Asset Condition and Health Analysis for Respond project

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Executive summary

Electricity North West Limited (ENWL) have carried out two years of fault level mitigation technology trails as part of the Respond project to investigate how active fault level management will help distribution network operators to quickly connect customers' low carbon demand and generation and at a lower cost than traditional reinforcement.

The use of active fault management means that the network will be operated in a way that is different to normal, both in terms of the operation of assets to clear faults, and potentially the properties of the fault current. As such ENWL wanted to understand whether this new way of operating the assets will have any impact on the asset condition and risk.

Background to the Project

ENWL have carried out increased asset condition monitoring of assets on the network which may have been affected by their Respond project,

EA Technology and were asked to outline a strategy for how the data gathered as part of the Respond project could be used to assess the effects of the new techniques on existing assets, in line with the CNAIM methodology for assessing health and aging of assets.

Scope and Objectives

The Scope of the project was for EA Technology to work with ENWL to review condition assessment results and to calculate Health indices based on condition information before the trial and at the end of the trial.

The objective of the project was to determine whether active fault management had an impact on the condition of the associated network assets.

Conclusions

From the analysis of asset condition and the calculation of Asset Health Score, the following conclusions have been determined:

C1. Of the circuit breakers included in the study, only the Broadheath circuit breaker showed a potential deterioration in asset health.

C2. The increase in Asset Health Score was driven by the long auxiliary contact operating time at the end of the trial period.

C3. There is no evidence of correlation between the fault mitigation technologies and increase in circuit breaker Health Score.

C4. There was no increase in Asset Health Score for either of the transformers on which monitoring was carried out.

C5. No fault level mitigation technology operations were recorded in either of the substations, so the correlation between fault level mitigation technology and transformer asset Health could not be evaluated.

Contents

1. Background & Introduction

Electricity North West Limited (ENWL) commenced their LCNF Respond project in January 2015. The concept behind the Respond project is to investigate how active fault level management will help distribution network operators to quickly connect customers' low carbon demand and generation and at a lower cost than traditional reinforcement. By combining innovative technical and commercial solutions with existing assets, the Respond project will trial the effectiveness of this concept.

The use of active fault management means that the network will be operated in a way that is different to normal, both in terms of the operation of assets to clear faults, and potentially the properties of the fault current. As such ENWL need to understand whether this new way of operating the assets will have any impact on the asset condition and risk.

As part of this project ENWL have committed to carrying out increased asset condition monitoring of assets on the network which may be affected by the Respond project.

EA Technology developed the Condition Based Risk Management (CBRM) and subsequent Common Network Asset Indices Methodology (CNAIM) system for ENWL and were asked to outline a strategy for how the data gathered as part of the Respond project could be used to assess the effects of the new techniques on existing assets, in line with the CNAIM methodology for assessing health and aging of assets.

2. Scope and Objectives

The aim of the project was to determine whether the use of fault level management had a significant impact on the condition of the network assets.

The impact, on the assets, of changing the way that the network is operated can be difficult to quantify. It is not possible to set up a controlled trial as the conditions faced by any two network assets will be significantly different, whether they are involved in the trial or not. This will depend on network loading, faults, environmental and third-party influences.

EA Technology proposed that the impact on the assets should be quantified in two ways:

1. By direct measurement and comparison of key condition information before and after the trial, and

2. By comparison of the initial and final Health Index after the trial.

The asset models for the transformer and circuit breaker assets involved in the study are well-defined and the key inputs for these assets have been included in the ENWL condition monitoring exercise.

2.1 Scope of project

The scope of the project was to work with ENWL to finalise which substations the active fault management will be installed in, with consideration given to the asset types, ages and health indices of assets in those substations.

ENWL would then carry out a condition assessment before the beginning of the trial and the data used to update the Health Index. Further monitoring and assessment would be carried out during the trial and EA Technology would analyse and compare asset condition information before and after the trial period, taking into account the impact of the fault management equipment.

EA Technology would recalculate Health indices based on condition information before the trial and at the end of the trial.

2.2 Objective of project

The objective of the project is to determine whether active fault management had an impact on the condition of the associated network assets.

