Fault Level

Outram Research Ltd

John Outram
www.outramresearch.co.uk

Fault Level

- Accurate fault level - The challenge facing planners and operations managers

An alternative to modelling

- Slow-time and real-time fault level measurement – exploiting network disturbances – a solution
- Benefits and savings – a Case study

The Challenge arising…

- Ageing infrastructure
- Potential for increasing faults
- Increasing significance of customer minutes lost
- Loss of well-understood generation capacity
- Increase in Distributed Generation
- Increased demand for connection

Plus we must aim for…

- Increased efficiency
- Best utilisation of network capacity
- Maximum use of other resources

At the same time as…

- Keeping the network safe
- Maintaining/Increasing security of supply.

What do we mean by Fault Level?

Fault Level, Fault Current, Prospective Fault Level all mean the same thing…

The worst case current that can flow in the event of a fault.

It is also expressed as Power on all three phases, i.e. Fault Current x Nominal Voltage (P-N) x 3

It is the current

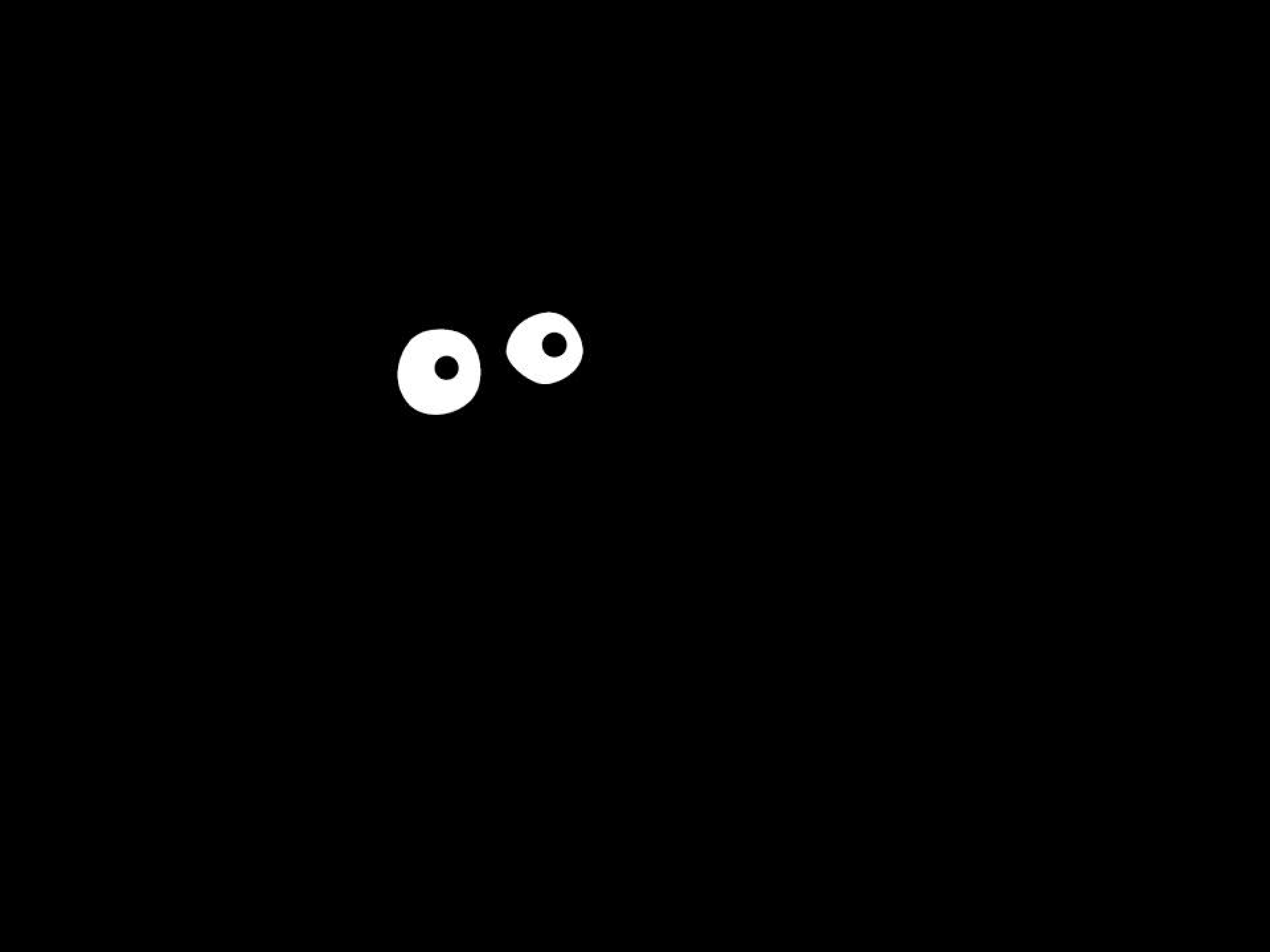
- we must interrupt **safely**
- for which the **infrastructure must be designed**.

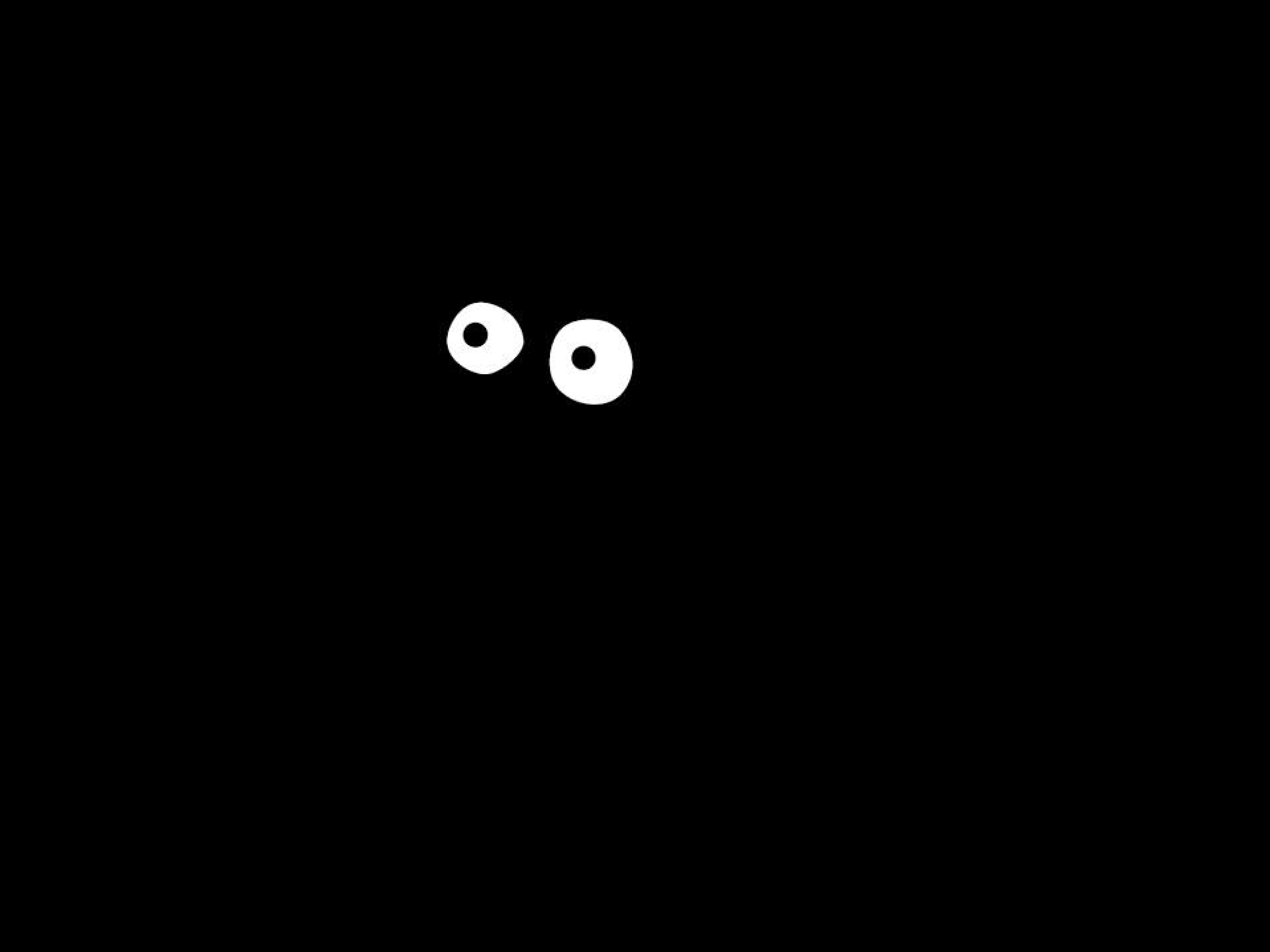
Put another way…

Given an infrastructure and existing protection circuitry there is a

maximum fault level that can be accommodated
in that section of the infrastructure.

It is the operator's responsibility to keep the Fault Level available from the generation system below this critical infrastructure limit…. And without knowing the Fault Level….



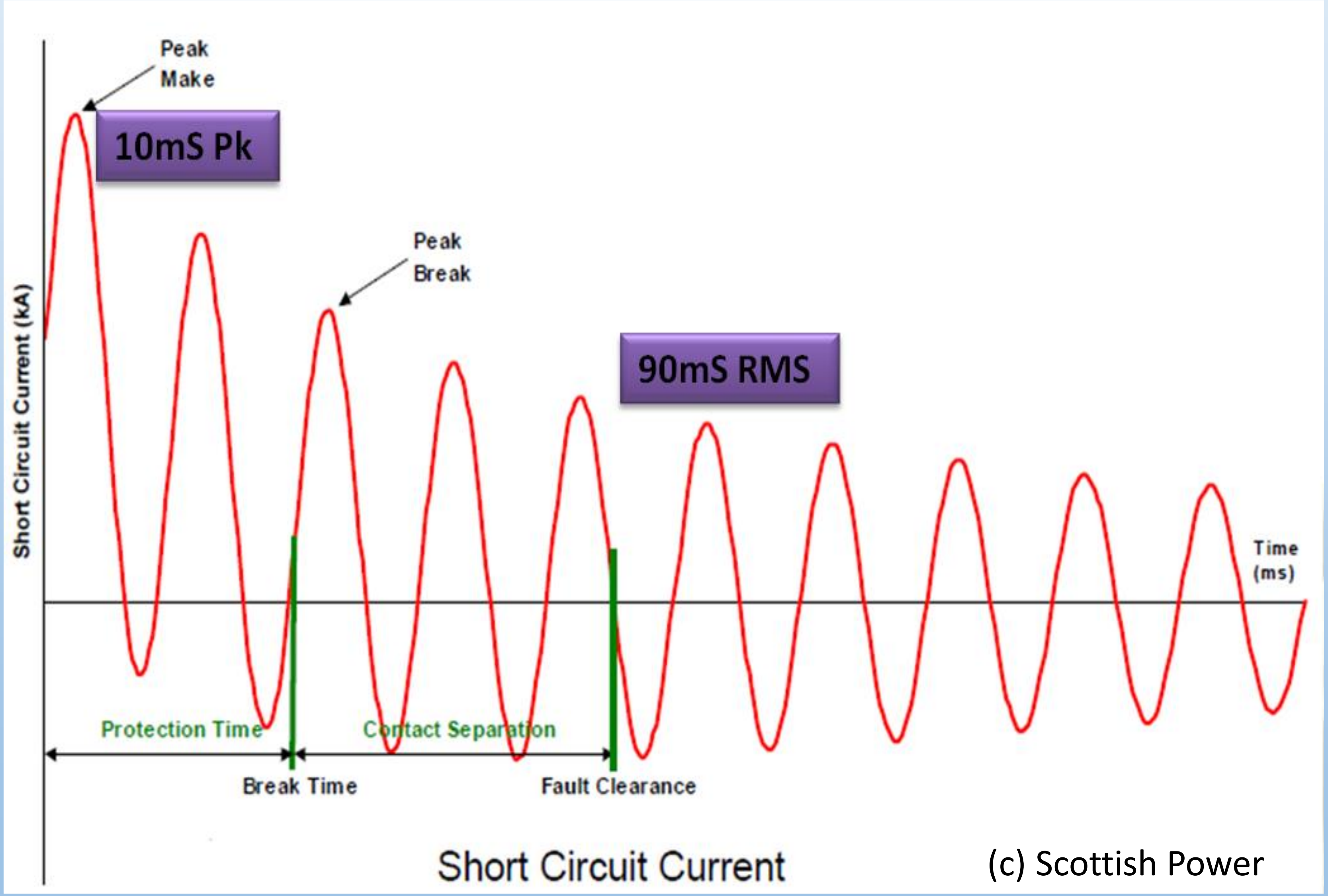


Fault Level is affected by

- Static contributors
  - Cables/Transformers/Breakers etc.,
- Dynamic contributors
  - Sub-transient & Transient reactances
  - Short term Motor contribution
  - Distributed Generation

(as well as the nominal Voltage!)

Fault Current waveshape



Components of Fault Level
dominated by

Total source impedance, Zsource, from all relevant generators and forcing voltage

DC offset – arising from inductive Zsource, and ratio of Inductive (X) to resistive(R) components of the source impedance. (difficulty of getting current through an inductor to change abruptly) Decay is slowest for high X/R ratios

Decaying sources e.g. upstream or downstream motor contribution, PV (?)

