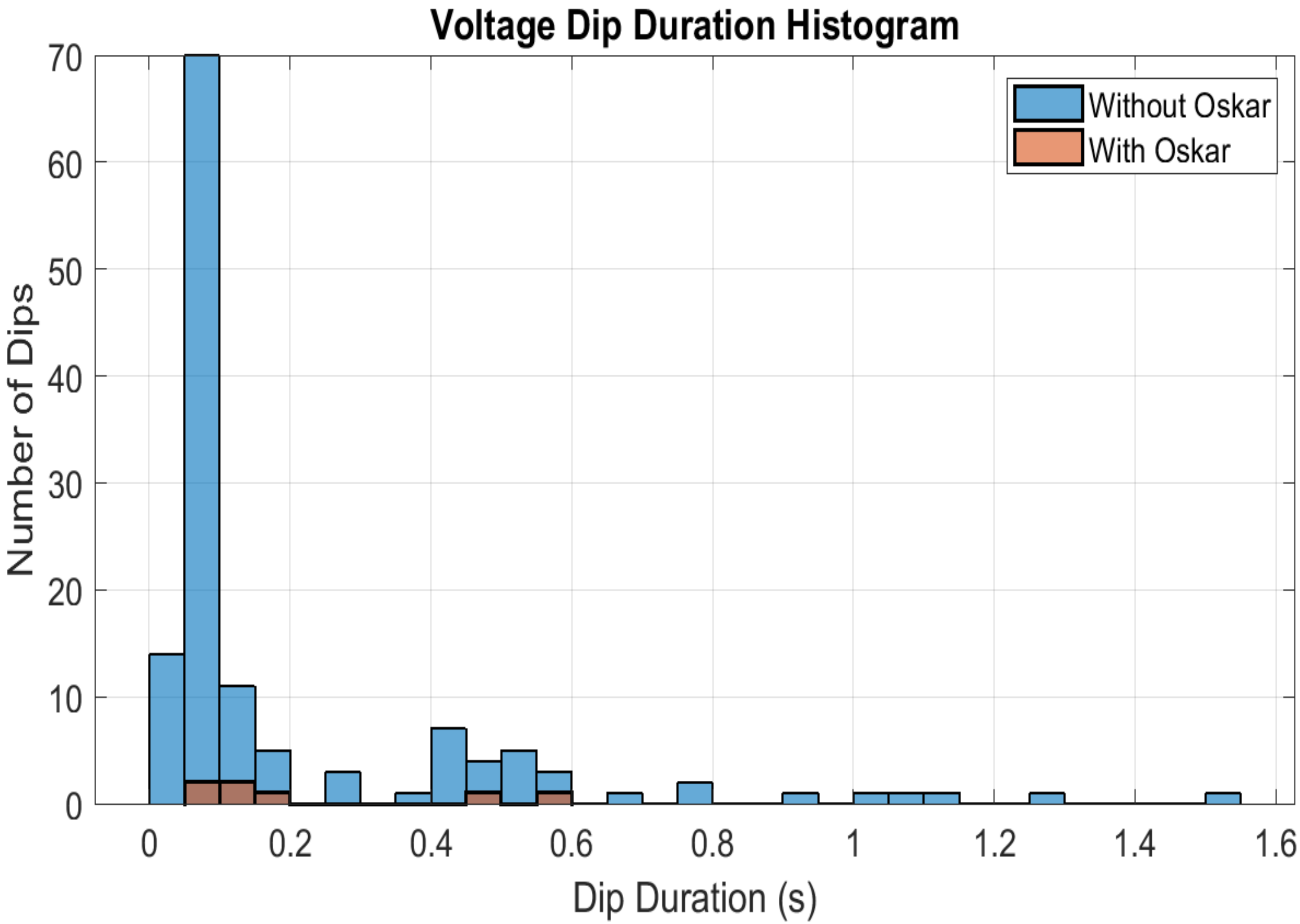


NRS048 dips, compensated



Those events are now longer voltage dips!

