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RESPOND FLAT VALIDATION

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RESPOND FLAT VALIDATION

Electricity North West Ltd

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1 INTRODUCTION

1.1 RESPOND PROJECT

The Electricity North West's Respond, second tier Low Carbon Network funded project, is investigating active fault level management techniques as a cost beneficial alternative to traditional reinforcement of network assets.

Central to the control of the Respond fault level mitigation techniques is the Fault Level Assessment Tool, FLAT. The FLAT assesses fault levels in near real time and when the calculated fault levels exceed a predefined threshold it sends an enable command to the fault level techniques which only operate in the event of a fault to manage the fault current safely.

This report presents the results of the validation of the FLAT as required for the delivery of Successful Delivery Review Criteria, SDRC 9.1.4, as shown below.

CRITERIA	EVIDENCE
Validate the Fault Level Assessment	Publish report on validation of the Fault Level Assessment Tool by November 2016

2 VALIDATION METHODOLOGY

2.1 OVERVIEW

This report presents the validation of the FLAT demonstrated through comparison with simulated fault level results obtained using an IPSA representation of the Electricity North West distribution network.

In turn, confidence in the fault level results from the IPSA model was established through an independent exercise by TNEI in which simulated fault levels were compared with 'actual' fault level values obtained using the Fault Level Monitor (FLM) device manufactured by Outram Research Limited (ORL). The overall process is shown in Figure 2-1. Results of the FLM monitoring and TNEI comparison are reported separately, specifically within:

- Outram report entitled "Respond Project Fault Level Report for Electricity North West Ltd" V3 dated 21/07/2016
- TNEI report entitled "LCNF Fault Level Monitoring and Modelling of ENW Network" R3 dated 10/11/2016.

The overall comparison between FLM fault levels, IPSA results and FLAT outputs is considered to provide a robust validation of the FLAT. The TNEI comparison has found reasonable agreement between the FLM and IPSA results, but concluded that the IPSA simulated peak make fault contribution is most likely underestimated. This work has increased the understanding of the IPSA simulated fault levels and therefore they are considered a credible benchmark for comparing the FLAT results.

Validation of the FLAT is required to demonstrate that the FLAT results are credible values for basing the control of the fault level mitigation. Also, an understanding of the accuracy of the FLAT results versus 'actual' fault levels is required in order to inform settings of the limits that will be used to "enable" and "disable" the fault mitigation techniques in the future. For example, a FLAT upper limit setting of 90% of the switchgear rating with an understanding that the FLAT fault level results are approximately 10% greater than actual fault levels, can be then be comprehended as the "enable" command being initiated when the FLAT results exceeds 90% of the rating or the actual fault level exceeds approximately 82% (0.9/1.1) of the rating.

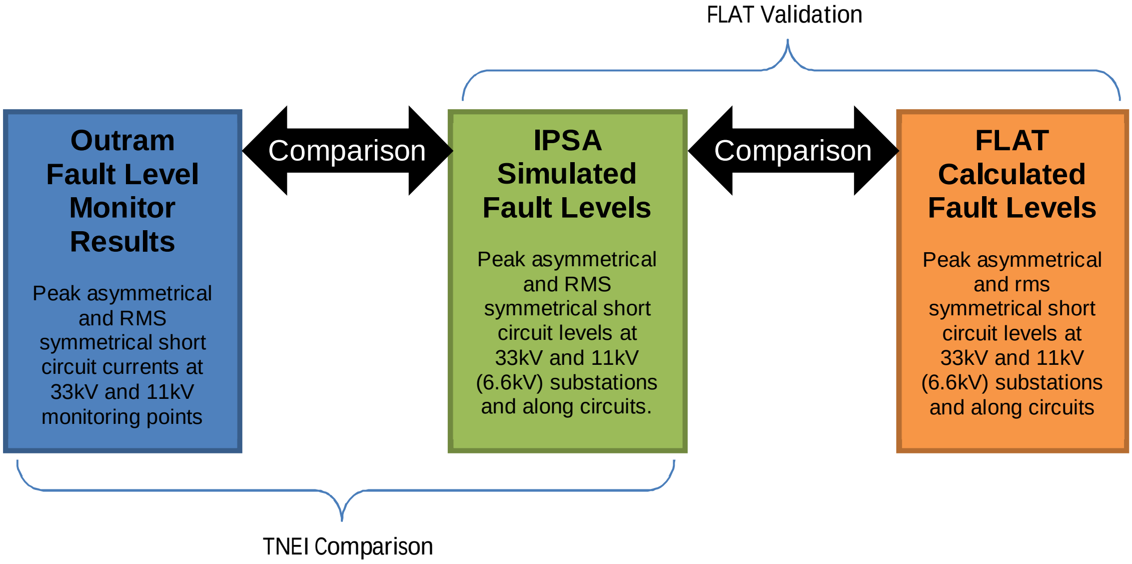


Figure 2-1: Overall validation process

2.2 VALIDATION SCOPE

The validation has been undertaken based upon four selected networks, namely Broadheath 11kV, Denton West 6.6kV, Irlam 6.6kV and Wigan 33kV which are four of the fourteen Respond trial sites. Comparisons of three phase peak asymmetrical make and RMS break fault currents were undertaken for all 33kV and 11kV/6.6kV locations within these networks where results were available from the FLAT and the TNEI IPSA study. Wigan 33kV is limited to the substation only since it does not directly feed HV circuits.