3. Selection of Substations

ENWL carried out work to identify fault level mitigation technical solutions to be trialled as part of the Respond project, the technologies selected for trial in substations were:

- Adaptive protection
  A technique that re-sequences the operation of circuit breakers and is retrofitted into existing substation equipment, and

- I_s-limiters
  A current limiting device which detects a rapid rise in current when a fault occurs and responds in less than 5milliseconds to break the current.

In order to select appropriate substations for trial installation of these technologies, substations were assessed using the following criteria:

- Voltage levels
- Existing or potential future fault level issues
- Fault history of outgoing circuits
- Age of substation switchgear and protection relays
- Physical constraints

Based on these criteria a number of substations were selected for installation of fault level mitigation equipment. The substation list is shown in Table 1.:

Table 1: Substations included in Respond study

Substation	S/S Number	Voltage at Site	Technology Deployed
Bamber Bridge	400201	11kV	HV Is Limiter
Broadheath	100134	11kV	HV Is Limiter
Althletic St.	400052	6.6kV, 33kV	EHV Is sensing equipment
Wigan BSP	200421	6.6kV, 33kV	EHV Is sensing equipment
Longridge	400416	6.6kV	HV Is sensing equipment
Hareholme	400092	6.6kV	HV Is sensing equipment
Nelson	400044	6.6kV	HV Is sensing equipment
Mount St	100622	6.6kV, 33kV	EHV adaptive protection
Offerton	302872	6.6kV, 33kV	EHV adaptive protection
Atherton Town Centre	205318	11kV	HV adaptive protection
Denton West	100111	33kV, 6.6kV	HV adaptive protection
Blackbull	400403	6.6kV	HV adaptive protection
Irlam	100615	6.6kV	HV adaptive protection
Littleborough	304884	6.6kV	HV adaptive protection

4. Fault Operations in Selected Substations

The faults in the trial area which caused operation of the respective fault level mitigation as shown in the table below.

Table 2: Operations of fault level mitigation technology

Respond fault ref	Substation name	Date	FLM technique
1	Atherton Town Centre	29/07/2016	Adaptive protection
2	Atherton Town Centre	28/08/2016	Adaptive protection
3	Atherton Town Centre	16/09/2016	Adaptive protection
4	Blackbull	03/04/2017	Adaptive protection
5	Littleborough	08/05/2017	Adaptive protection
6	Bamber Bridge	22/05/2017	Is-limiter
7	Littleborough	20/06/2017	Adaptive protection
8	Irlam	17/08/2017	Adaptive protection
9	Bamber Bridge	18/08/2017	Is-limiter
10	Hareholme	01/01/2018	Is sensing
11	Littleborough	18/02/2018	Adaptive protection

5. Condition Assessment of Assets

Within the substations selected for inclusion in the study, a number of assets were selected for condition assessment so that the condition of assets could be monitored before and after the 2-year trial period.

The condition assessment techniques to be applied to the assets included in the trial are shown in Tables 2–4.

Table 3: Partial Discharge Monitoring of Assets in Trial

Site	Voltage	Fault Level Mitigation	Installation
Broadheath	11kV	Is-Limiter	Permanent
Littleborough	6.6kV	Adaptive Protection	Roaming ~1
Denton West	6.6kV	Adaptive Protection	Roaming ~1
Offerton	33kV	Adaptive Protection	Roaming ~1
Atherton T.C	11kV	Adaptive Protection	Roaming ~2
Blackbull	6.6kV	Adaptive Protection	Roaming ~2
Mount St	33kV	Adaptive Protection	Roaming ~2
Irlam	6.6kV	Adaptive Protection	Permanent Until Fault ~1
Atherton T.C	11kV	Adaptive Protection	Permanent Until Fault ~1
Littleborough	6.6kV	Adaptive Protection	Permanent Until Fault ~1
Denton West	6.6kV	Adaptive Protection	Permanent Until Fault ~2
Blackbull	6.6kV	Adaptive Protection	Permanent Until Fault ~2
Offerton	33kV	Adaptive Protection	Permanent Until Fault ~2
Mount St	33kV	Adaptive Protection	Permanent Until Fault ~2

Table 4: Trip timing Tests of Assets in Trial

Site	Voltage	Fault Level Mitigation Technique	Installation
Broadheath	11kV	Is-Limiter	Permanent T13 11kV CB
Littleborough	6.6kV	Adaptive Protection	Bus section CB
Denton West	6.6kV	Adaptive Protection	Bus section CB
Offerton	33kV	Adaptive Protection	Bus section CB
Atherton T.C	11kV	Adaptive Protection	Bus section CB & T11
Blackbull	11kV	Adaptive Protection	Bus section CB
Mount St	33kV	Adaptive Protection	Bus section CB
Irlam	6.6kV	Adaptive Protection	Bus section CB

