The work described in this report was carried out under contract as part of the BERR Emerging Energy Technologies Programme, which is managed by AEA Energy & Environment. The views and judgements expressed in this report are those of the contractor and do not necessarily reflect those of the BERR or AEA Energy & Environment.
Summary

This project forms part of the Distribution Working Group PG02 Work Programme which is focussed on technology, tools, techniques, processes and standards required to construct power systems compatible with the developing trends in low-carbon energy technology.

The initial specification for the main project on dynamic network ratings, which will develop modelling tools for network planning utilising static and dynamic ratings, is given in an appendix to this report. The main body of this report contains more detailed sections so that either the whole of this report or parts of it can be included by the DWG project managers in the final specification for the main project. Early sections of this report cover UK, European and US standards and recommendations, current practice and ongoing studies for overhead line, cable and transformer ratings. The gaps to be filled by the main project are identified, leading to a proposed structure and work packages for the project. A summary table of standards and recommendations, and a review of the literature with references, conclude the report.
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### Appendix I: Statement of Requirement for the Main Project

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1 Introduction

The aim of this scoping study is to provide background and scope out the needs of the main project (DWG PG2 - P08) on dynamic network ratings. The aim of the main project will be:

- to develop practical and enduring modelling tools for the planning of electrical networks utilising static and dynamic equipment ratings in order to maximise the connection of sustainable generation technologies.

The initial specification for the main project is given in Appendix I.

The main body of this report contains more detailed sections so that either the whole of this report or parts of it can be included by the DWG project managers in the final specification for the main project.

1.1 Requirements for the Scoping Study

The requirement for this scoping study stated that the deliverables would include:

- a review of the literature - to provide a background to the existing methodologies for determining the static and dynamic ratings of distribution equipment
- current practice within the network operator community – national and international
- any studies or projects that might be relevant to the main project
- the structure for the main project, to include:
  - aim and objectives
  - work programme
  - required deliverables - i.e. models and reference documentation – to enable network planners to determine seasonal (static) and real-time (dynamic) ratings for future low carbon networks designs.

1.2 Refining the Requirements

Prior to the EA Technology scoping study kick-off meeting in February 2007, the DWG Project Manager indicated that the scoping study needed to:

1. Clearly define objectives, success criteria and deliverables.
2. Clearly define realistic and deliverable work packages that together would achieve the objectives.
3. Show a clear structure of how best to sequence and group these work packages into a project.
4. Document the above in a tender specification.

Decisions made at the EA Technology kick-off meeting (which was attended by the DWG Project Manager, a second Distribution Network Operator representative and a Generator representative), are given in sections A and B below.
A: The Scoping Study:

- The objective of the scoping stage is to add more detail to the “Statement of Requirement” and to identify the gaps that need to be filled by the project so that the tender specification can focus on the gaps.

- Preparation of a table of UK and European/US standards for each of cables, overhead lines and transformers and an initial listing of key parameters used in the standard algorithms would form part of the scoping stage.

- Consideration of the IPR for the project.

- The report would include sections on static ratings (standards and expert views), dynamic ratings (standards and expert views), gaps, literature references and the table of standards.

B: The Main Project:

- The deliverable for the main project would give a greater understanding of dynamic circuit ratings, proposing enhanced capability of assets and proposing a path for implementation; proposals would drill down to risk (and the cost of reducing risk), standards and acceptability/adoptability/practicability.

- The main focus is on cables, overhead lines and transformers.

- The main project would include a workshop for explaining the thinking to the industry (e.g. demonstrating an algorithm or spreadsheet) and for eliciting objections/criticisms leading to acceptance by the industry; after that, it would be the responsibility of a user group to take the ideas forward in a step-by-step process.

- If the new ratings were included in an ENA Engineering Recommendation, this would assist industry acceptance and be a good route for implementation.
2 Standards and Expert Views

This section covers standards, recommendations and current practice within the national and international network operator community, and some studies that might be relevant to the main project. The information in this section is based on expert views.

2.1 Standards

A summary table giving all the standards and recommendations discussed in this section is given in Section 5 Table 1: Standards and Recommendations.