Application of this knowledge:

to Cable/Infrastructure rating, Breaker selection

RMS Break. Choose a Breaker rating to exceed the maximum Fault Level arising just before the "open" action.

e.g. If Breakers are to open at say 100 - 120ms after fault inception, specify a Breaker rating greater than the Fault Level at T, where T is some time before the 100ms minimum opening instance – e.g. **90ms.**

Application of this knowledge:

Breaker selection

Peak Make. The breaker may have Peak Make rating at some fixed multiple of the RMS Break rating. In some countries typically **2.55** corresponding to an X/R ratio of 14.

If the anticipated **X/R ratio** and the corresponding multiple is expected or measured to **exceed** this, then consider whether the RMS Break level of the **breaker** should be **de-rated**.

Historically…
Knowledge through modelling

Assume a high quality mathematical tool, then need to

Know All Relevant Network Characteristics, e.g.

Fixed network features:

- **Transmission medium, Cables, Isolators, Transformers, Breakers, Joints**

Operational or temporary features:

- **Switching arrangements, Motors, Distributed Generation, Mitigation devices**

Application of modelling in the UK

HV	-	>= 132kV	- comprehensive
MV	-	> 33kV	- large scale
LV	-	<= 11kV	- on demand, not necessarily kept up to date

Limitations of modelling

- Time to build
- Could be based on incomplete or incorrect information

Consequences

- Is it accurate?
- Use models conservatively depending on care with which they are built.

? What about where

- Network characteristics not known?
- Characteristics are variable e.g. DG?
- Computer model needs validation?

An Alternative…
Knowledge through measurement.

Fault Level Monitor (FLM)
- a complementary tool

Consideration of Network behaviour

Network behaviour MUST be indicative of network characteristics……

Characteristics → Behaviour

Can we work this backwards?

Behaviour → Characteristics → Fault Level

Behaviour

Means:

Response to disturbances

The best disturbances are little mini-faults

FLM – a tool to MEASURE and exploit network behaviour

Base it on e.g. Power Quality Analyser

- Already examining network characteristics:
- Robust, Safe, Sub-Station ready, operate at wide voltage levels
- May sample fast enough and have enough processing capacity

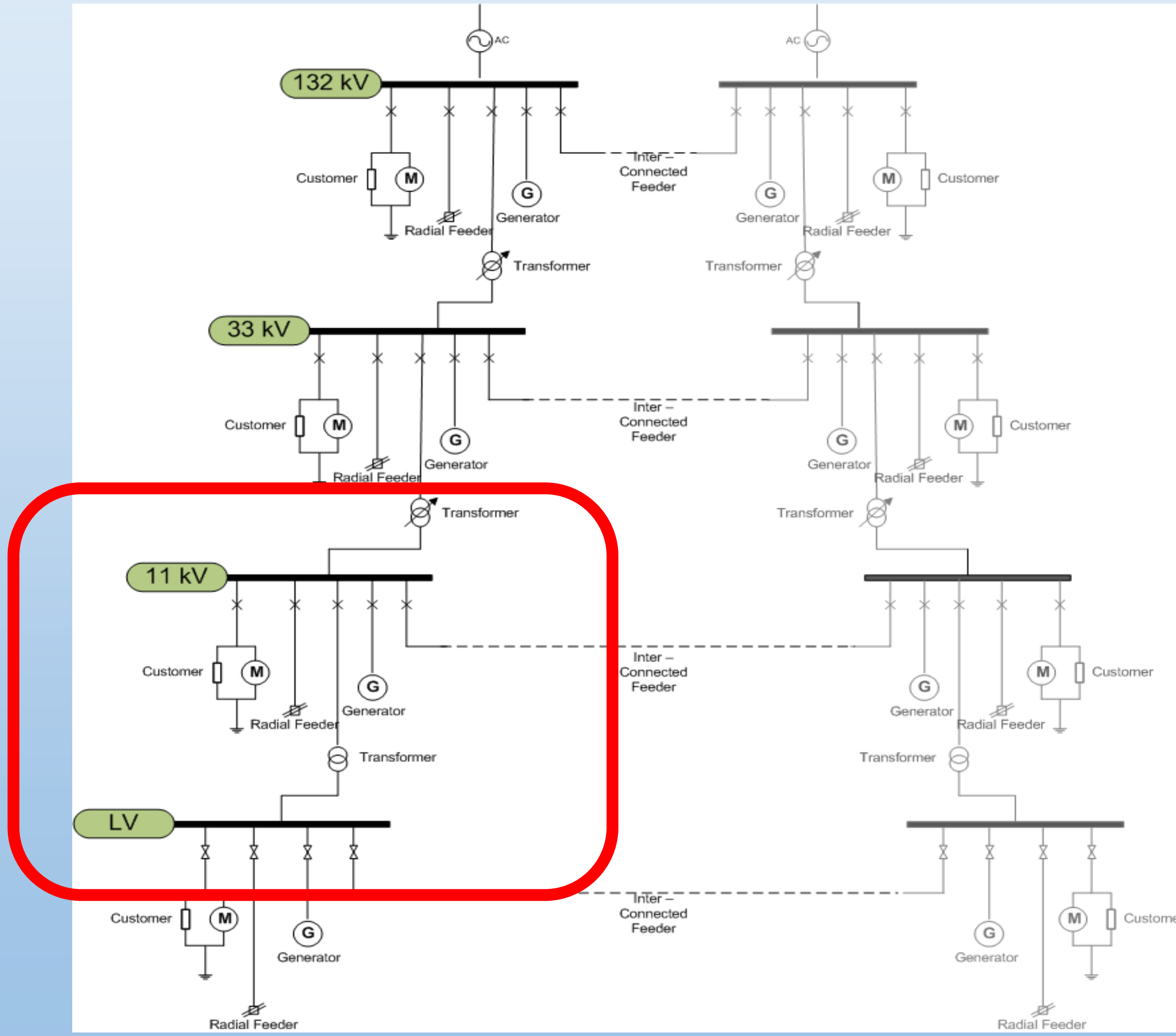
Use natural disturbances

- Potentially applicable to any voltage level if VTs, CTs available

Or artificial disturbances

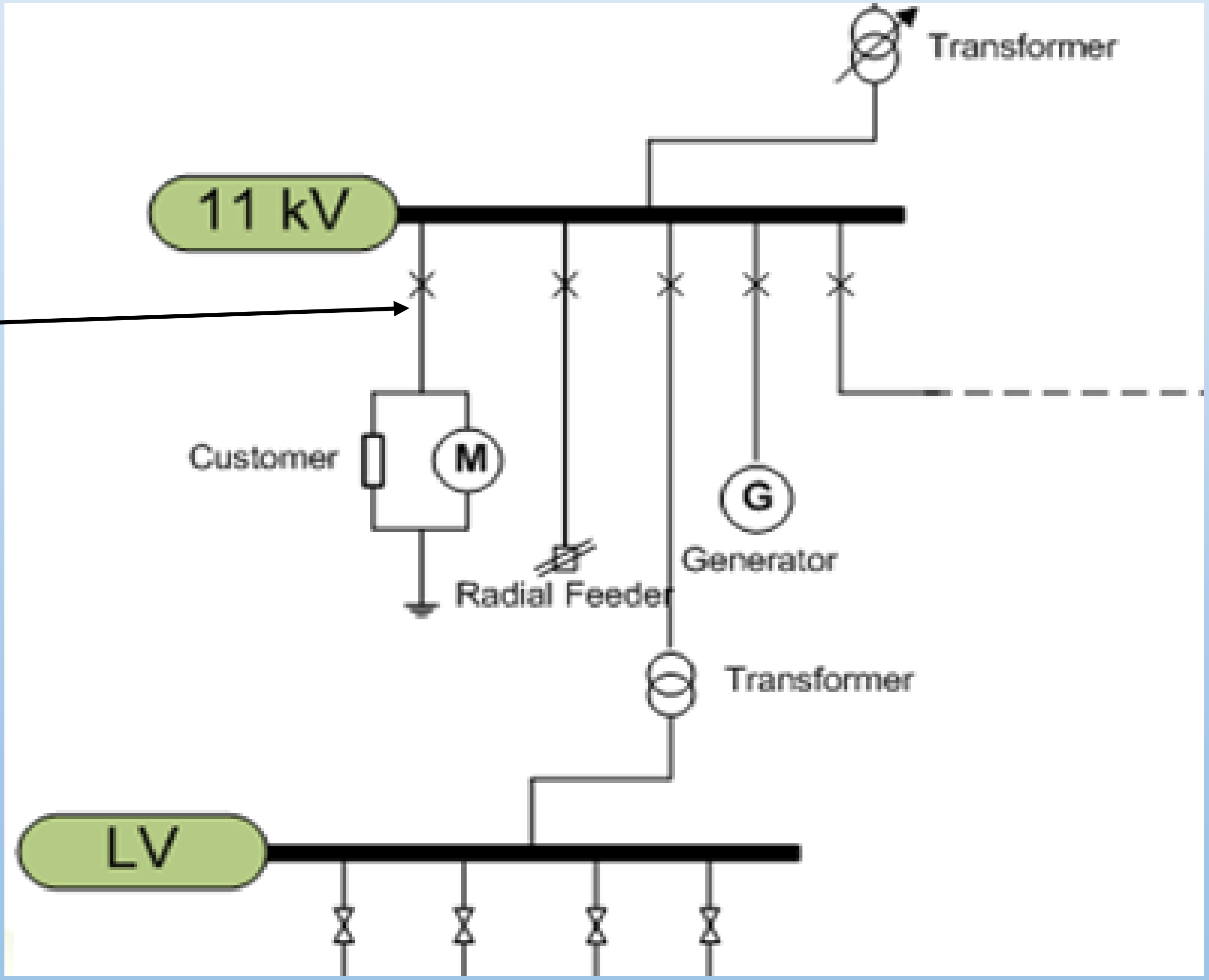
- Optionally create small disturbances to give information to work on (may involve additional hardware.)

Possible FLM connection points



Example FLM Connection

Make connection and measurement HERE



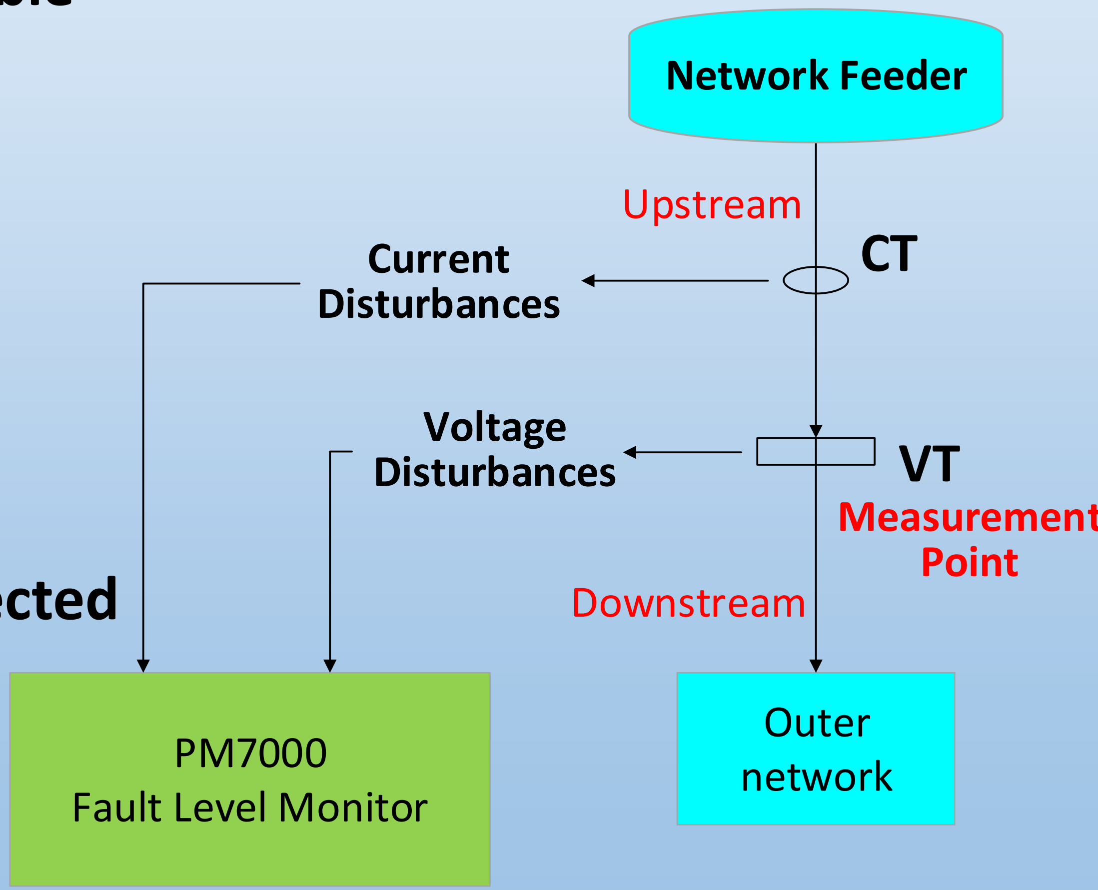
Using Natural Disturbances

Advantage:

- Small, low power, portable
- Passive (Non-invasive)
- Easy to use

Limitations:

- Variable-time
- Must be on a Radial network or a radiallised section of an interconnected network.