Table 5: DGA Testing of Assets in Trial

Site	Voltage	Fault Level Mitigation Technique	Measurements
Broadheath	11kV	Is-Limiter	DGA
Wigan	33kV	Adaptive Protection	DGA

5.1 Evaluation of Circuit Breaker Asset Health

At the beginning of the project it was intended that the impact of the trial on asset Health would be evaluated using the CBRM models that were in use by ENWL at the time. Since then the Common Network Asset Indices Methodology (CNAIM) has been adopted by all UK DNO's, so the impact on asset health will be evaluated using the CNAIM methodology.

The CNAIM Health Index formulation for the Circuit breaker assets is shown in Figure 1.

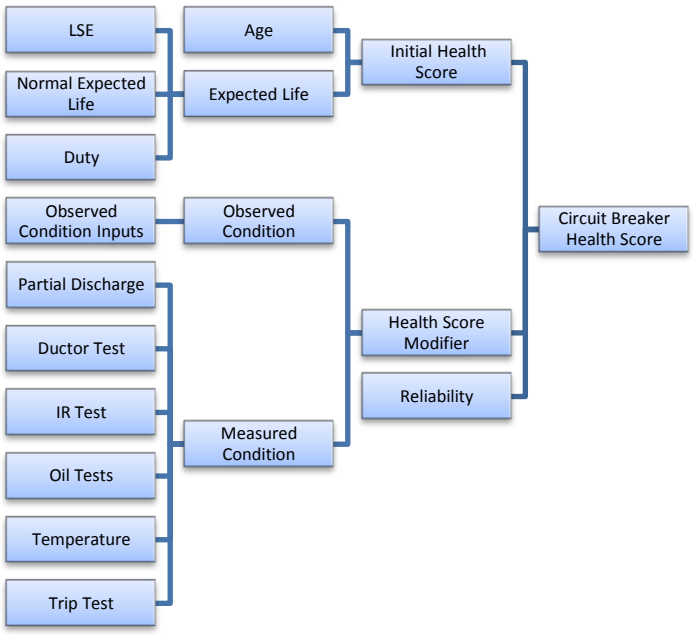

Figure 1: Circuit Breaker Health Score Formulation

For the circuit breakers involved in the study the Initial Health Score will be affected by asset age, location and duty. The age of the asset will increase during the study and will lead to an increase in asset health score. As such the modelling will maintain a constant age for all calculations.

The circuit breaker measurements identified for collection by ENWL at the start of the project were:

- Trip Timing
- Partial Discharge

These measured parameters have been used in the CNAIM Health Score methodology to calculate the corresponding Health Score. The circuit breaker condition has been assessed at the beginning and at the end of the Respond trial. There is some transformation of the data carried out before it is fed into the CNAIM model, so initial results have been compared with the input data in the ENWL CNAIM models where appropriate to ensure that the initial Health Score values align with those in CNAIM.

The initial and final results are then used to calculate the Measured Condition Factor within the CNAIM model in order to determine the impact of any changes in measurements on the asset Health.

The results of the tests are summarised below:

Table 6: Summary results of Circuit Breaker Condition Assessment

Site	Circuit Breaker	Test Time	Partial Discharge	Trip Test
Broadheath	T13	Start	Medium	Pass
		End	Medium	Fail - long Acon time and no Mcon time recorded.
Littleborough	Bus section CB	Start	Medium	Pass
		End	Medium	None
Denton West	Bus section CB	Start	Medium	Pass
		End	Medium	Pass
Offerton	Bus section CB	Start	Medium	None Provided
		End	Medium	None Provided
Atherton T.C	Bus section CB	Start	Medium	Pass
		End	Medium	Pass
Atherton T.C	T11	Start	Medium	Pass
		End	Medium	Pass
Blackbull	Bus section CB	Start	Medium	Pass
		End	Medium	Insufficient Data - Trip Free with only end time recorded
Mount St	Bus section CB	Start	Medium	None Provided
		End	Medium	None Provided
Irlam	Bus section CB	Start	Medium	Pass
		End	Medium	Pass

Note that the partial discharge testing did not identify significant discharge issues before or after the test period. Some discharge activity was detected, but this was aligned with the external activity measured, so was not identified as a cause for concern. The ENWL data inputs for the CNAIM model are categorised such that this type of activity is classed as '2' for the input value, with this being mapped to a 'Medium' level of activity. This may have been re-aligned in the new data collection process or new model mapping within ENWL, but for the purpose of consistency for this project the same method has been used in this study.