Comparisons between the FLAT and IPSA results have been undertaken for the substation busbars and for locations along the feeders. Both types of location are important in terms of the future application of the FLAT results in controlling the enabling or disabling of fault mitigation techniques. Fault mitigation could be required if the fault level reaches the rating of equipment either at Primary substations or out on the network along a feeder. Greater fault levels are likely to occur at substations, but the equipment ratings are also likely to be greater there. However locations along feeders could present a greater constraint even though the potential short circuit currents could be less because the equipment rating is also likely to be less there.

The scope of the validation was to examine the overall agreement between the FLAT and IPSA results, but not assess the model details in order to identify specific mismatches in either the modelled parameters or network arrangement.

The FLAT is part of Electricity North West's new Control Room Management System which is presently being developed by Schneider Electric. The complex process of transferring the electrical model from the existing Electricity North West systems into the new Advanced Distribution Management System (ADMS) chiefly lies within the ADMS project which is not due to complete until 2017. Development of part of the model has had to be advanced in order to enable the FLAT during the Respond trial. The interface with the Advanced Distribution Management System (ADMS) project means that it is not believed to be appropriate or efficient to resolve individual data issues as part of the FLAT validation. Errors are likely to be associated with the wider processes being developed to extract the data from existing systems for the ADMS and therefore should be resolved as part of that. Hence detailed comments on and correction of specific mismatches between the FLAT and IPSA results due to inconsistencies in the model parameters or configurations are deemed to be outside of the scope of the validation task.

The comparison depends upon matching results from TNEI's IPSA study and FLAT. Inconsistency between node names used in the IPSA and ADMS models meant that in some cases a manual approach was needed to pair them. However, it became evident that results were not available from both simulations for every location; in some cases results were available from one source, but not the other. It is considered that sufficient comparisons were possible in order to validate the FLAT results. Results from either the IPSA or FLAT evaluation were expected to be missing and therefore their identification was not the objective of this task and not pursued.

2.3 FLAT

Respond is using the FLAT to calculate fault levels in near real time across the Trial areas using network data available through the Advanced Distribution Management System (ADMS). Fault currents are automatically re-evaluated when the system configuration changes or according to a configurable time delay (every five minutes in this case).

When the calculated fault level exceeds or drops below predefined upper and lower limit settings, the tool "enables" or "disables" the fault level mitigation technique via the ADMS respectively. The techniques will only be enabled at times when the calculated fault level is greater than the threshold setting which will normally be below the equipment rating by a suitable margin. It is noted that the "enable"/"disable" threshold has been set low during the first stage of the Respond trials to ensure that the alternative fault level mitigation techniques are permanently enabled to be able to test their operation.

2.4 FLM OUTRAM MONITORING

Fault Level Monitors were installed and determined the fault level at five Respond trial sites, specifically:

I. Broadheath
II. Denton West
III. Hindley Green
IV. Irlam Primary
V. Wigan BSP

Hindley Green was initially selected for the Respond trials but deemed unsuitable for the trials and subsequently replaced by Denton West. Although the FLM was installed at Hindley Green, it was not included in TNEI's IPSA study and consequently is not included in this validation.

The FLM analyses network responses to naturally disturbances to estimate upstream and downstream fault contributions separately. The combined total fault level is determined by summing the individual components assuming that they occur at the same time and are in phase.

10ms Peak Upstream, 10ms Peak Downstream, 90ms RMS upstream and Combined 10ms Peak fault current results in kA were obtained for each site.

The Outram FLM report concluded that the results were good and unambiguous.

2.5 TNEI STUDIES

Electricity North West undertakes business as usual network planning using IPSA and Dinis power system analysis tools, hence they maintain comprehensive network models in both softwares and the results are well understood. Consequently, IPSA was chosen as a benchmark when looking to validate fault levels calculated using the FLAT.

TNEI were contracted to calculate 33kV and 11kV(6.6kV) fault levels for samples of the Respond trial networks and make comparisons with the FLM results to assess the level of confidence of the simulated fault levels. TNEI extended Electricity North West's existing IPSA model to include the downstream 11kV (6.6kV) networks by importing data into IPSA from Dinis. Fault levels were simulated and compared to the FLM results for:

I. Broadheath
II. Denton West
III. Irlam Primary
IV. Wigan BSP

2.6 DATA SOURCES

2.6.1 FLAT Results

The FLAT fault level results used in this validation exercise were taken from simulations undertaken by Electricity North West as tabulated in Table 2-1.