Overhead Lines

The overhead line ratings used in the UK are based on experiments carried out on transmission lines and are listed in Engineering Recommendation P27 (ENA ER P27, 1986). Static ratings for summer and winter are included, but not all conductor types currently in use by DNOs. ER P27 uses one algorithm with many fixed parameters. The original algorithm, written by CERL’s Price (CEGB 1979), was based on measurements made by Stringfellow and made many assumptions, eg values for emissivity are fixed, wind direction is normal to the line. The ACE report 1041 (1986) converted the CEGB method and developed it for distribution lines. ER P27 then took the ratings from ACE 104 to produce a list of numbers, achieving results “by hand” which can also be calculated by OHRAT (see section 2.3.1). In the public domain, CIGRÉ have produced a set of equations2 for calculating ratings which are based on the principles established by Price but with some differences or discrepancies.

ER P27 uses a probabilistic method for calculating ratings. (Ratings are either probabilistic or deterministic, where “deterministic” makes assumptions, eg for weather conditions, and “probabilistic” defines a set of weather conditions, eg the worst, and works out the current under those conditions, then measures it for a year, giving a relationship between (a) the original rating and (b) how often the rating is exceeded.)

The 2002 ENA TS 43-122 standard for XLPE covered-conductors has two methodologies for calculating overhead line ratings, one of which is the ER P27 methodology which has not been verified experimentally.

In summary, the standards and recommendations currently used in the UK for overhead line ratings, listed with a US standard for calculating the current-temperature relationship of bare overhead conductors, are:

<table>
<thead>
<tr>
<th>Country</th>
<th>Standards:</th>
</tr>
</thead>
<tbody>
<tr>
<td>UK</td>
<td>ENA TS 43-122 (static probabilistic ratings)</td>
</tr>
<tr>
<td></td>
<td>Recommendations:</td>
</tr>
<tr>
<td></td>
<td>ENA ER P27 (static probabilistic ratings, based on the ACE 1041 standard)</td>
</tr>
<tr>
<td>USA</td>
<td>Standards:</td>
</tr>
<tr>
<td></td>
<td>IEEE 738-1993</td>
</tr>
</tbody>
</table>

1 ACE report 104
2 CIGRÉ equations
Cables

For each standard used in the UK, there are different equations for different types of bondings, for different cable configurations (eg trefoil or laid flat), for whether the cable is in ducts or surrounded by concrete, etc. There are basic equations for each of these in each of the standards (for both steady and cyclic ratings), for example IEC 60853 would allow the calculation for drying out of soil, and IEC 60287 gives steady ratings. The parameters are listed in the standards.\(^3\)\(^4\)

Standards and recommendations currently used in the UK and Europe for cable ratings are:

<table>
<thead>
<tr>
<th>UK/Europe</th>
<th>Standards:</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEC 60287 = BS 7769 (steady static ratings)</td>
<td></td>
</tr>
<tr>
<td>IEC 60853 (cyclic and emergency static ratings)</td>
<td></td>
</tr>
<tr>
<td>UK Recommendations etc:</td>
<td></td>
</tr>
<tr>
<td>ENA ER P17 Parts 1-3 (static ratings)</td>
<td></td>
</tr>
</tbody>
</table>

Transformers

Standard IEC 60076-7 (2005) was a major change from the earlier IEC 60354 (1991), increasing the use of fibre optic temperature sensors in transformers which radically increases the possibilities of obtaining a proper thermal modelling of power transformers.

The standards currently used in the UK, Europe and the USA for transformer ratings are:

<table>
<thead>
<tr>
<th>UK/Europe</th>
<th>Standards:</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEC 60076-7 (continuous or cyclic load and emergency ratings)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>USA</th>
<th>Standards:</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANSI/IEEE C57.91 (1995)</td>
<td></td>
</tr>
</tbody>
</table>

Switchgear

Ratings for older oil-filled switchgear at reduced ambient temperature are covered in ENA ER S33 (1982). The new international standard IEC IEC62271-1 (targeted to replace IEC60694 in December 2007) will include switchgear ratings.

2.2 Current Practice

The information in this section is based on expert views. Further examples are given in Section 6: Literature Review.

Overhead Lines

In the UK, DNO overhead line engineers base their ratings on Engineering Recommendation P27. The fact that the CIGRÉ document\(^2\) is based on the same source as the UK document, would suggest that international practice is similar to UK practice.
Cables

In the UK, DNO cables engineers base their ratings either on CRATER (see section 2.3.1) or on manufacturers’ ratings or a combination of both. Alternatively, some use distribution ratings (which are based on what happens in a “long” emergency, e.g., the load which one of two 2 parallel circuits could take for 2 days).

Distribution ratings are only used regularly for MV paper cable (3-core) and polymeric cable (single-core and 3-core). These are given in Engineering Recommendation P17:

- ENA ER P17 Part 1 – 11kV paper cable (1976)
- ENA ER P17 Part 2 – 33kV paper cable (1976)

Other DNOs base their static ratings on cyclic ratings or, in certain cases, steady ratings.