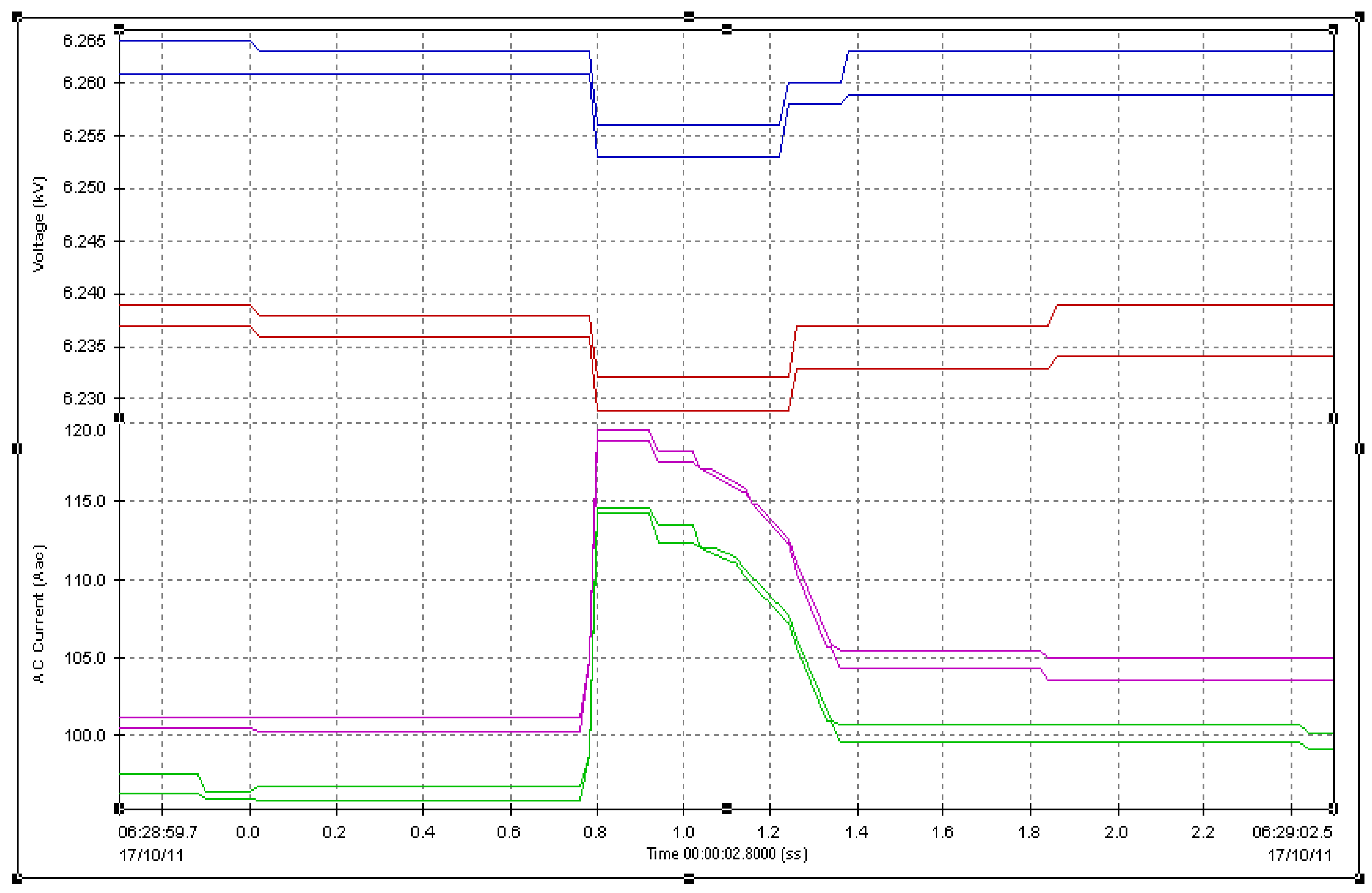


Natural Disturbances available

- DOWNSTREAM changes e.g.
  Load variation on feeder (or piece of network) of interest:
  Produce changes in current and consequent changes in voltage dependent on UPSTREAM characteristics

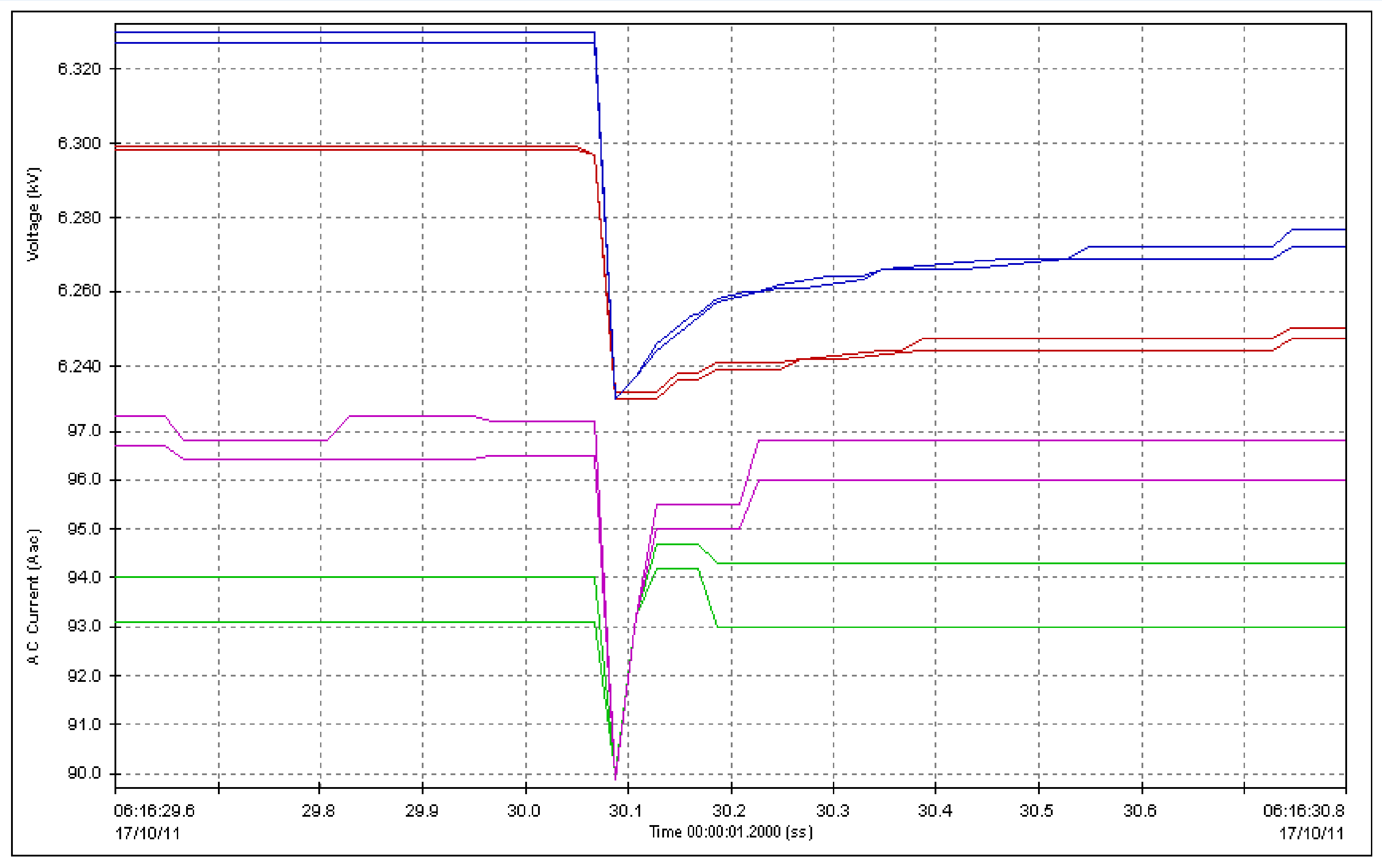
- UPSTREAM voltage changes e.g.
  Tap changes, or load variation on other feeders:
  Produce changes in current dependent on DOWNSTREAM characteristics

Natural Downstream disturbance 3 seconds on screen – 0.1% voltage, 18A



Yields Upstream information

Upstream disturbance - 1 second on screen, 1-1.5% Voltage, 3-7A (Asymmetrical event)



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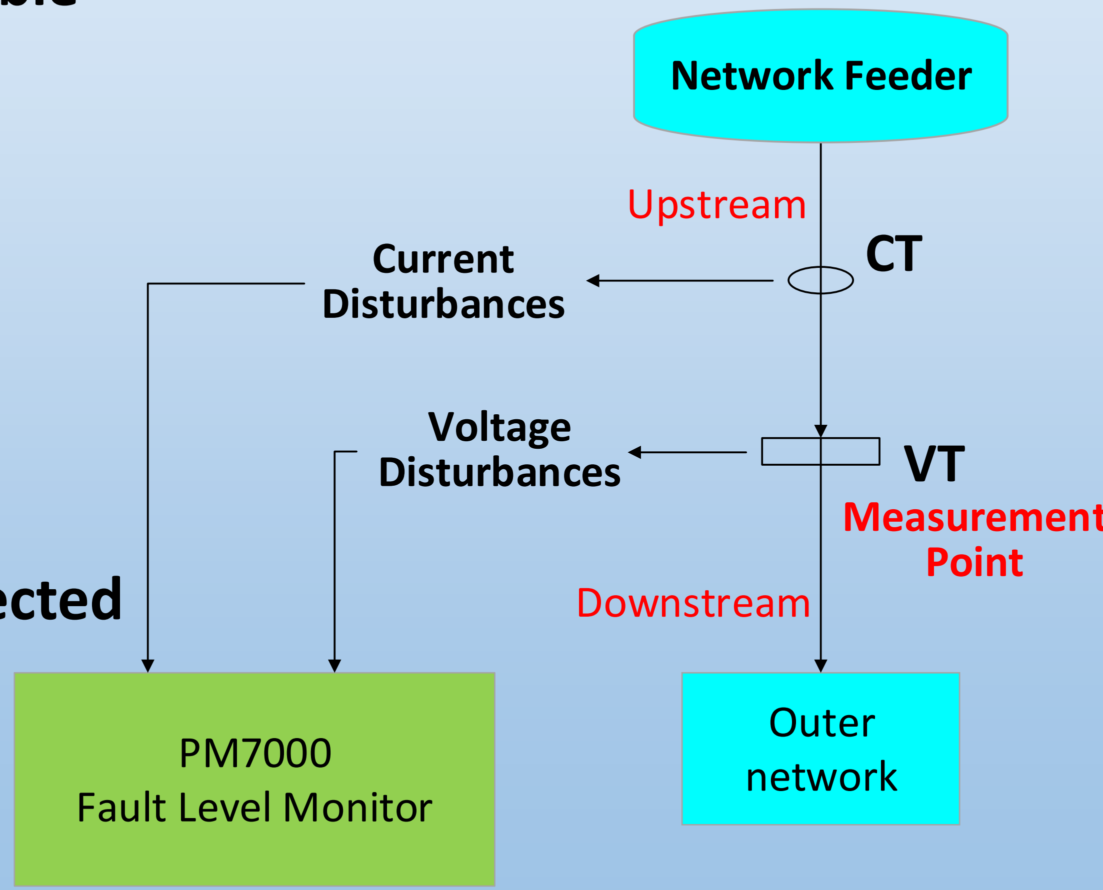
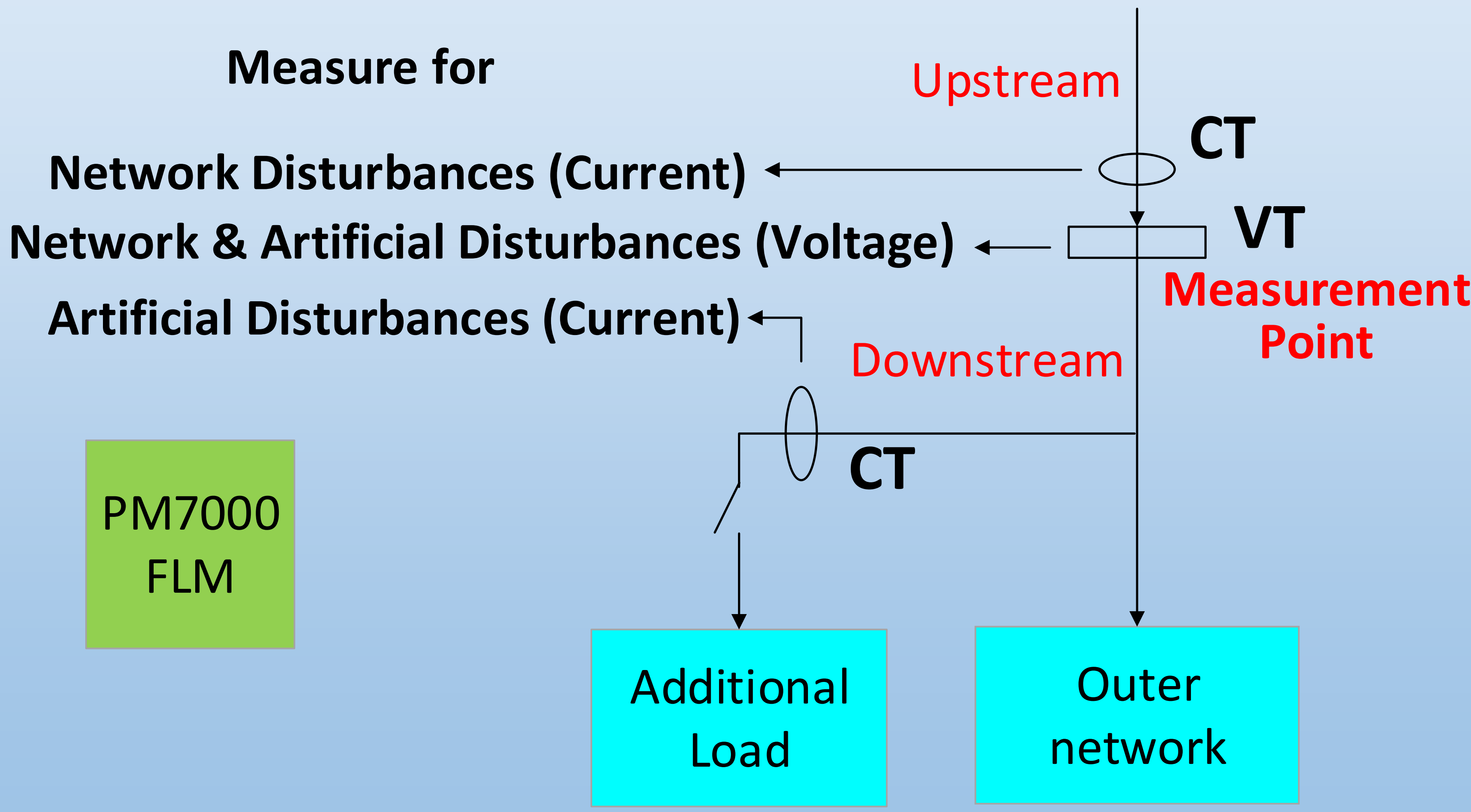