Table 2-1: FLAT result files

Location	Filename	Study Date/Time
Broadheath	broadheath_IEC_28092016	28/09/2016 16:16:22
Denton West	Denton West FLs_BFC_9sep2016	08/09/2016 18:38:39
Irlam	irlam FLs_BFC_9Sep2016	08/09/2016 18:36:40
Wigan	Wigan FLs_BFC_9sep2016	08/09/2016 18:39:43

2.6.2 IPSA Results

The IPSA fault level results along the feeders used in this validation exercise were taken from Appendix H of TNEI's report entitled "LCNF Fault Level Monitoring and Modelling of ENW Network" R3 dated10/11/2016. Corresponding substation fault level results similarly relating to the maximum loading system normal condition were taken from tables in section 5 of the aforementioned TNEI report, specifically:

Broadheath	TNEI Table 5-2
Denton West	TNEI Table 5-7
Irlam	TNEI Table 5-11
Wigan BSP	TNEI Table 5-16

3 FAULT LEVEL METHODOLOGIES

3.1 FAULT LEVEL METHODOLOGIES

It is important to consider the differences in the fault calculation methodologies employed within IPSA and the FLAT in order to inform the comparison of their results. Table 3-1 summaries aspects of the IPSA and FLAT fault calculation methodologies employed to provide the results that are compared as part of the validation.

Table 3-1: Fault calculation methodologies

Parameter	IPSA	FLAT
Fault Calculation Methodology	Fault calculations using fully detailed D-Q axis machine models and network parameters	IEC 60909
Fault Type	3 phase	Maximum of 3 phase, phase to ground, phase to phase and phase to phase to ground fault currents
Make Fault Current	Peak asymmetrical current at 10ms	$I_p = x \sqrt{2} I_k$" x is determined using Method C I_k" = cV_n / Z_k" c – voltage factor V_n – rated voltage Z_k" – equivalent positive impedance for sub-transient period
Break Fault Current	RMS symmetrical current at 90ms	Ib = μ Ik" , μ=1
Pre-fault Voltage	Pre-fault load flow voltages	Does not consider pre-fault load flow, but employs the c factor c_{max} = 1.1 for voltages >1kV

3.2 FLAT METHODOLOGY

The ADMS and FLAT offer alternative fault current calculation applications. The results employed in this comparison were obtained using the Breaker Fault Capacity (BFC) application which checks the AC and DC components of simulated fault level against the capability of each circuit breaker. Three phase, phase to ground, phase to phase and phase to phase to ground fault currents are calculated in order to establish the maximum fault level used to assess the circuit breaker. The BFC calculation can be configured by the user and in this case all calculations have been undertaken using IEC60909[1].

IEC 60909 is a planning standard for assessing the worst case short circuit currents potentially using hand calculations. Only one network solution leading to the calculation of Ik" is required as the peak and break short circuit currents are then calculated using Ik".

[1] IEC 60909-0:2016 Short-circuit currents in three-phase a.c. systems - Part 0: Calculation of currents

Other configurable fault calculation parameters are:

- Power of the transmission network = Maximum, reflecting the modelling of the upstream fault infeed
- Pre-fault voltage = Maximum, reflecting the use of c_{max}

The BFC application reports fault levels at circuit breaker locations included in the ADMS model. Not all actual circuit breakers are presently represented in the ADMS model and therefore the validation has been based upon the results arising from the existing system model. It is recognised that more fault level results will be evaluated by the FLAT BFC application when all circuit breakers are eventually represented within the timescale of the overall ADMS project.

The FLAT results used in the validation are based on the assumption that μ=1, i.e. there is no decrement in symmetrical fault current by the break time, although subsequent development of the FLAT is likely to facilitate a variable break time and corresponding variable μ value .

3.3 IPSA FAULT CALCULATION METHODOLOGY

IPSA calculates the fault level more accurately by procedures only practical using a computer, evaluating network solutions for each time instance considering time varying impedances. IPSA's fault calculation method is very configurable and the options adopted as part of the TNEI work are summarised in Table 3-1. In particular the calculation reflects pre-fault network voltages and considers the decrement in fault current due to time (10ms make and 90ms break).

The locations where IPSA calculates fault levels is also configurable with one of the options being "all nodes"; the TNEI report tabulates fault current results at nodes corresponding to distribution substations along the feeders.

3.4 COMPARISON OF FAULT CALCULATION METHODOLOGIES

Overall, the identified differences in the fault level calculation will lead to mismatches between the FLAT and IPSA results.

Make and break fault levels calculated using the FLAT are expected to be greater than the equivalent IPSA results due to the use of a c factor of 1.1 rather than the use of pre-fault load flow results, but recognising that generator impedances are adjusted by a correction factor K_G within the IEC 60909 methodology applied by the FLAT.

Break fault currents calculated using the FLAT are expected to be greater than equivalent TNEI IPSA results due to the assumption that there is no AC decay.

4 FAULT LEVEL MODELS

It is also important to consider the differences in the network models used within the IPSA and FLAT simulations in order to inform the comparison of their results. Table 4-1 summaries aspects of the IPSA and FLAT models employed to provide the results that are compared as part of the validation.