Internationally, Cyme International Inc’s CYMCAP5 is Canadian software, designed to simulate thermal behaviour of cable installations, which is widely used in the world. The software, which is based on IEC standards rather than US standards, gives static ratings and has some dynamic ratings capability.

Transformers

Traditionally in the UK, the DNOs typically use cyclic rating factors of 130% for transformers with load and 100% of rating for generation; these are derived from the IEC 60354 standard and typical scenarios when assessing the firm capacity of a network.

2.3 Studies

The information in this section is based on expert views - details on EA Technology and EPRI are given in subsections 2.3.1 and 2.3.2. See also Section 6: Literature Review.

In the UK, up to the 1970s, ERA were the main organization producing static and cyclic ratings theory. In recent years, EA Technology have carried out a number of studies on both static and dynamic circuit ratings (see section 2.3.1).

Internationally, there is a lot of work carried out in CIGRÉ committees, e.g., recently on cable crossings, draft standard IEC 60287-3-3 issued January 2006. CIGRÉ committee work in this area is often done by EDF (e.g., author Eric Dorison). There is also work in the Netherlands (e.g., KEMA, NUON), the USA (e.g., EPRI, CYME) and other countries (see Section 6: Literature Review).

2.3.1 EA Technology

EA Technology has expertise in relation to dynamic ratings of electrical distribution network equipment, much of which has been performed in the context of EA Technology Strategic Technology Programme (STP6), including:

Overhead Networks: EA Technology is currently verifying the accuracy of the ratings used for overhead lines. The work involves the measurement of the change in temperature of the lines with changes in ambient temperature and wind speed. In addition, an assessment package has been produced (OHRAT), to calculate more accurate ratings for overhead lines than is currently available in engineering recommendations.
**Cables:** EA Technology is developing dynamic cable ratings in the context of the CRATER (Cable Rater) software. The CRATER package has been developed to provide a means to calculate more accurate ratings for cables than is currently available in the engineering standards. A program for a prediction tool building on historic data is being developed.

**Substations:** EA Technology is assessing models for predicting the temperature of transformers with respect to their loading. The EA Technology transformer model provides a true thermal rating of the transformer based on field measurement enabling the overload rating to be calculated without exceeding critical internal temperatures. This work will provide a useful basis and source of information on the behaviour of transformers when developing a dynamic ratings system for transformers.

### 2.3.2 EPRI

In the 1990s, EPRI (Electric Power Research Institute) developed the DTCR (Dynamic and Predictive Thermal Circuit Ratings) software\(^7\)\(^8\) for dynamic ratings of substations and transmission circuits based on real-time monitoring of weather conditions, circuit loads, and other parameters, eg line tension, sag, and temperature.

EPRI is also engaged in a supplemental project\(^7\) which will develop a predictive thermal circuit rating methodology for transmission lines based on neural network approaches.

North American energy companies use deterministic ratings, but EPRI are currently reviewing the probabilistic methodology used in Europe and other parts of the world “due to its advantages over deterministic ratings”\(^7\). Improvements in the probabilistic rating methodology applied to North American power circuits are planned for 2007.
3 Gaps to be Filled

Taking into account the standards, expert views on current practice and ongoing studies given in section 2 above and the literature review detailed in section 6, the following gaps which need to be filled by the main project have been identified:

1. Definitions of dynamic ratings at different levels, eg “basic dynamic circuit ratings”, “predictive dynamic circuit ratings”, “real-time dynamic circuit ratings”.

2. Further exploration of existing models for overhead line ratings with a view to: (a) making a comparison of models, (b) assessing the suitability for the UK, (c) evaluation, eg inconsistencies in the CIGRÉ/Price methodology (see section 2.1).

3. Existing models for cable ratings: (a) comparison, (b) suitability for UK, (c) evaluation.

4. Existing monitoring equipment, eg temperature measurement, for overhead lines and cables: (a) comparison of equipment, (b) suitability for the UK (c) evaluation.

5. Understanding how dynamic circuit ratings should actually be used by the industry.
   - Is the first step a set of “advanced” tables similar to P17 and P27 but with, say, 3 or 4 different ratings for each of the present ratings?
   - What are the alternatives to tables? (eg Algorithms based on “advanced” tables)
   - What is the road map for moving from the P17/P27 type tables towards the alternative(s)? (eg Start the road map with IEC standard static ratings, then plug seasonal Met. Office weather data into the same equations to give new seasonal ratings based on IEC, and then consider how the seasonal data changed the ratings.)