Applying artificial disturbances



Using artificial disturbances

Advantage:

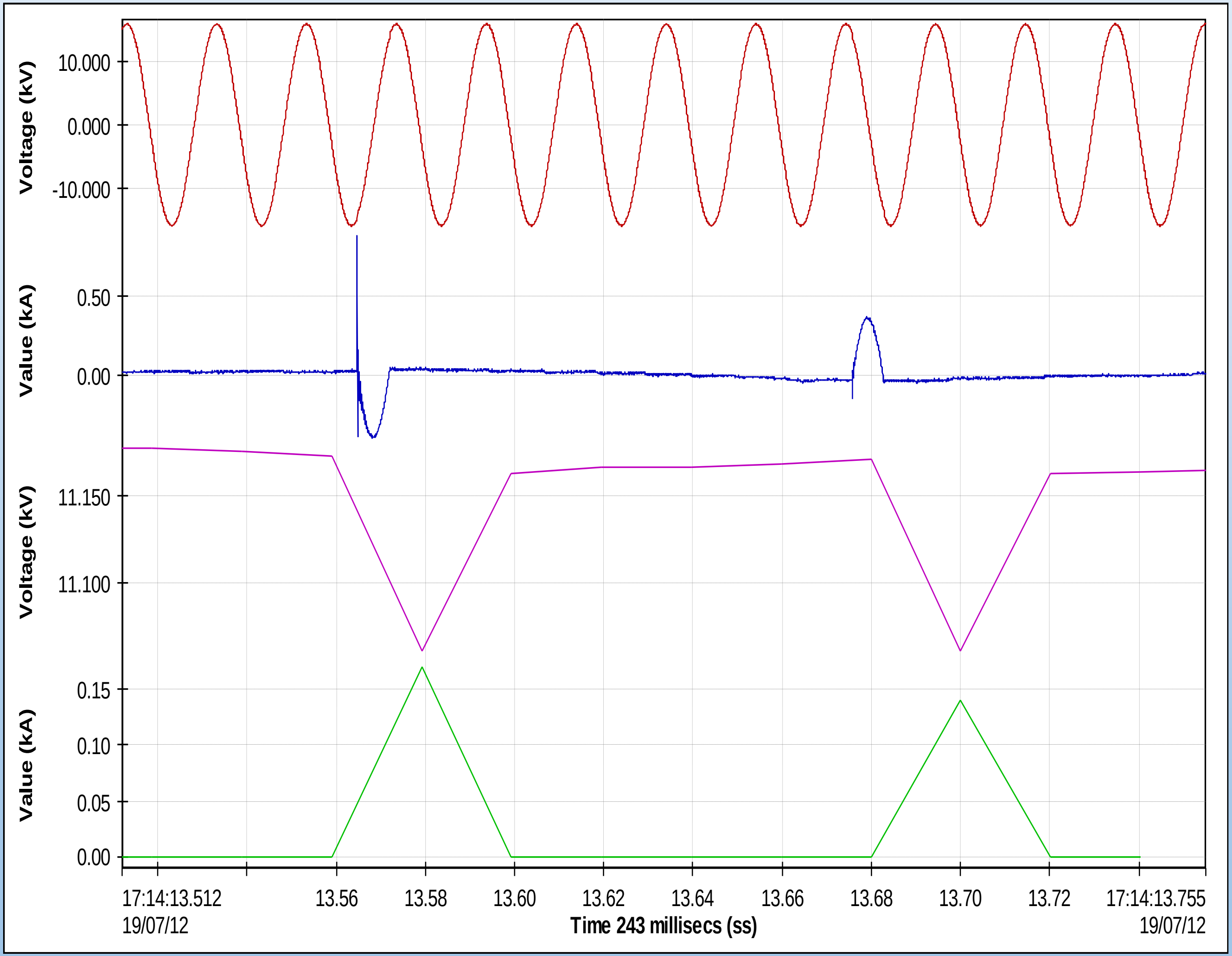
- Real-time on demand.
- Radial - by design.

  The current sensors see ALL the current change, so it will work for interconnected network and it will automatically combine upstream and downstream components.

Disadvantage:

- Needs substantial hardware

A real example – Artificial Disturbances



Negligible Power Quality impact unless repeated frequently.

~1% Voltage disturbance on Vac only for 1 cycle (twice).

Can yield combined information

Design FLM solution to give

- RMS “Break” Fault Level, selectable time T (e.g. 90ms) after Fault Inception
- Peak “Make” Fault level, ½ cycle after Fault Inception
- Motor contribution from attached loads (also at ½ cycle)

Sources of Error

- Systematic errors:
  - VT and CT errors, especially phase errors
  - Network not representative – e.g. motors not present
- Random errors:
  - Instrumentation noise
  - Background Network noise
  - Low Disturbance level (or lack of disturbances)

BUT REMEMBER – The goal also includes reducing need to rely on possibly inadequate model data

Initial Difficulties

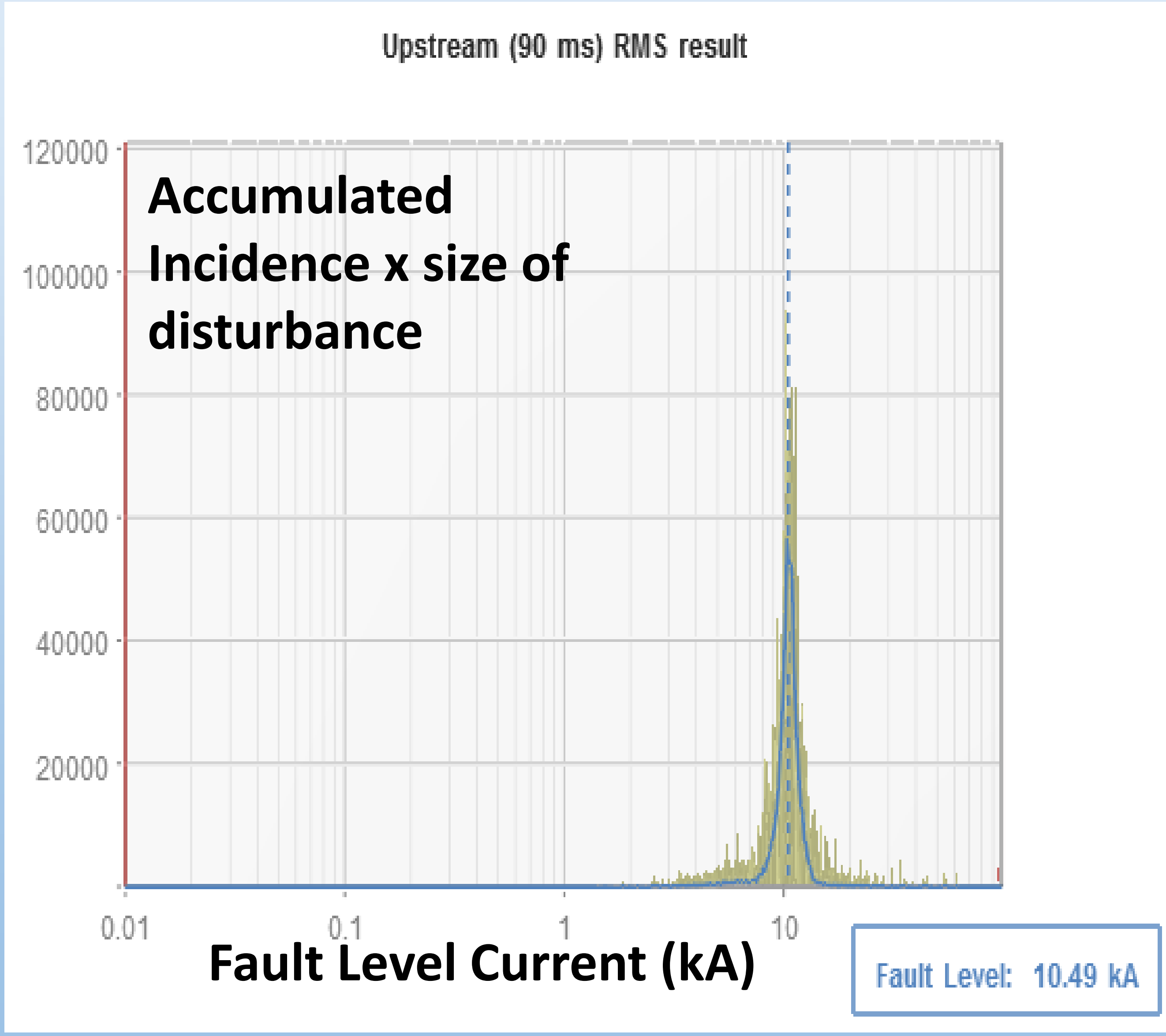
Such products have not been available – how do we know it works?

- Test sites non-existent –
  Difficulty of comparison against real faults
- Motors not present –
  What assumptions should be made, if any.
- Are the existing modelling assumptions relevant (e.g. 1 MVA of motor contribution per x MVA of load

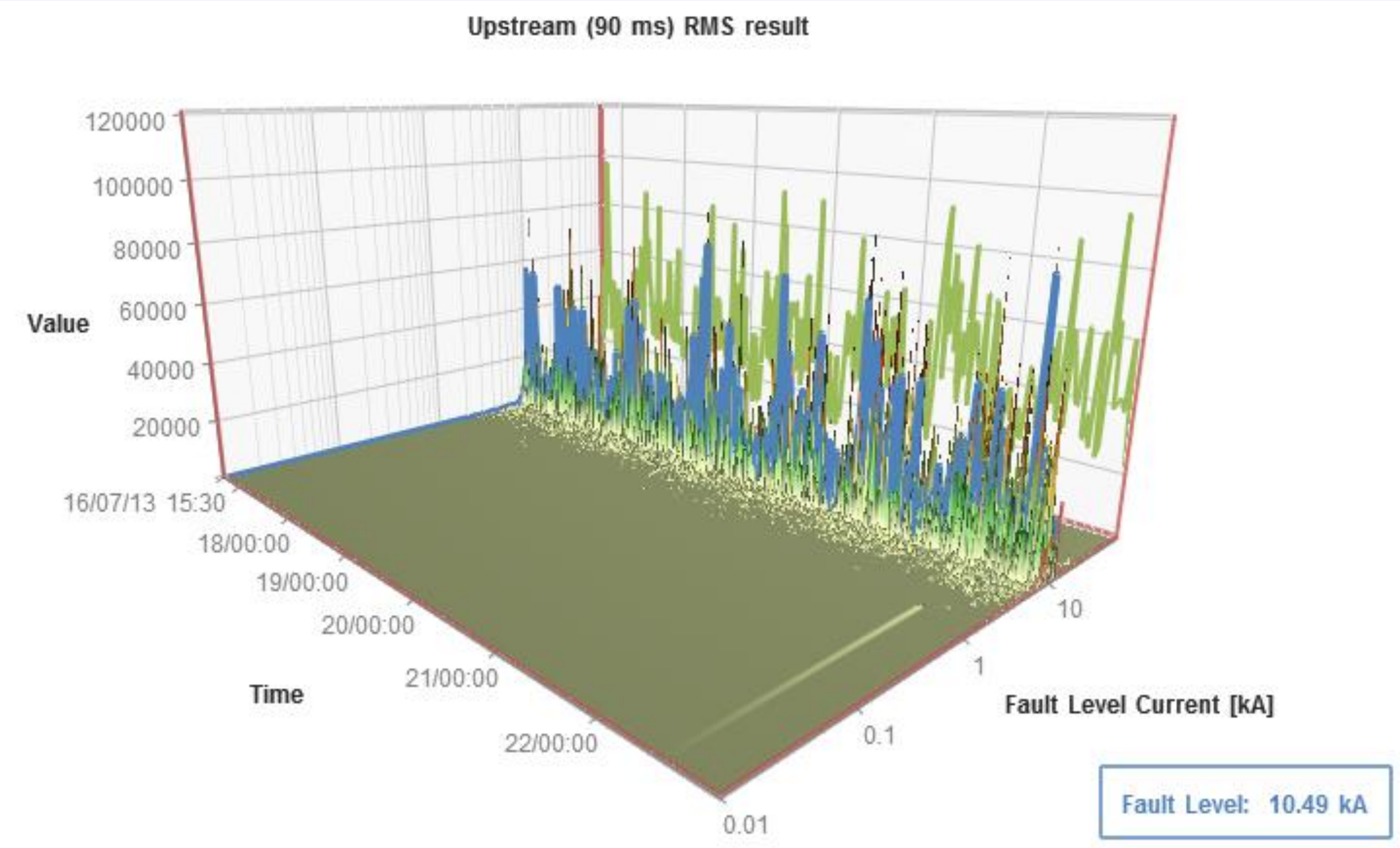
What kind of result should we expect?