Table 4-1: Network models

Parameter	IPSA	FLAT
Network Model Source Data	Network models for all voltage systems down to the 11kV (6.6kV) busbars of Primary substations were imported from the IPSA+ Master Network Model provided by Electricity North West, Broadheath, Denton West and Irlam HV networks were imported to IPSA2 using Dinis text files	ADMS model based upon Electricity North West's GIS data reflecting asset parameters including impedances and ratings
Network Topology	System normal as defined in the Electricity North West Long Term Development Statement	The FLAT results correspond to the network configuration that existed at the date and time that the studies were undertaken as shown in Table 2-1
Upstream System Model	132kV system and grid supply transformers modelled in full with the 275kV and 400kV grid fault infeeds represented as equivalents	Equivalent R + jX model based upon the 33kV break fault levels tabulated in the Long Term Development Statement
Load Fault Contribution Representation	The fault contribution from the load is represented by an equivalent induction motor connected to the substation 11(6.6)kV busbar modelled broadly in line with ER G74 guidelines	No load fault contribution is modelled
Load Modelling	The IPSA results correspond to maximum loading conditions. Loads on each feeder have been modelled to match the feeder's maximum measured total load current by scaling each distribution substation load according to its rating	Loads are not modelled
Distributed Generation	Distributed generation greater than 200kW is modelled at the actual connection point (several 33kV generators are represented, but no 11kV generators were of sufficient capacity). All distributed generation was assumed to be connected for the fault level studies	Distributed generation is not represented in the present ADMS model used by the FLAT
Transformer AVC Voltage Set Point	33kV/HV transformers have 1pu voltage set point	Transformer tap positions are assumed to be neutral

Overall, it is expected that the majority of network parameters should be the same as they represent the same equipment. Mismatches may exist due to inconsistencies in the different sources, but these are expected to be eventually resolved as data quality is improved as part of the ADMS project and others. It is not possible to comment on how any inconsistencies in network data will affect the agreement between the FLAT and IPSA results without detailed comparisons outside the scope of this work.

It is noted that the network upstream of the 33kV busbar is presently modelled as an equivalent fault infeed in the ADMS model used by the FLAT.

The FLAT's use of the ADMS network model means that it's results will reflect the present network configuration, whilst the IPSA study used within this validation was based upon the normal network arrangement. However, the network at the time that the FLAT results were calculated for this validation is understood to be normal and therefore differences in network topology are not expected to have a significant impact on the validation.

Load fault contributions are not included in the FLAT results because specific fault infeeding loads are not modelled in the ADMS network model. Representation within the IPSA model of load fault contributions in general accordance with ER G74 is expected to increase IPSA peak asymmetric fault currents.

Although distributed generation is not represented in the ADMS model used by the FLAT, there are very few embedded generators included in the IPSA models and therefore the representation of distributed generation is not expected to lead to significant differences in the results of the two softwares.

5 DETAILED COMPARISON OF FLAT RESULTS

The following standard format has been adopted for the presentation of the detailed results of the FLAT validation comparisons for each substation location for which FLAT and IPSA results are available:

i) Table of peak asymmetrical make and RMS break fault levels for the substation busbars

ii) Summary table of the outcomes of the comparison of FLAT and IPSA fault current results for nodes along the feeder, including:

   a. The number of locations for which results are included in the validation

   b. Maximum and average mismatches between the FLAT and IPSA results expressed as percentages of the IPSA result, with accompanying comments (averages are of the whole group of results including outliers)

   c. The number of results unavailable from the IPSA and FLAT outputs, along with an associated comment

   d. Graph showing the frequency of the mismatches between the FLAT and IPSA results in the validation group, (separately for make and break)

iii) Discussion of the validation results for each substation location

5.1 BROADHEATH

Table 5-1: Comparison of Broadheath Substation FLAT and IPSA fault level results

Broadheath Fault Node Name	Voltage Level (kV)	IPSA		FLAT		Difference (%)	
		Peak Make (kA)	RMS Break (kA)	Peak Make (kA)	RMS Break (kA)	Peak Make	RMS Break
broadh_11_a	11	32.55	11.16	34.24	11.85	5.2%	6.2%
braodh_11_b	11	32.55	11.16	34.24	11.85	5.2%	6.2%

At Broadheath 11kV substation, the FLAT make and break fault levels are slightly greater than the IPSA results by approximately 5% and 6% respectively.