Voltage Dip Duration Distribution



Residual Voltage Distribution

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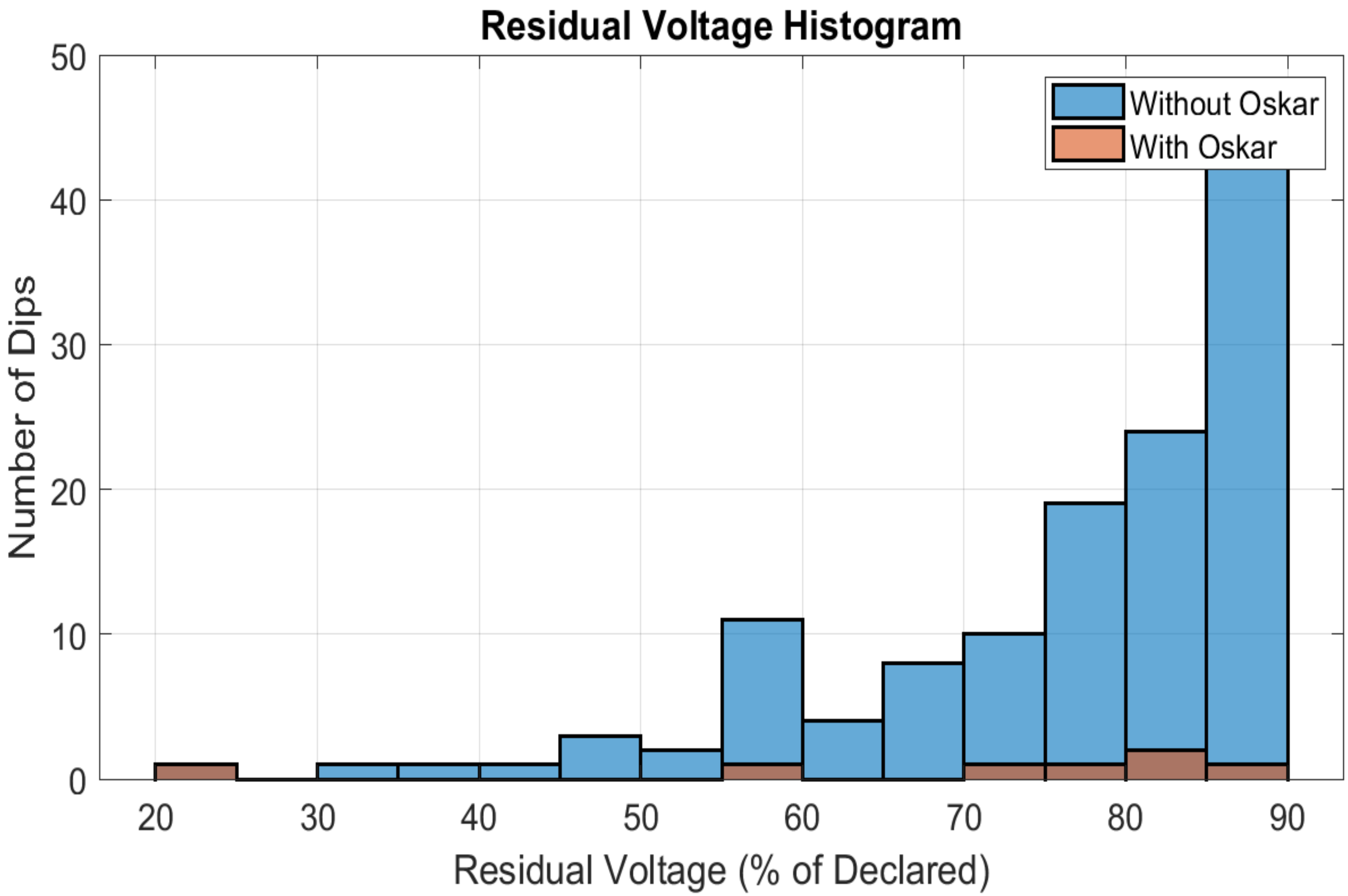