For a noisy network, we must expect a noisy set of results.

Show results over a period of time as a Probability Density Function (PDF)



As a 3D surface plot, or series of PDFs describing a longer period of time – e.g. a day, week or month



How well can this system work?

11kV tests of PM7000 FLM at S & C Electric, Chicago, USA, July 2012, using pairs of very short (5ms), fairly high current (500A) pulses.

(With Western Power Distribution – approx. ¼ of UK)

Fault Level Results			
	Predicted	*Actual*	*Error*
Peak	30.63kA	31.34kA	**2.26%**
RMS	12.72kA	13.10kA	**2.90%**

How well can this system work?

LV tests of PM7000 FLM at Kelvatek, 29th May 2013

(With Scottish Power Energy Networks - approx. 1/7 of UK)

Day 1		Actual	10ms Peak	10ms RMS	10ms Motor					
			5.809	3.908	0.287					
Disturbance			Predictions				Errors			
Typ V step	V step	Typ I step	Prediction (kA) (all 2% span filter)							
(V)	as % 415V	(A)	10ms Peak	10ms RMS	10ms Motor		10ms Peak	10ms RMS	10ms Motor	
0.4	0.10%	2.3	5.881	3.973	N/A		1.2%	1.7%	N/A	
0.8	0.19%	9	5.902	4.059	0.277		1.6%	3.9%	-3.5%	
1.4	0.34%	17	5.823	3.983	0.272		0.2%	1.9%	-5.2%	
3.1	0.75%	38	5.815	3.942	0.282		0.1%	0.9%	-1.7%	
3.1	0.75%	38	5.807	3.931	0.287		0.0%	0.6%	0.0%	*

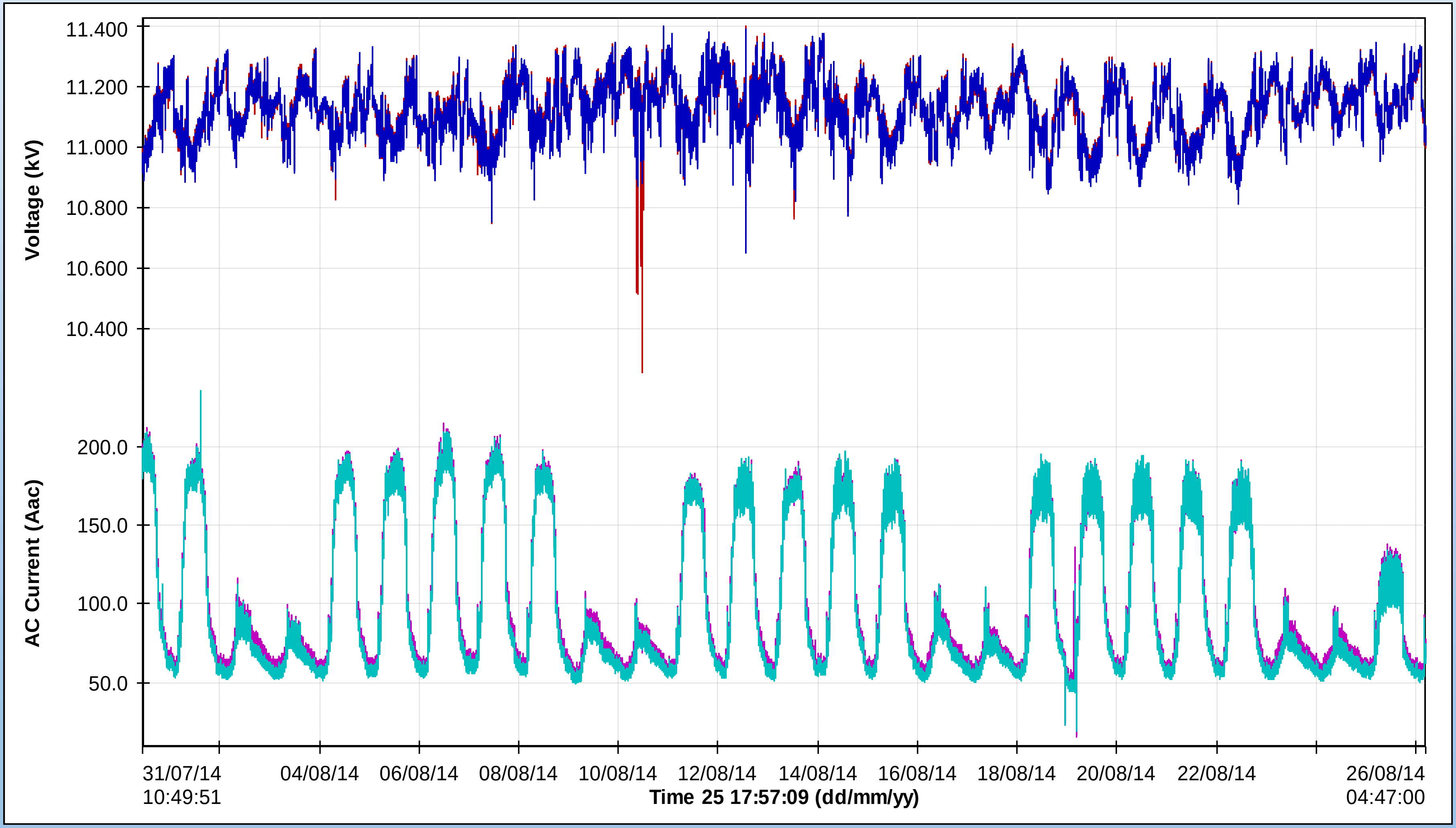
* Test repeated for additonal diagnostics

Case Study 1.
Different numbers of Transformers

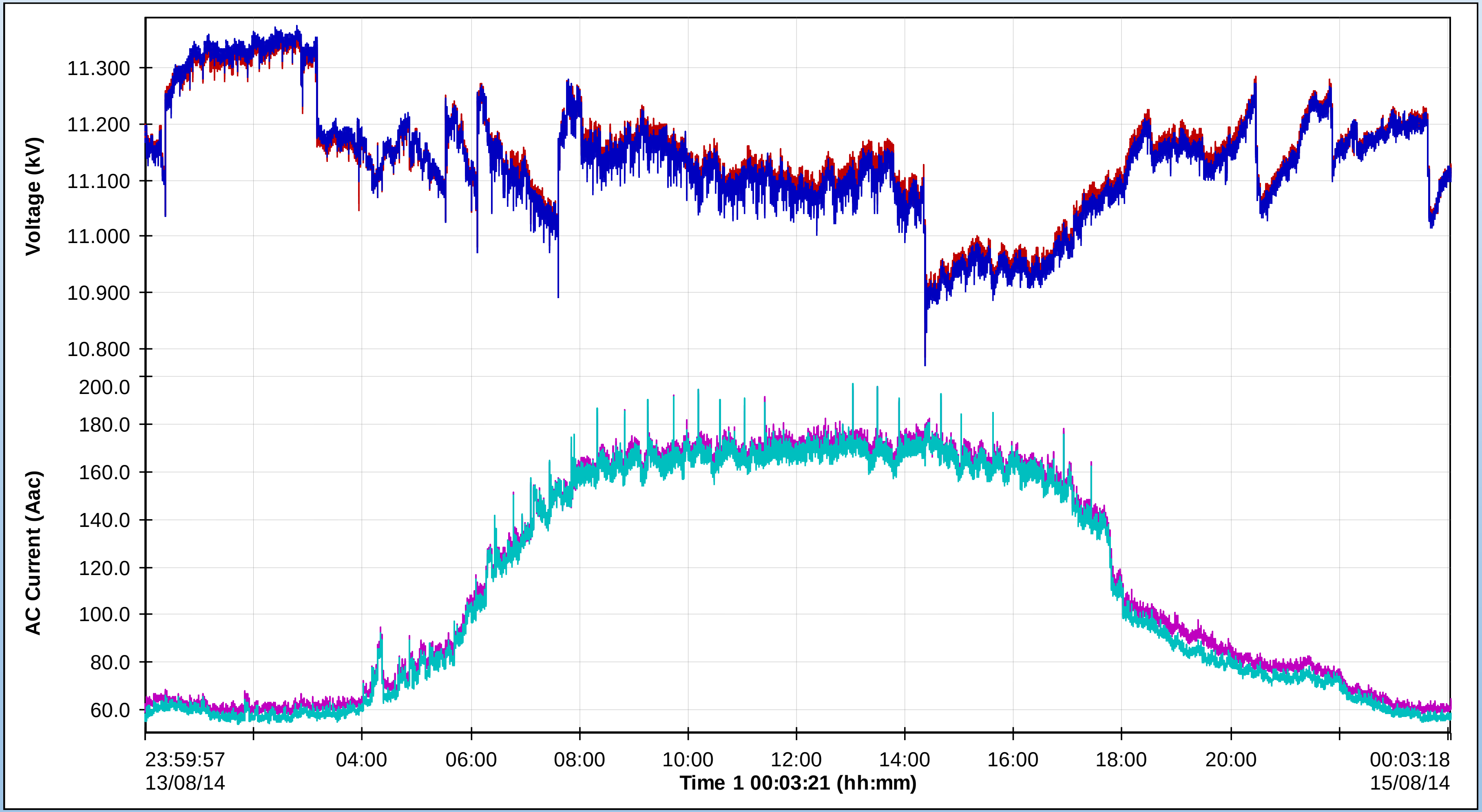
Reading town (pop. 155,000) typically served at 11kV by two parallel transformers. SSE wanted to validate their models for 2, 1 and 3 transformer running.