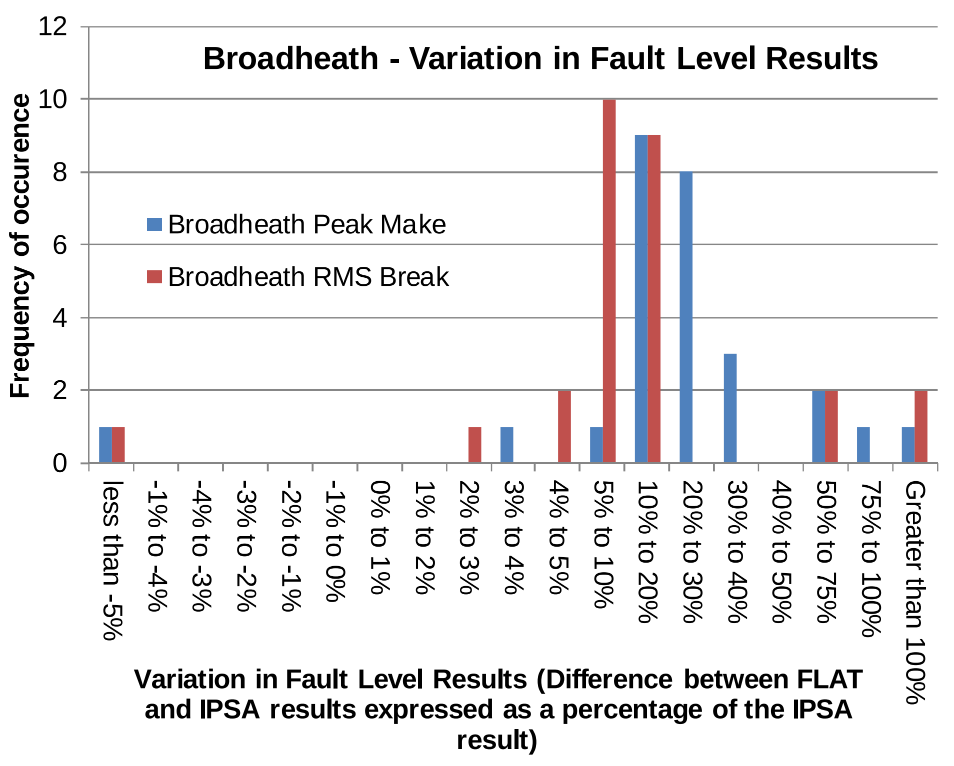
This trend continues and the FLAT make and break fault level results for nodes along the feeders exceed the IPSA results as indicated by the average mismatches based upon consideration of all results as shown in Table 5-2. However, these averages are affected by outliers believed to be associated with differences in parameters rather than the different fault calculation methodologies. Therefore, it is judged that averages excluding the outliers are a better reflection on the similarity of the FLAT and IPSA results.

Excluding the outliers and only considering variations between the FLAT and IPSA make results in the range 10% to 30% indicates that the FLAT make fault level results are on average 19.8% greater than the IPSA results.

Correspondingly, the FLAT break fault level results are on average 9.4% greater than the IPSA results based on an analysis of variations between the FLAT and IPSA break results in the range 5% to 20%.

Table 5-2: Comparison of Broadheath Feeder FLAT and IPSA fault level results

Site Name	Broadheath		Number of results included in validation
Voltage	11.0 kV		27
	Peak Make (%)	Break RMS (%)	Comment
Maximum Mismatch	109.3%	118.0%	The maximum variations are associated with the Woodcote feeder which has an auto transformer and are attributed to differences in the model.
Average Mismatch	27.1%	18.2%	When excluding the outliers; break fault levels from the FLAT are on average greater than the IPSA results with the mode being 5 - 20%. FLAT make fault currents are typically 30 - 10% greater than the corresponding IPSA results.
		Comment	
Number of Missing IPSA Results	23	There are very few results missing from the TNEI study and most are isolated reflecting slight variations in the model toplogies.	
Number of Missing FLAT Results	113	The results missing from the FLAT study are associated with the Atlantic St (Madans), Linotype/Budenberg, Record, B&Q Atlantic St, Atlantic Retail Park and The Fleet circuits and are likely explained by the lack of circuit breakers in the ADMS network model.	



5.2 DENTON WEST

Table 5-3: Comparison of Denton West Substation FLAT and IPSA fault level results

Denton West Fault Node Name	Voltage Level (kV)	IPSA		FLAT		Difference (%)	
		Peak Make (kA)	RMS Break (kA)	Peak Make (kA)	RMS Break (kA)	Peak Make	RMS Break
dentwe_6.6_a	6.6	39.51	13.65	40.37	14.05	2.2%	2.9%
dentwe_6.6_b	6.6	39.51	13.65	40.37	14.05	2.2%	2.9%

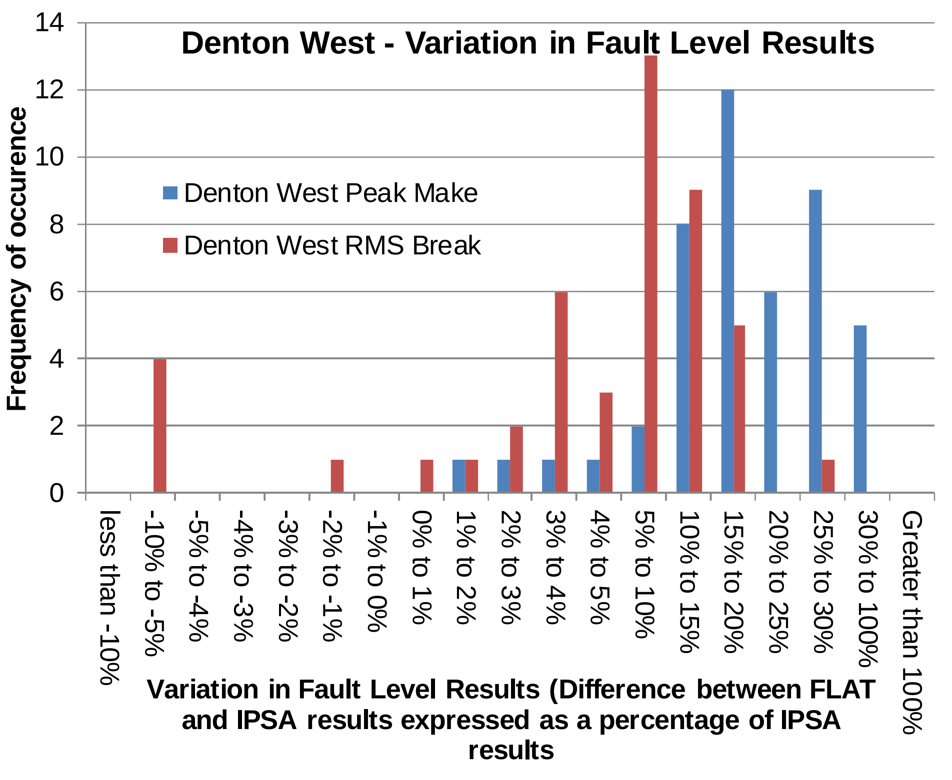
The FLAT make and break fault level results closely match the IPSA results at Denton West 6.6kV substation, with only approximately 2% and 3% mismatch respectively.