The Trip Testing did not raise any major issues, however the end data file for Blackbull only contained 'Trip Free' operations and as such it was not possible to assess any change in performance. The end result for Broadheath had a long Acon (Auxiliary Contact) operating time,

which could suggest a slow opening circuit breaker or an issue with the auxiliary contacts or wiring. As there is no Mcon (Main Contact) operating time on the profile, it was not possible to determine whether the circuit breaker was actually slow in opening or the exact cause of the long operating profile. For the purpose of the CNAIM model only Pass or Fail values are allowed, so this circuit breaker has been classed as 'Fail'.

Where no profile has been provided or there is insufficient data then it has been assumed that the result is a pass – this is in line with the default values used within the CNAIM model.

Using these values, and Initial Health Score and Observed Condition data from 2016, the resulting CNAIM Health Index values (assuming a constant Initial Health Score and Observed Condition inputs) are shown in the following table.

Table 7: Health Score of Circuit Breakers

Site	Circuit Breaker	Test Period	Initial Health Score	Observed Condition Factor	Measured Condition Factor	Overall Factor	Health Score
Broadheath	T13	Start	2.31	0.83	1.1	1.1	2.54
		End	2.31	0.83	1.47	1.47	3.39
Littleborough	Bus section CB	Start	3.76	0.83	1.1	1.1	4.13
		End	3.76	0.83	1.1	1.1	4.13
Denton West	Bus section CB	Start	2.41	0.83	1.1	1.1	4.13
		End	2.41	0.83	1.1	1.1	4.13
Offerton	Bus section CB	Start	3.91	0.83	1.1	1.1	4.3
		End	3.91	0.83	1.1	1.1	4.3
Atherton T.C	Bus section CB	Start	1.26	0.83	1.1	1.1	1.39
		End	1.26	0.83	1.1	1.1	1.39
Atherton T.C	T11	Start	1.26	0.83	1.1	1.1	1.39
		End	1.26	0.83	1.1	1.1	1.39
Blackbull	Bus section CB	Start	0.72	0.83	1.1	1.1	0.79
		End	0.72	0.83	1.1	1.1	0.79
Mount St	Bus section CB	Start	3.91	0.83	1.1	1.1	4.3
		End	3.91	0.83	1.1	1.1	4.3
Irlam	Bus section CB	Start	1.12	0.9	1.1	1.1	1.23
		End	1.12	0.9	1.1	1.1	1.23

Of the circuit breakers included in the study, only the Broadheath circuit breaker showed a potential deterioration in asset health. The increase in Asset Health Score was driven by the long auxiliary contact operating time at the end of the trial period. As no Main Contact time was recorded it is unclear where the deterioration has occurred but, as no fault mitigation operations were recorded at this substation, there is no correlation between the fault mitigation technologies and increase in circuit breaker Health Score.

5.2 Evaluation of Transformer Asset Health

At the beginning of the project it was intended that the impact of the trial on asset Health would be evaluated using the CBRM models that were in use by ENWL at the time. Since then the Common Network Asset Indices Methodology (CNAIM) has been adopted by all UK DNO's, so the impact on asset health will be evaluated using the CNAIM methodology.

The CNAIM Health Index formulation for the Transformer assets is shown in Figure 2.