FLM connected to feeder serving town centre (offices)
Ran 1 week (normal 2 transformers)
Check results. 1 transformer running approved
Ran 1 week (1 transformer)
Ran 1 week (3 transformers)

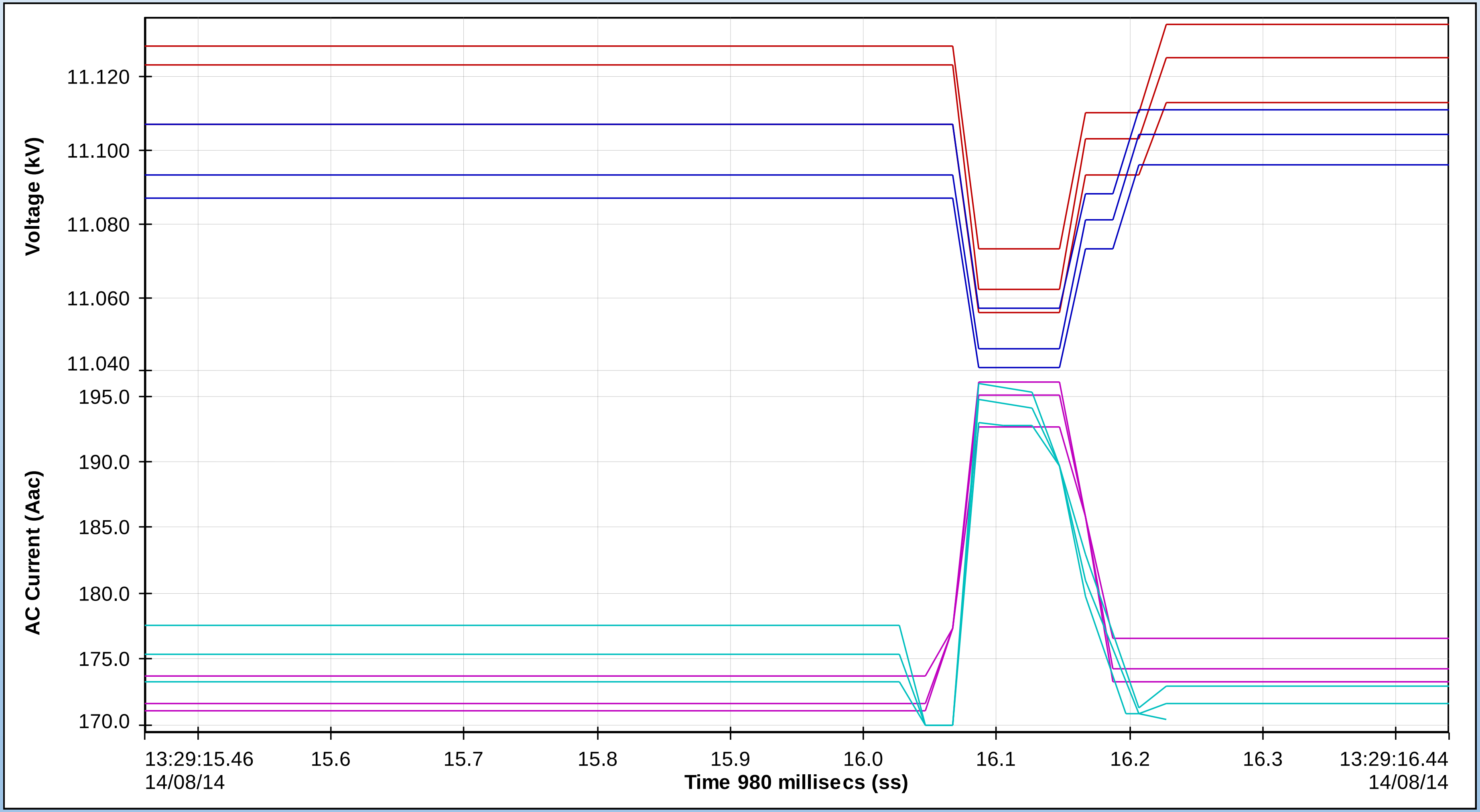
Voltage and current envelope showing daily/weekly load variation



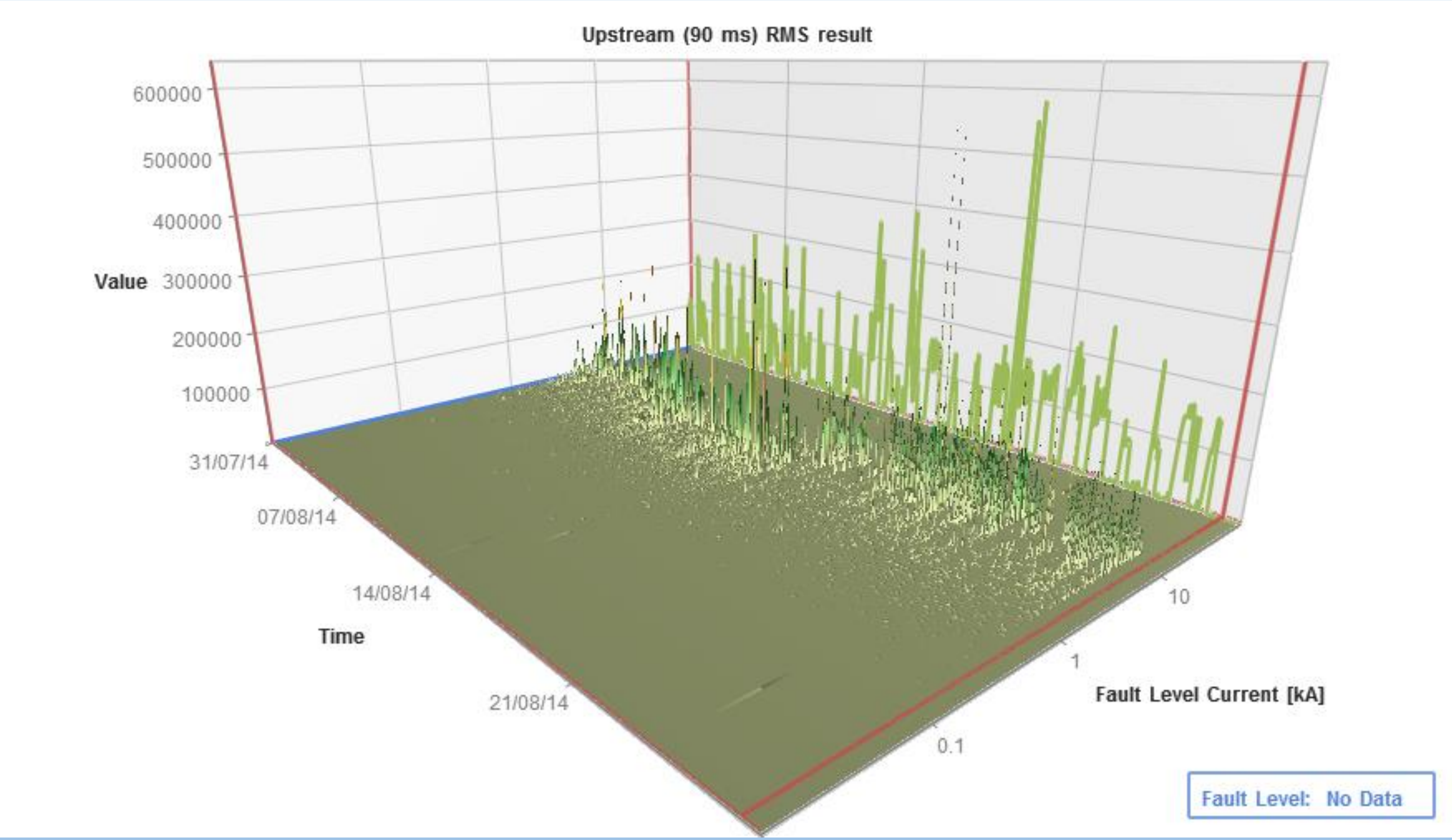
Voltage and current envelope one day with small spikes visible



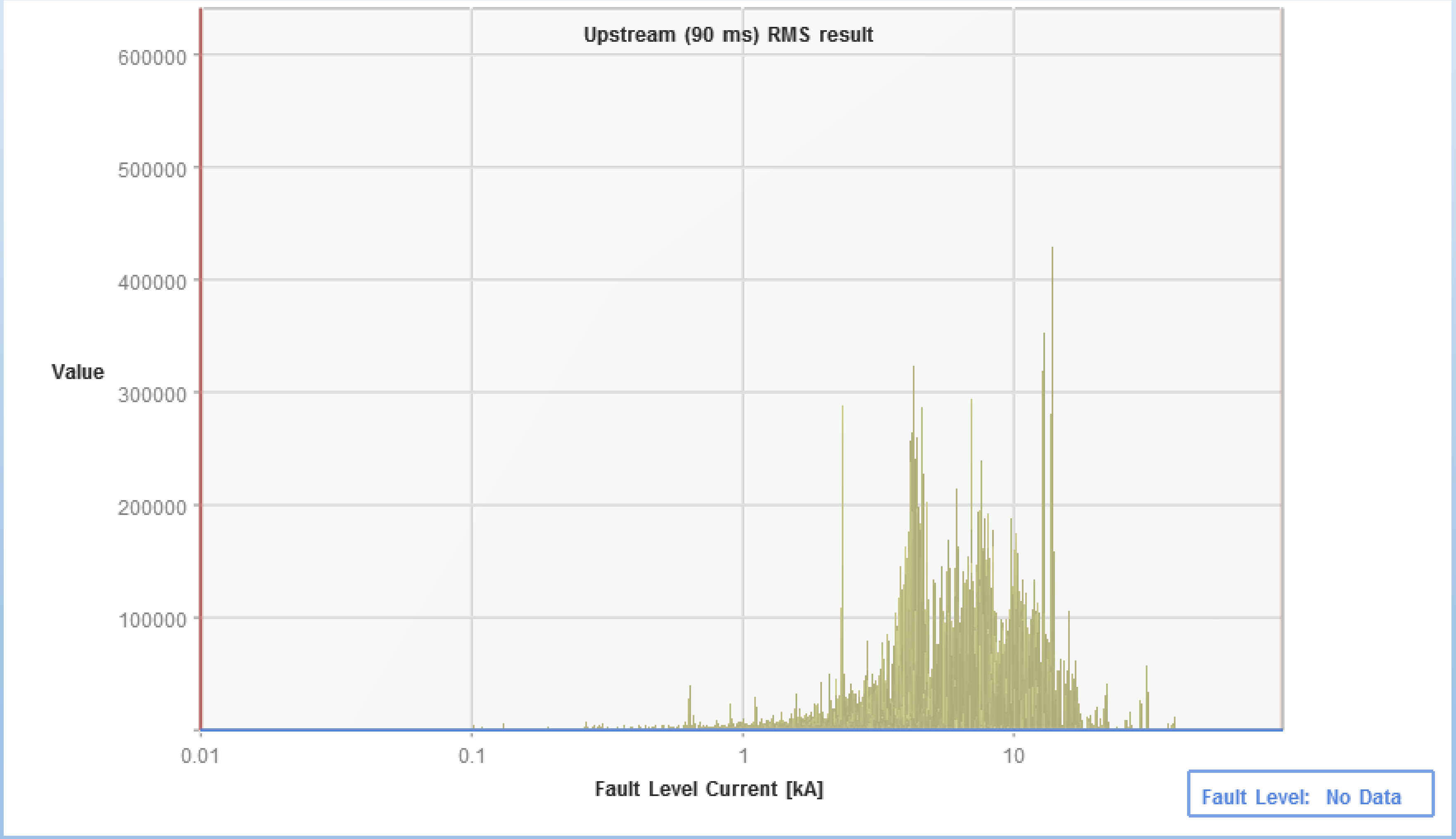
Example small spike
25A produced ~40V = 0.4% variation



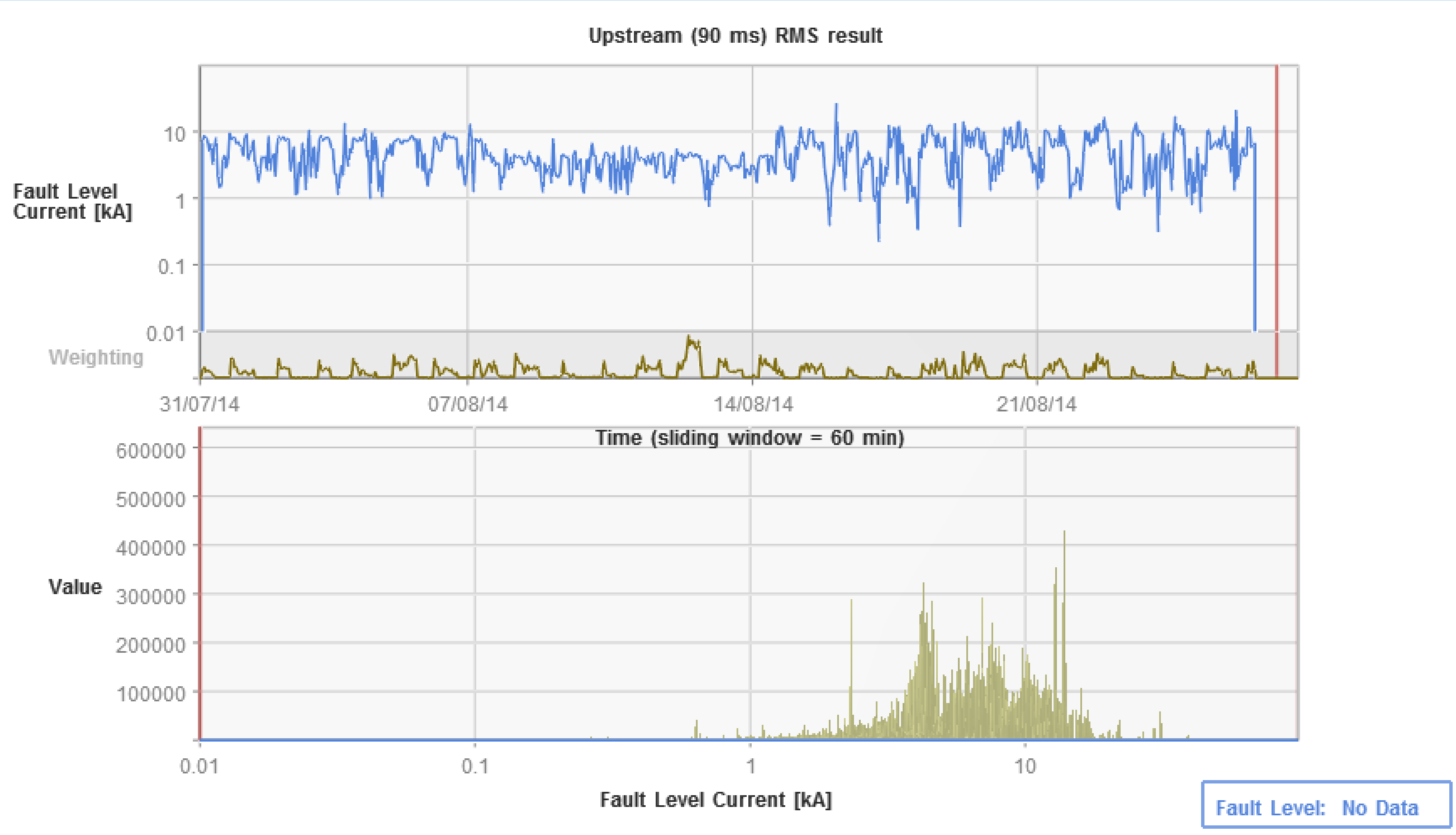
Reading Town – 3 week trial
90ms RMS Fault Level