FLAT make and break fault level results for nodes along the feeders exceed the IPSA results. Excluding the outliers and only considering variations between the FLAT and IPSA make results in the range 10% to 20% indicates that the FLAT make fault level results are on average 16.3% greater than the IPSA results.

Correspondingly, the FLAT break fault level results are on average 9.6% greater than the IPSA results based on an analysis of variations between the FLAT and IPSA break results in the range 5% to 15%.

Table 5-4: Comparison of Denton West Feeder FLAT and IPSA fault level results

Site Name	Denton West		Number of results included in validation
Voltage	6.6 kV		46
	Peak Make (%)	Break RMS (%)	Comment
Maximum Mismatch	76.1%	26.5%	The 76% mismatch at Thomson Rd clearly reflects a mismatch in specific modelling data as there is a close match between results for nearby nodes.
Average Mismatch	20.5%	7.3%	Break fault levels from the FLAT are on average greater than the IPSA results with the mode being between 5 and 10%. FLAT make fault currents are typically 20 - 10% greater than the corresponding IPSA results.
		Comment	
Number of Missing IPSA Results	5	Overall, not significant as there are two unique sites missing from the TNEI study. It could be that these are new connections, not represented in the source Dinis model.	
Number of Missing FLAT Results	5	Three of the results missing from the FLAT study are connected together (Debdale cct) and therefore it is possible that the ADMS model is configured differently than the IPSA model.	



5.3 IRLAM PRIMARY

Table 5-5: Comparison of Irlam Substation FLAT and IPSA fault level results

Irlam Fault Node Name	FLAT Name	Voltage Level (kV)	IPSA		FLAT		Difference (%)	
			Peak Make (kA)	RMS Break (kA)	Peak Make (kA)	RMS Break (kA)	Peak Make	RMS Break
irlamp_6.6_a	T12	6.6	34.71	11.86	38.78	13.42	11.7%	13.1%
irlamp_6.6_b	T11	6.6	34.71	11.86	38.78	13.42	11.7%	13.1%

At Irlam 6.6kV substation, the FLAT make and break fault level results are greater than the IPSA results by approximately 12% and 13% respectively.

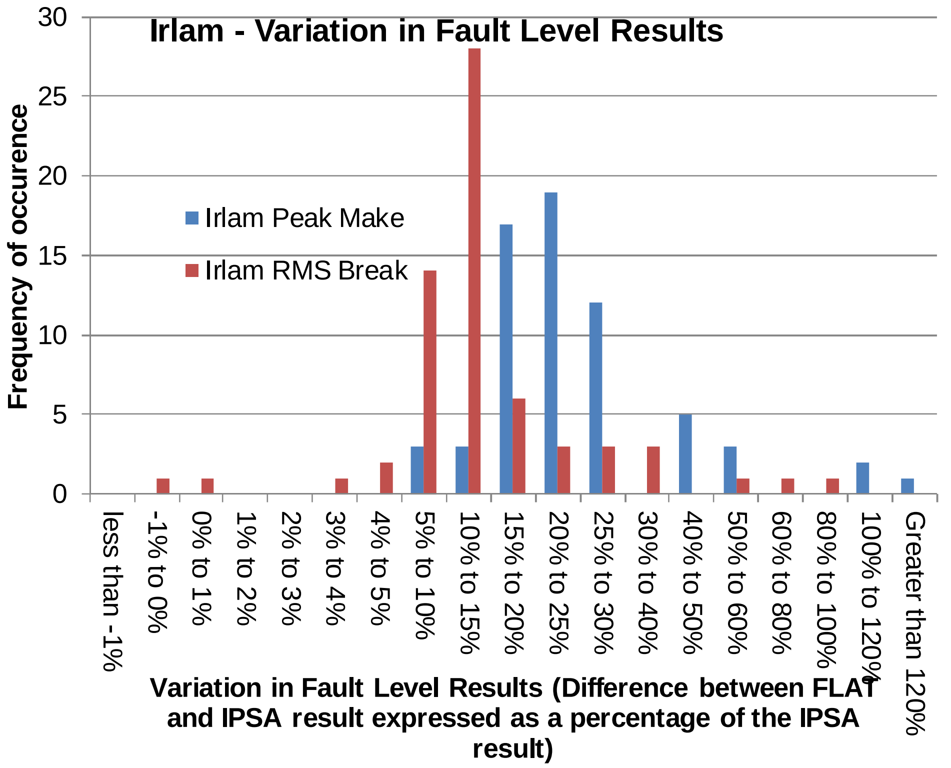
FLAT make and break fault level results for nodes along the feeders exceed the IPSA results. Excluding the outliers and only considering variations between the FLAT and IPSA make results in the range 15% to 30% indicates that the FLAT make fault level results are on average 22.3% greater than the IPSA results.