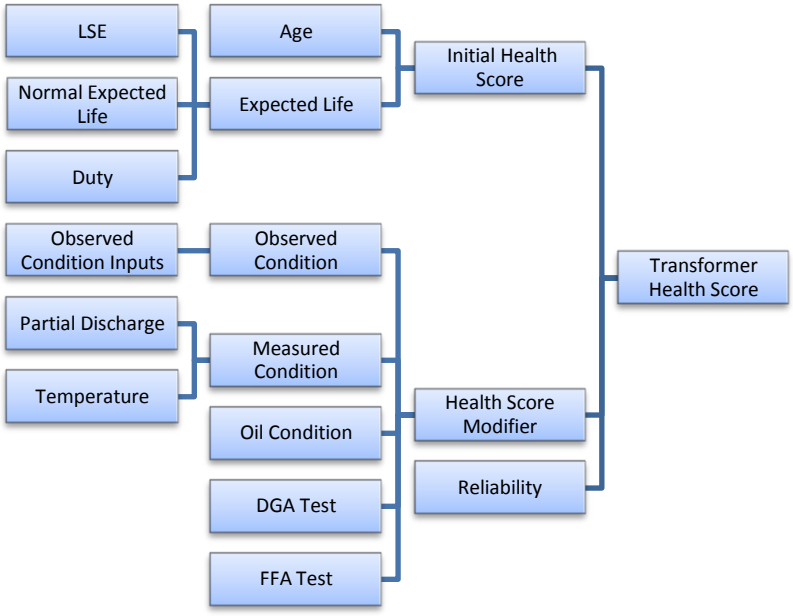

Figure 2: Transformer Health Score Formulation

For the Transformers involved in the study the Initial Health Score will be affected by asset age, location and duty. The age of the asset will increase during the study and will lead to an increase in asset health score. As such the modelling will maintain a constant age for all calculations.

The Transformer measurements identified for collection by ENWL at the start of the project were:

- Dissolved Gas Analysis (DGA)

These measured parameters have been used in the CNAIM Health Score methodology to calculate the corresponding Health Score. The Transformer DGA has been assessed continuously during the Respond trial. There is some transformation of the data carried out before it is fed into the CNAIM model, so initial results have been compared with the input data in the ENWL CNAIM models where appropriate to ensure that the initial Health Score values align with those in CNAIM.

The initial and final results are then used to calculate the DGA Factor and DGA Collar within the CNAIM model in order to determine the impact of any changes in measurements on the asset Health.

The results of the tests are summarised below:

Table 8: Summary results of Transformer DGA Assessment

Site	Transformer	Test Period	Hydrogen (ppm)	Methane (ppm)	Ethane (ppm)	Ethylene (ppm)	Acetylene (ppm)
Broadheath	T13	Start	5	23	0	0.7	0
		End	13.7	8.8	1.4	12.3	0
Wigan	GT2	Start	7.3	3.6	0.1	0.4	0
		End	31.2	3.8	0.8	0.5	0

The DGA levels were monitored throughout the trial and DGA values are available throughout the period. There are some short periods where the gas levels increased, but the increase was not sufficient to indicate any issues within the transformer.

Using the DGA levels at the beginning and end of the trial and the Initial Health Score, Observed Condition, Measured Condition, FFA, and Reliability data from 2016, the resulting CNAIM Health Index values (assuming constant values for all except the DGA inputs) are shown in the following table.

Table 9: Health Score for Transformers

Site	Transformer	Test Period	Initial Health Score	Condition Factor	Oil Test Factor	DGA Factor	DGA Min HI	Overall Factor	Reliability factor	Health Score
Broadheath	T13	Start	4.43	1.0	1.2	1.0	0.00	1.2	0.6	3.19
		End	4.43	1.0	1.2	1.0	0.55	1.2	0.6	3.19
Wigan	GT2	Start	2.08	1.0	0.9	1.0	0.00	0.9	1.0	1.87
		End	2.08	1.0	0.9	1.0	0.45	0.9	1.0	1.87

There was no increase in Asset Health Score for either of the transformers on which monitoring was carried out. No fault level mitigation technology operations were recorded in either of the substations, so the correlation between fault level mitigation technology and transformer asset Health could not be evaluated.Conclusions

From the analysis of asset condition and the calculation of Asset Health Score, the following conclusions have been determined:

C6. Of the circuit breakers included in the study, only the Broadheath circuit breaker showed a potential deterioration in asset health.

C7. The increase in Asset Health Score was driven by the long auxiliary contact operating time at the end of the trial period.

C8. There is no evidence of correlation between the fault mitigation technologies and increase in circuit breaker Health Score.

C9. There was no increase in Asset Health Score for either of the transformers on which monitoring was carried out.

C10. No fault level mitigation technology operations were recorded in either of the substations, so the correlation between fault level mitigation technology and transformer asset Health could not be evaluated.

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