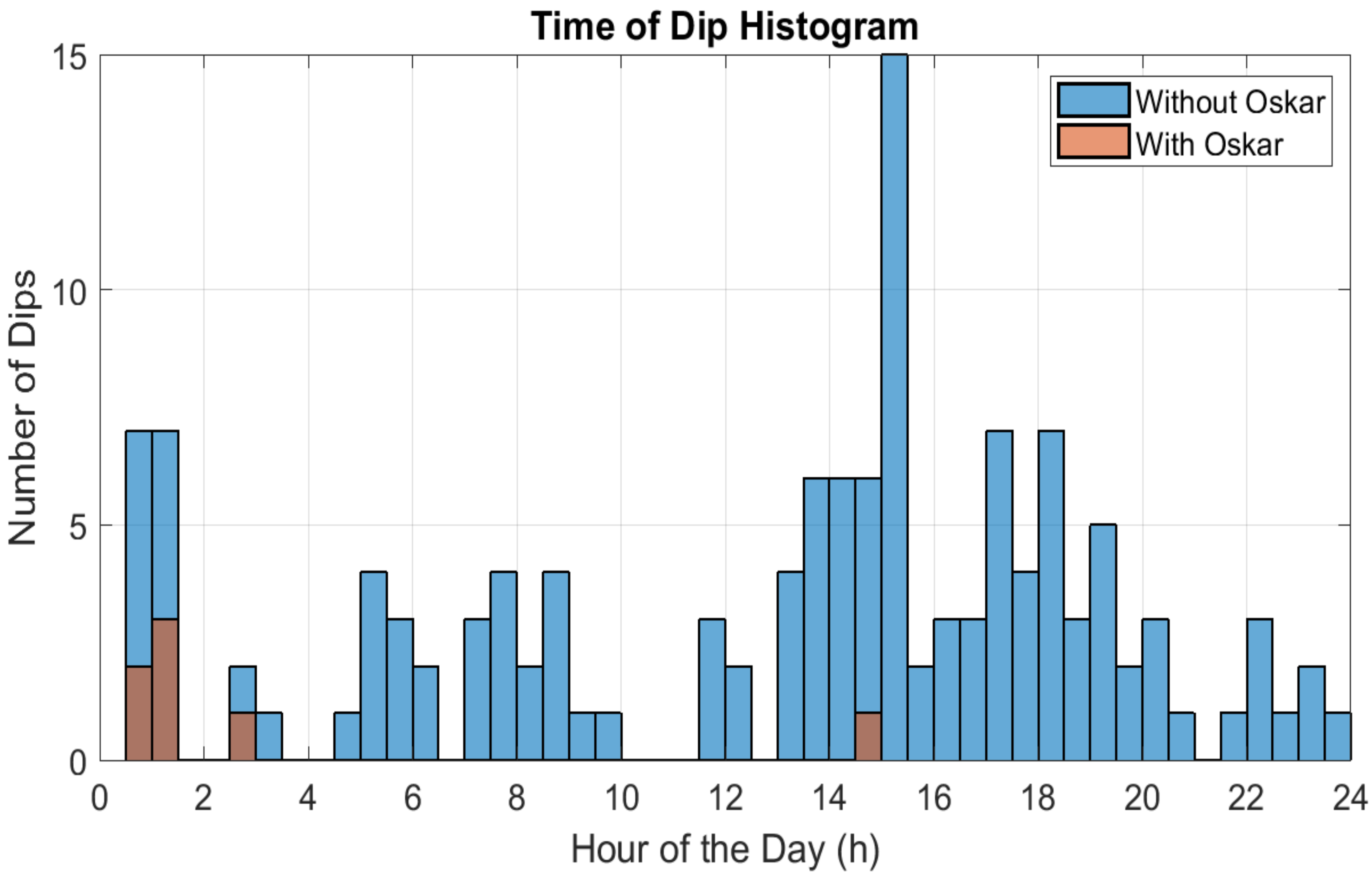
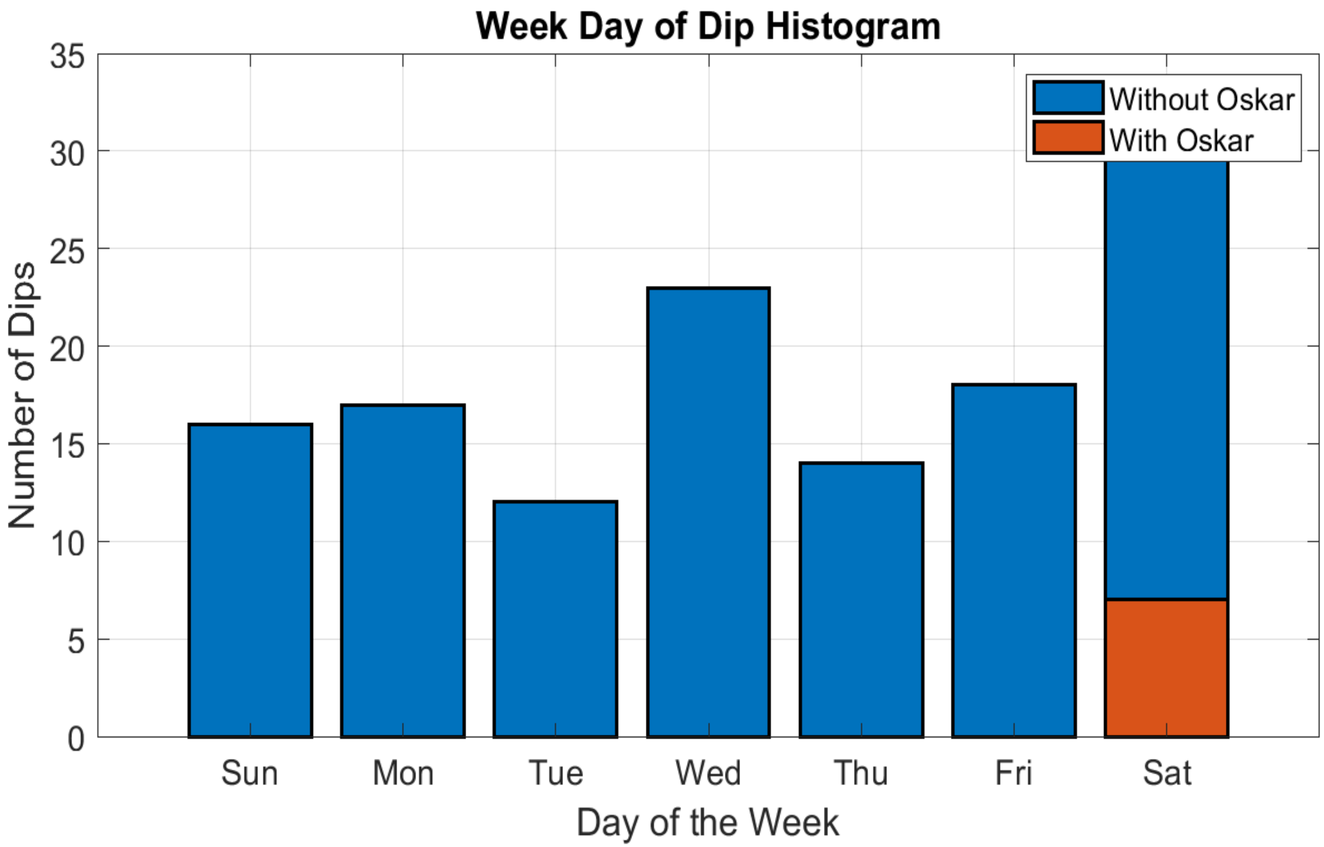