Correspondingly, the FLAT break fault level results are on average 11.1% greater than the IPSA results based on an analysis of variations between the FLAT and IPSA break results in the range 5% to 15%.

Table 5-6: Comparison of Irlam Feeder FLAT and IPSA fault level results

Site Name	Irlam		Number of results included in validation
Voltage	6.6 kV		65
	Peak Make (%)	Break RMS (%)	Comment
Maximum Mismatch	145.5%	90.6%	The 145% error at Prospect Rd and other large mismatches for nodes along the Dean Rd feeder are likely to reflect differences in the modelling.
Average Mismatch	29.2%	15.8%	When excluding the outliers; break fault levels from the FLAT are on average greater than the IPSA results with the mode being between 5 and 15%. All Make fault level results are greater than the IPSA results, typically between 15 and 25%.

		Comment
Number of Missing IPSA Results	11	The majority of the results missing from the IPSA study are random and likely to reflect inconsistencies in the model.
Number of Missing FLAT Results	35	The results missing from the FLAT study are associated with the Tramway, Curlew Drive and Roseway Avenue feeders perhaps reflecting a different configuration.



5.4 WIGAN BSP

Table 5-7: Comparison of Wigan Substation FLAT and IPSA fault level results

Wigan Fault Node Name	FLAT Name	Voltage Level (kV)	IPSA		FLAT		Difference (%)	
			Peak Make (kA)	RMS Break (kA)	Peak Make (kA)	RMS Break (kA)	Peak Make	RMS Break
wigan_33_a	T12	33	24.11	8.27	23.87	9.05	-1.01%	9.38%
wigan_33_b	T11	33	24.11	8.27	23.86	9.05	-1.03%	9.37%

At Wigan 33kV substation, the FLAT make fault level results are slightly less than the IPSA results (-1%), whilst the FLAT break fault level is approximately 9% greater.

5.5 SUMMARY OF MISMATCH RESULTS

Table 5-8: Summary of the mismatches between FLAT and IPSA fault level results expressed as percentages of the IPSA results (excluding outliers)

Location	Mismatch between FLAT and IPSA Fault Level Results at the Substation		Average Mismatch between FLAT and IPSA Modal Fault Level results for nodes along Feeders	
	Make %	Break %	Make %	Break %
Broadheath	5.2	6.2	19.8	9.4
Denton West	2.2	2.9	16.3	9.6
Irlam	11.7	13.1	22.3	11.1
Wigan	-1.0	9.4	-	-

Table 5-8 summaries the average mismatches between the FLAT and IPSA results (excluding outliers) expressed as percentages of the IPSA results.

5.6 DISCUSSION OF MISMATCH RESULTS

The match between the FLAT and IPSA fault level results for the substations are affected by the fault calculation methodology and the network model. Use of an equivalent representation of the upstream system beyond the immediate 33/11(6.6)kV transformers at Broadheath, Denton West and Irlam will have a significant effect on the substation fault level results. Therefore, it is suggested that substation results are not the most appropriate for judging the difference attributable to the two methodologies. However, the mismatches between the substation results are useful within the interpretation of the mismatch of the FLAT and IPSA fault levels for nodes along the feeders. Mismatch between FLAT and IPSA results at the substation would be reflected in a corresponding mismatch between simulated fault levels at nodes along the feeder, although the mismatch would be diminished by the effect of the feeder impedance. So in broad terms, a greater mismatch at the substation would explain a greater mismatch at nodes along the feeder.

Fault level results for nodes along the feeders are considered more reflective of the agreement due to the two fault current calculation methodologies and they show that FLAT fault currents are greater than the corresponding IPSA results. The mismatch between the FLAT and IPSA make fault currents are consistently greater than the mismatches between break fault levels.

The mismatch between the FLAT and IPSA make fault level results varies between 16.3% and 22.3% with the least mismatch corresponding to only 2.2% mismatch at the substation and the greatest average mismatch between results along the feeder corresponding to 11.7% mismatch at the substation. Although the extent of the mismatch between the FLAT and 'actual' fault level cannot be established precisely from this sample due to the inherent differences in the network models, it is possible to deduce that based on this sample FLAT asymmetrical make fault level results are approximately 15% greater than the corresponding IPSA results which are judged to underestimate actual fault levels through comparison with FLM measurements.