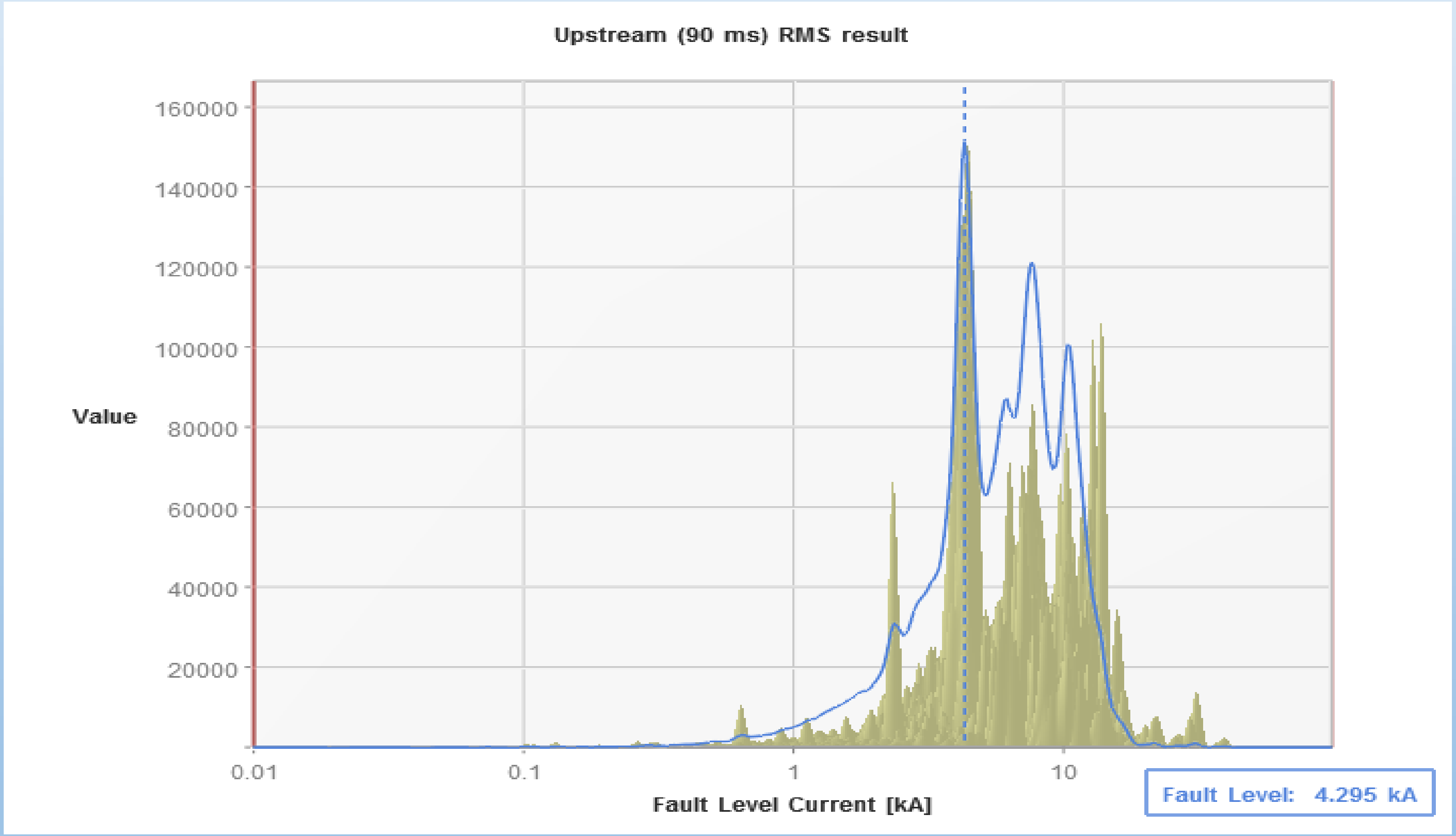
Probability Density Function (PDF) for full period



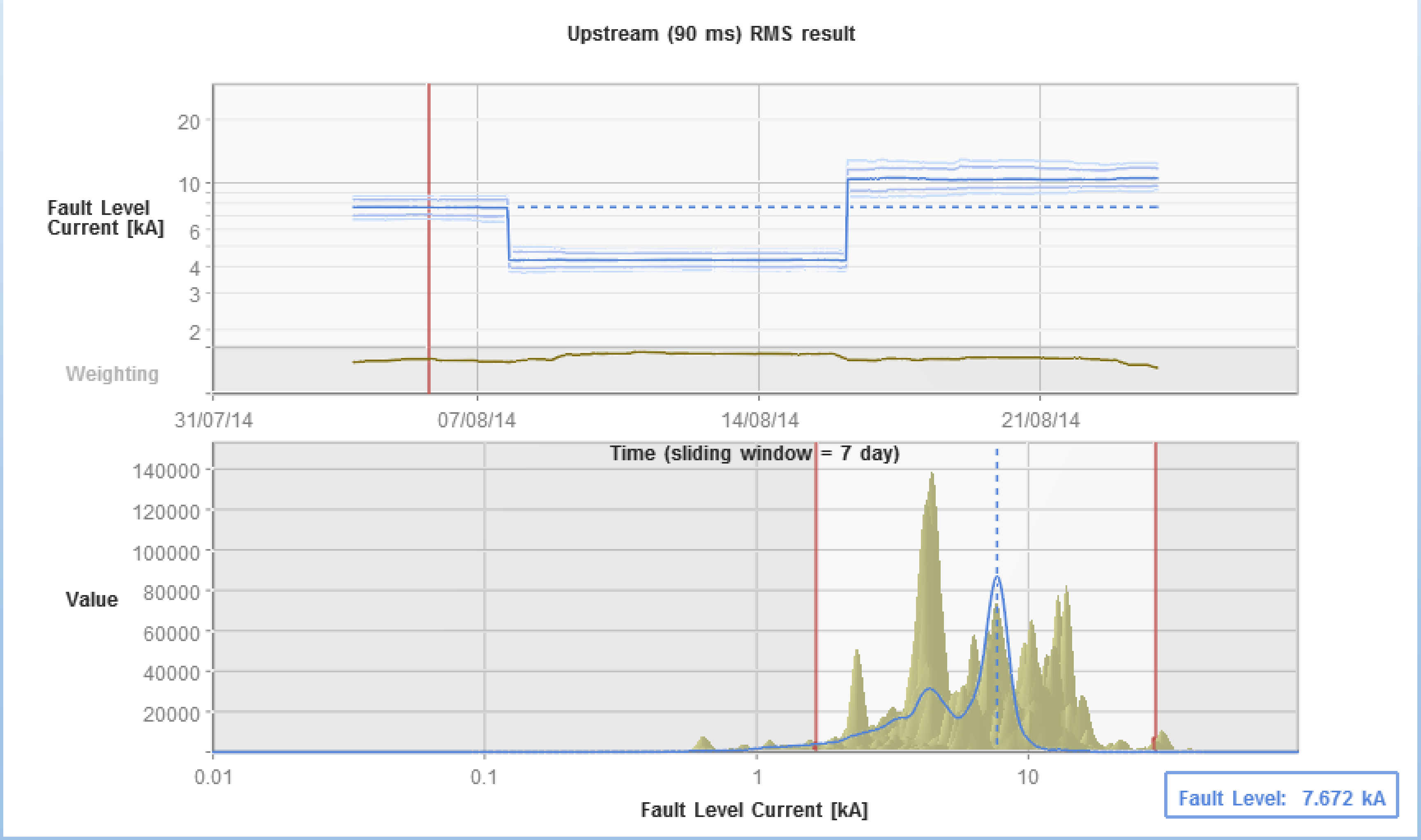
Individual 30 min. interval results, weighting & PDF



Probability Density Function (PDF) with filtering, for full period (blue line)



Time graph and PDF with filtering, for 7 day sections(blue line)



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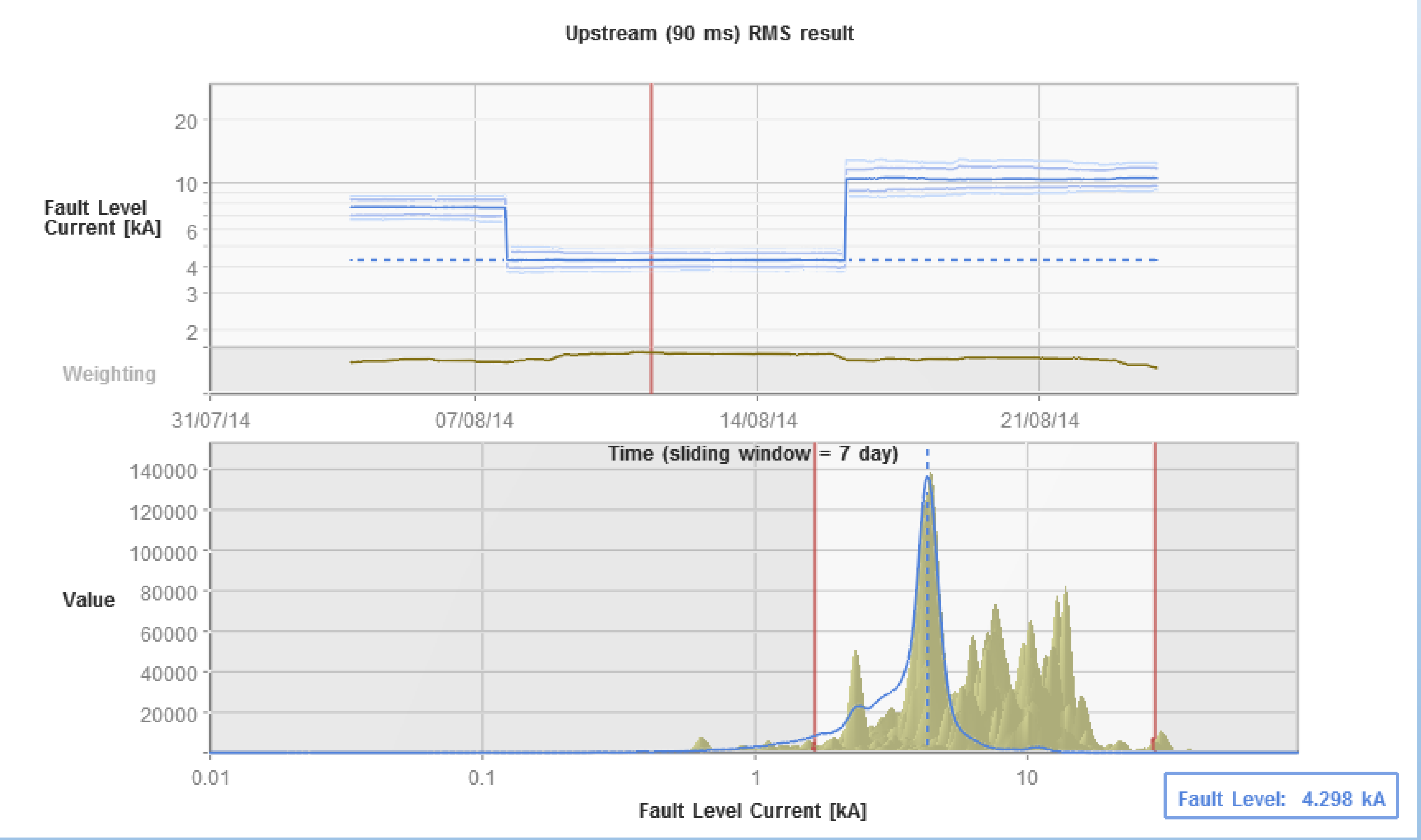