Time of Day Distribution



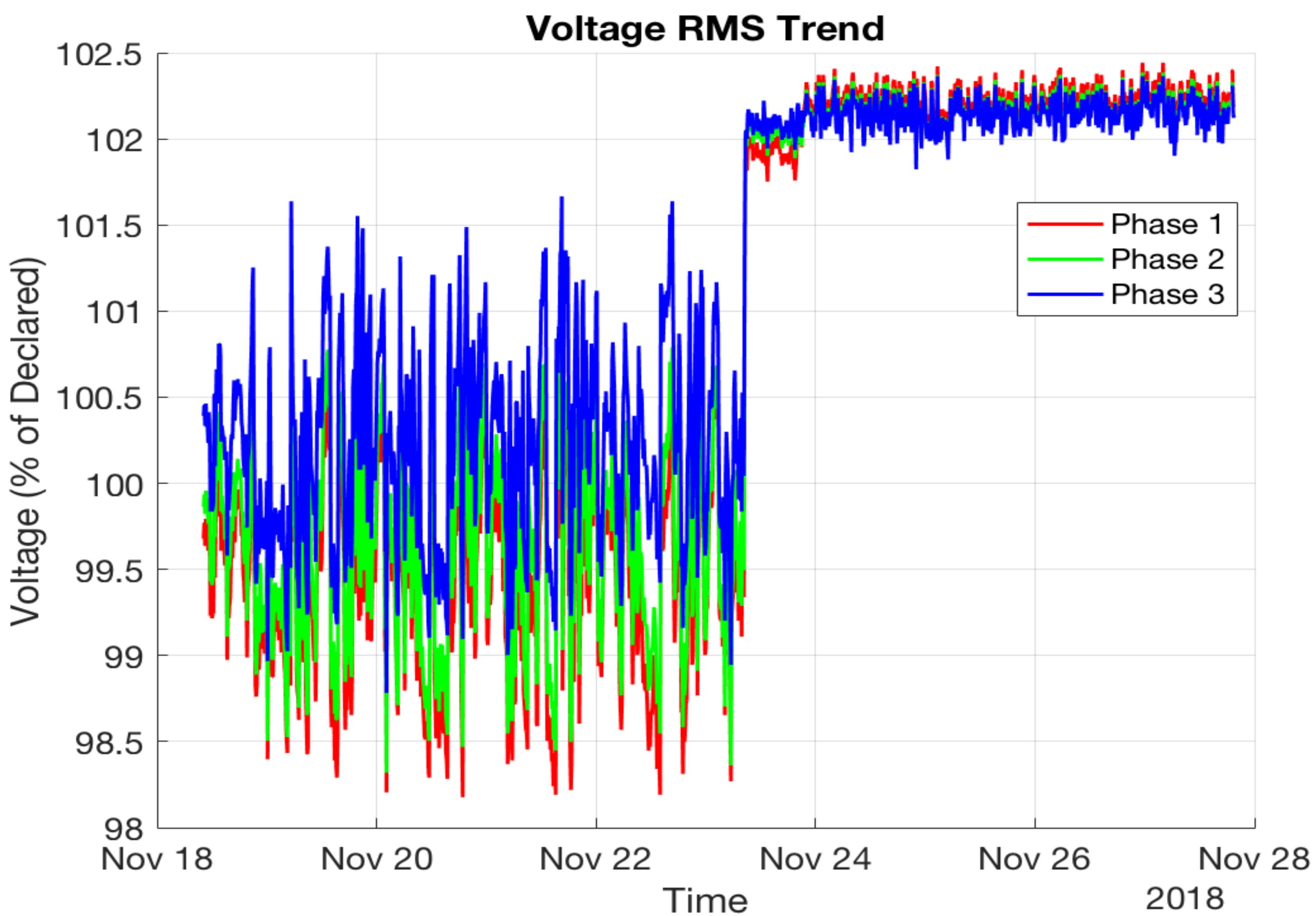
Day of the Week Distribution



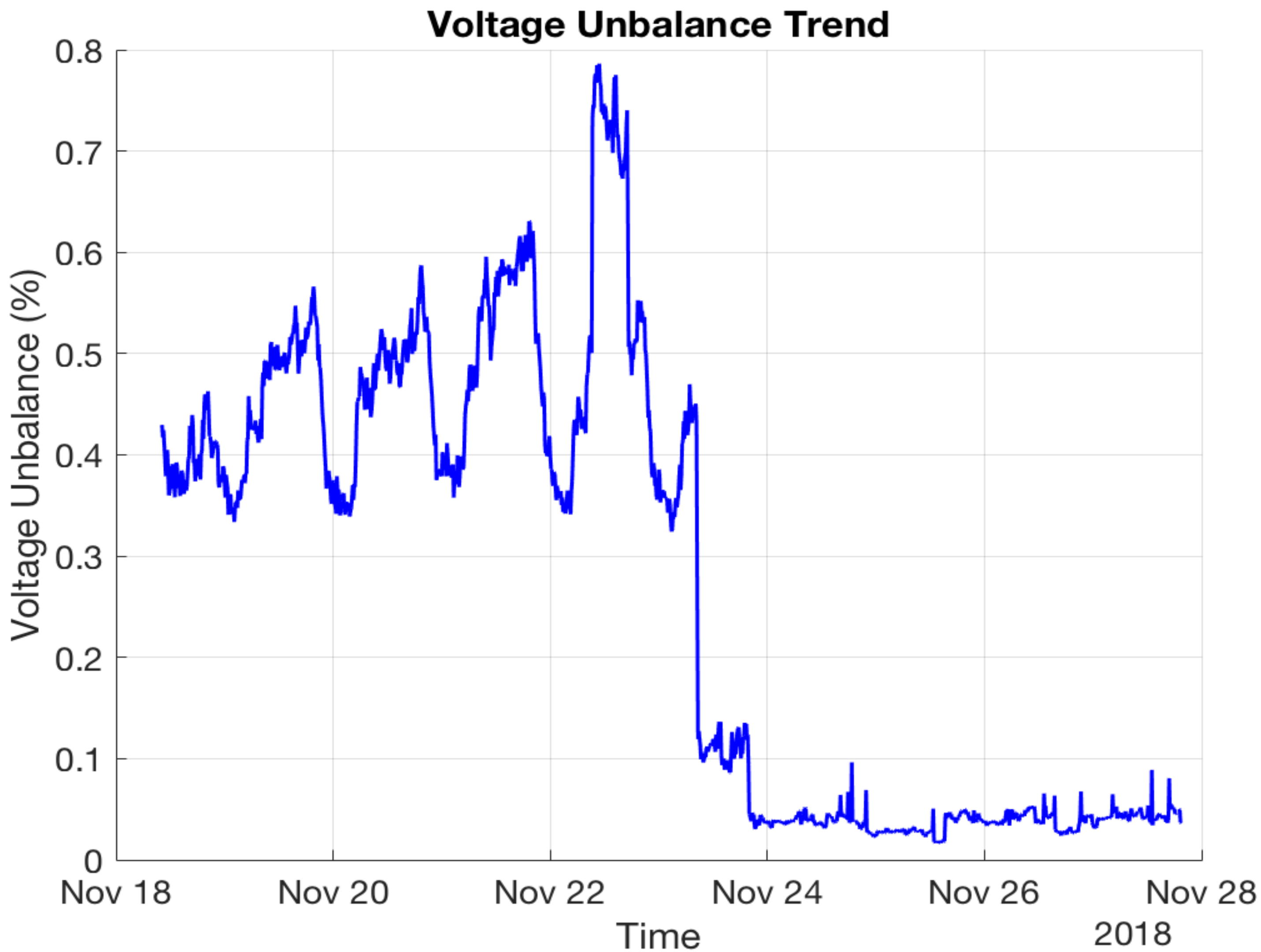
Voltage Dips Avoided

Dip Type	Number of dips recorded	Number of dips with OSKαR®	Number of dips avoided
Y	96	4	92
X1	7	0	7
X2	13	1	12
Z1	2	0	2
Z2	3	0	3
S	8	0	8
T	2	1	1
All Dips	131	6	125

Voltage magnitude is regulated



Unbalance of voltage is improved



In Conclusion (memoriam…)

- Users of electricity in Southern Africa will have to take LOCAL control over PQ
- Conditioning the voltage LOCALLY to the level of immunity needed
- Immunity level = operational risk realising as financial risk (loss of income)
- National Energy Regulator will not (can not) change the situation
- PQ regulation as envisaged by NERSA in 2002, is outdated
- Enforcing of minimum standards did not happen, and will not happen
- Utilities want to, but can do little to improve PQ
- Users will have to budget for taking LOCAL control of PQ
- Active voltage conditioning can make the difference to dips, swells, poor regulation, unbalance and flicker
- And if dips are the CONCERN, than compensate using a series “STATCOM”

Questions...


WHY CAN'T YOU TAKE RESPONSIBILITY FOR YOUR OWN ACTIONS?
I BLAME MY UPBRINGING.