The mismatch between the FLAT and IPSA break fault level results varies between 9.4% and 11.1%. There was not an exact correlation between the ranking of the match between substation break fault levels and the average match of break results for along the feeders, but the greatest mismatch at the substation does concur with the greatest average mismatch along the feeder. Again, although the extent of the mismatch between the FLAT and 'actual' fault level cannot be established precisely from this sample due to the inherent differences in the network models, it is possible to deduce that FLAT RMS break fault level results are approximately 9% greater than the corresponding IPSA results based on this sample.

6 CONCLUSIONS & RECOMMENDATIONS

6.1 SUMMARY

The FLAT results have been validated via a robust approach involving comparison with IPSA results which have been compared to Outram FLM measurements. FLAT and IPSA fault calculation methodologies and network models have been compared in order to understand observed mismatches.

Validation conclusions have been drawn from consideration of four selected networks.

Some differences between the FLAT and IPSA results have been attributed to inconsistency in the network modelling. Resolution of such differences is outside of the scope of the validation and therefore these results have been omitted when reaching conclusions on the match of the FLAT and IPSA results. Instead, the average variance between the FLAT and IPSA results has been evaluated on the basis of only the most common ranges of variances.

IPSA results were available for some network locations where FLAT results were not available, and vice versa. This was considered to be explained by differences in the modelled network configurations and because the FLAT BFC application only provides fault current results at circuit breaker locations, but the present ADMS model does not include all actual circuit breakers. Resolution of such issues is outside of the scope of the validation exercise and instead falls within the ADMS development project.

6.2 CONCLUSIONS

The validation has concluded that the discrepancies between the FLAT and IPSA fault level results are attributed to differences in the fault current calculation methods and mismatches in network data. Unfortunately it is very difficult to quantify the split of the fault level mismatch between the two potential sources of discrepancy. Even by omitting outliers, the effect of differences in network data on the fault level results is uncertain.

FLAT asymmetrical make and RMS break fault levels are generally greater than the corresponding IPSA results.

Based on the sample of results included in the validation:

- FLAT asymmetrical make fault level results are approximately 15% greater than the corresponding IPSA results

- FLAT RMS break fault level results are approximately 9% greater than the corresponding IPSA results

The results of this validation should be considered along with the conclusion arising from the TNEI comparison with the Outram FLM results that IPSA peak make fault levels could be underestimated.

Overall, it is judged that there is considerable uncertainty in the FLAT results that must be reflected in a sensitivity margin when deciding the enable/disable fault mitigation limits employed by the FLAT.

I. First of all, the FLAT makes decisions based upon calculated break fault levels by comparing calculated break fault levels to the predefined enable/disable limits. However, make can be a greater constraint on fault level than break due to it being a greater percentage of the corresponding switchgear rating. Consequently, it will be necessary to include a safety margin in the FLAT break fault level limit to accommodate the possibility of a greater make fault level.

II. Secondly, the chosen limit will need to reflect that FLAT fault level results have been found to be greater than IPSA results. The magnitude of the margin reflected in the limit may need to reflect the minimum difference between FLAT and IPSA results rather than the average difference in order to be conservative and ensure safe operation of the fault mitigation techniques.

III. Thirdly, the enable/disable limits will need to reflect the perceived accuracy of the calculated fault level to the actual fault level as informed by the TNEI comparison of the IPSA simulated fault levels and those resulting from the installation of the FLM.

It is possible that the uncertainty around the FLAT results will lead to the need for unacceptable tolerances in the setting of the FLAT limits as they will reduce the sensitivity of the enable/disable function meaning. A consequence of this could be that fault mitigation techniques are enabled for extended periods and the enable/disable limits have reduced purpose.

6.3 RECOMMENDATIONS

1. Understanding arising from this work regarding the extent that FLAT results are greater than ‘actual’ fault levels should be considered when setting the limits for enabling and disabling fault mitigation techniques.

2. The sensitivity of the enable/disable of fault mitigation techniques using the limits arising from the first recommendation should be considered in order to inform the acceptability of the use of existing FLAT results.

3. FLAT RMS break fault levels being greater than the corresponding IPSA results is partly explained by the assumption that the ac fault current component does not decay away with time up to the break time. This finding supports the requirement to incorporate flexibility to accommodate a variable break time within the FLAT calculation methodology.

4. The validation is based upon comparison with the TNEI IPSA study results which could be considered a small subset of the Electricity North West network. Greater confidence could be established by validating the FLAT results against further IPSA results and more FLM results.

5. Differences between the ADMS network model used by the FLAT and IPSA model are apparent from the large mismatch between some results. Also, it is evident that some circuit breakers are not represented in the ADMS model. Consequently, it is recommended that the FLAT validation is repeated upon completion of the ADMS project when the FLAT BFC application will produce more results to be validated and when differences between the network models will have been resolved.

6. The differences between the ADMS and IPSA network models should be investigated as part of the ADMS project to be assured of the accuracy of the ADMS model for future use of the FLAT in business as usual.