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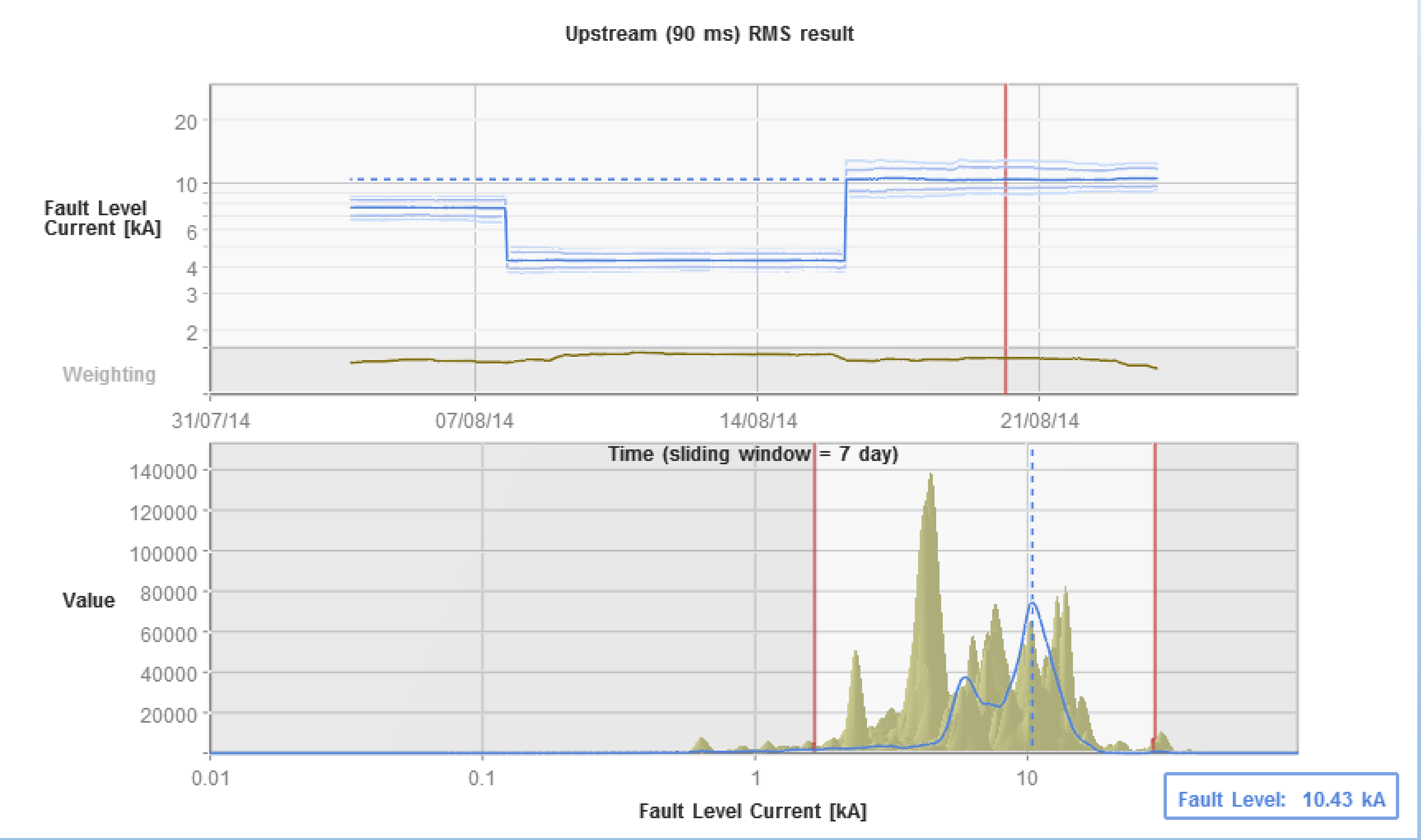


Case study 2.

Chester city centre.

Normally run as a four-transformer meshed group

Scottish Power want more security of supply

A fifth transformer is available, but can it be used?

Planners say NO (excessive Fault level)

Proposition the planners to:

1. Model four group operation as accurately as possible
2. Measure using FLM
3. Compare with model.

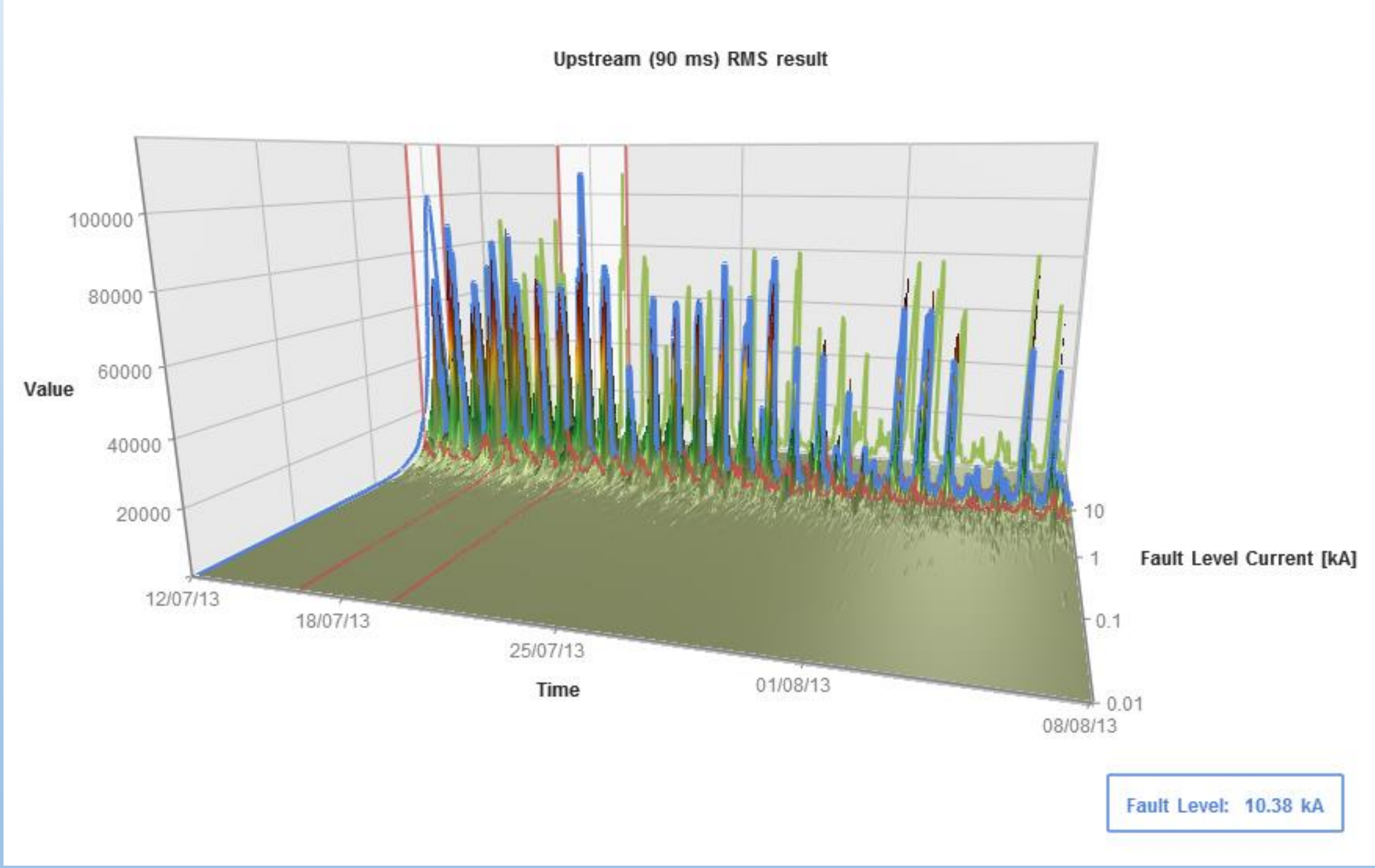
Proposition the planners to:

1. Model four group operation as accurately as possible
2. Measure using FLM
3. Compare with model.
4. If comparable, and well below fault level, then
5. Model five group
6. If result still adequately below fault level, then
7. Switch in fifth transformer, and do short measurement with FLM
8. Compare with model

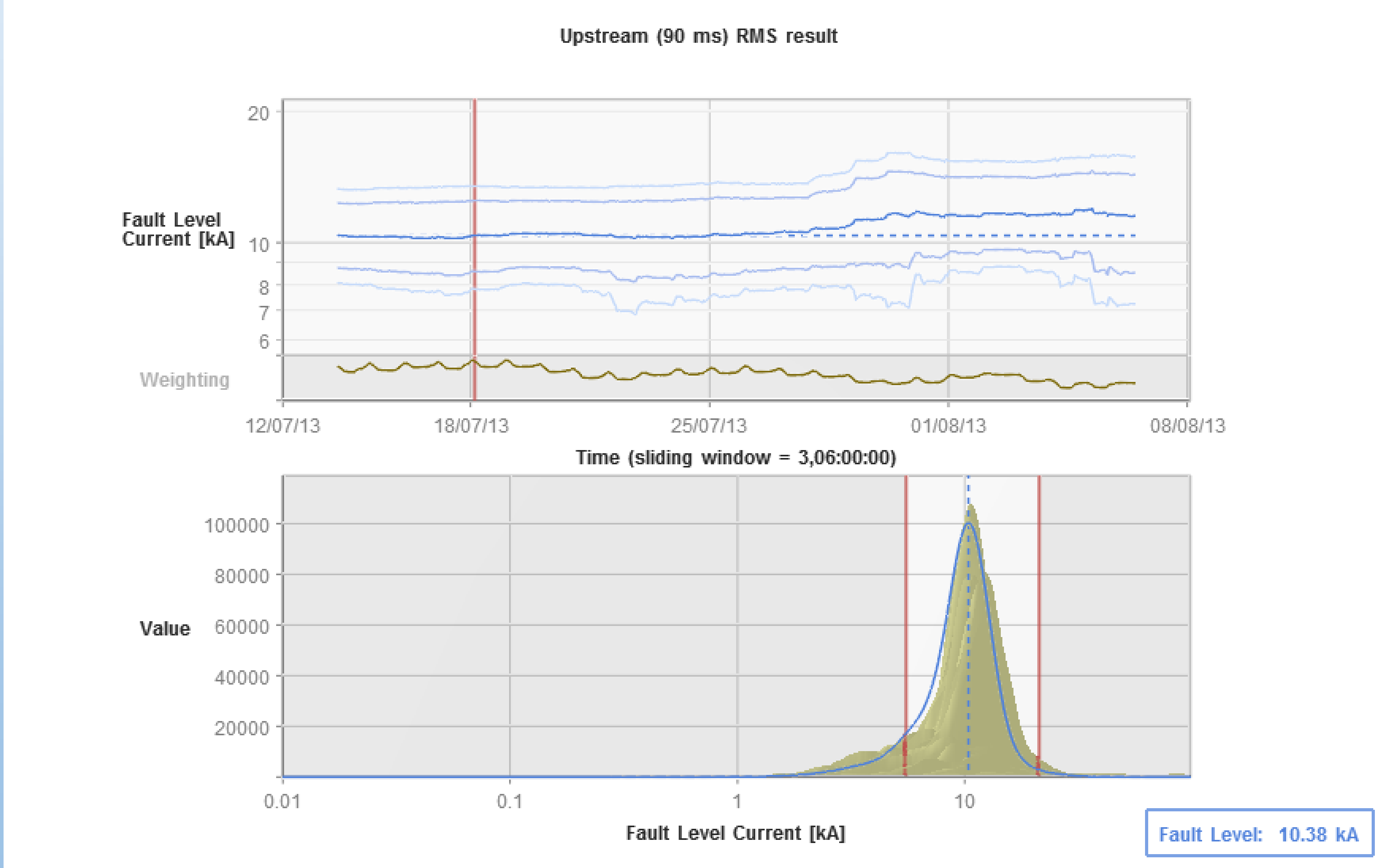
Proposition the planners to:

1. Model four group operation as accurately as possible
2. Measure using FLM
3. Compare with model.
4. If comparable, and well below fault level, then
5. Model five group
6. If result still adequately below fault level, then
7. Switch in fifth transformer, and do short measurement with FLM
8. Compare with model
9. If comparable and below fault level, extend measurement
10. If consistently below fault level,
11. Obtain approval to use fifth transformer when required.

3D result showing test period
Daily variation in disturbance energy visible



3D result showing test period and change in Fault level



Results at FLM location

Four group model (IPSA)	10.16kA*
Four group FLM	10.19 kA*
Five group model (IPSA)	11.68 kA**
Five group FLM	11.14 kA**

* Confidence gained that the IPSA model is accurate for Period 1 (4 Group) as the FLM result is ~0.3% out

** Results generated by FLM over the 2 weeks in Period 2 (5 Group) suggest that the FL is 4.8% lower than the IPSA model predicted

Conclusion: Despite the variation between FLM results and IPSA, both sets of results indicate that the Group could be run as a 5 group, should that offer operational benefits

A measurement solution exists!

Potential Use Cases:

I. Identify safety risks arising from overrated switchgear

II. Identify additional network capacity for new connections

III. Validate fault level reinforcement plans

IV. Observe the fault level contribution from connected customers

V. Improve existing understanding of fault level variance over several seasons / years

VI. Validate existing network models

VII. Identify optimum network running arrangements without exceeding fault level

VIII. Facilitate Active Network Management schemes that control network fault level

Other uses

Establish local Fault Level

- **As an aid to Harmonics planning**
- **To advise parameters to would-be Distributed Generation operators**
- **To help big polluters to police themselves**
- **Inform Automatic Disconnector settings (SEECO)**

Aid to Fire Retardent Index specification for Arc Flash protection clothing.   FACTS/Motor contribution

Where Next?

‘Facilitate Active Network Management schemes that control network fault level’

- Having an accurate Fault Level Monitor now opens the door to the possibility of real time Fault Level measurements from our network
- In turn this could enable DNOs to operate their networks closer to their fault level limits with confidence
- The FLM could be incorporated into sequenced switching and Active Network Management schemes to autonomously reconfigure the network, curtail generation and load to maintain an acceptable network fault level

Fault Level Monitor

Fault Level from real measurements.

John Outram
www.outramresearch.co.uk