6. Algorithms: (a) identification of algorithms which need to be in the public domain, (b) assessing whether the basic equations are sufficient for each algorithm or whether the full algorithm is needed, and (c) plan for bringing these in to the public domain.

7. Overhead line ratings: experimental verification of the P27 methodology with field trials (see section 2.1).

8. Understanding the risk/benefit under different network scenarios: (a) how much extra can be achieved by the system using dynamic ratings? (b) what is the risk of doing that? and (c) what is the cost/benefit?
   - for example:
     - Dynamic circuit ratings could be used to allow the connection of loads that are known to be only used in the winter or at night without upgrading the grid.
     - If loading the network more, eg to full capacity, is there enough leeway to manage N-1 and N-2 outages?
     - Use of dynamic emergency ratings in N-1 situations could avoid network reinforcement (ie reinforcement required because static ratings would have been breached during N-1 conditions.)
     - Dynamic circuit ratings could be used to maintain supply to a greater number of customers during N-2 conditions.

9. Developing a method which could identify points on the network where dynamic circuit ratings would be beneficial as part of normal operation (with the intention that measurements would then be made at these points).
   - for example: Impact of overhead line topology
10. Consideration of load management and network management systems (NMS), eg whether existing NMS have facilities for network reconfiguration when operating with dynamic circuit ratings.

11. Impact: studying the impact of using dynamic circuit ratings on other equipment, eg switchgear.

12. Communications: (a) consideration of the comms needed for dynamic circuit ratings, and (b) assessing the suitability of existing comms.

13. Recommendations for the application of dynamic ratings in practice.
4 Structure for the Main Project

4.1 Aim

The aim of the main project will be:

- to develop practical and enduring modelling tools for the planning of electrical networks utilising static and dynamic equipment ratings in order to maximise the connection of sustainable generation technologies.

4.2 Work Programme

The scope for the three stages of the main project, i.e. Stage A, Stage B and Stage C, is given in Appendix I. The overall Project Road Map is shown in Figure 1 and this shows the Work Packages within each stage. Many of the Work Packages consider the different types of distribution equipment (Overhead lines, Cables, Transformers and Switchgear). It should be appreciated that this also includes associated equipment, for example:

- Overhead Lines includes joints, grease.
- Cables includes joints, effect on sheath fault rating.
- Transformers includes tap changes, bushing.
- Switchgear includes busbars, VTs, CTs.

The proposed Work Programme for Stage A comprises Work Packages WP1 to WP7. This stage establishes the overall purpose of the development of dynamic ratings and reviews and defines a clear road map that will lead to the best chance of adoption of the agreed ‘best practice’ algorithms by DNOs. It explores the options and recommends the algorithms that are most appropriate and explains how they would be used in both planning and operational timescales. In planning timescales, this would include the sources of and volume of historical weather and loading data and the tools to process this information the type of measurement and communications technology. In operational timescales this would include the measurement and communication technology and the likely type of generation / load that would be compatible with the available technology.

Stage A will be reviewed by DWG PG2 and used to clarify the scope of stage B. The proposed Work Programme for Stage B comprises Work Packages WP8 to WP20. This stage develops initial spreadsheet models and uses these to improve understanding by industry stakeholders of the risks, benefits and uncertainties. A workshop at this stage is proposed to ensure that all aspects are considered and understood. This shall be designed to reduce the chance that the recommended algorithms are not considered acceptable by DNOs.

DWG PG2 will review stage B and clarify the concluding stage. The proposed Work Programme for Stage C comprises Work Packages WP21 to WP25. These finalise the spreadsheet models based on the industry feedback and fully document their structure, key parameters, uncertainties and recommended application in planning and operational timescales.

Details of each Work Package are given in the following section (section 4.3).
WP1 Standards, Current Practices and Constraints

WP2 Develop an understanding of what DCR will be used for. Explore criteria for adoption by DNOs. Definitions

WP3 Understand the Risks and benefits. Revise / agree road map.

WP4 Overhead Lines Algorithms and parameters (establishing current options and possibilities)

WP5 Underground Cables Algorithms and parameters (establishing current options and possibilities)

WP6 Transformers Algorithms and parameters (establishing current options and possibilities)

WP7 Switchgear / other plant Algorithms and parameters (establishing current options and possibilities)

WP8 Overhead Lines Develop spreadsheet model of selected algorithm

WP9 Underground Cables Develop spreadsheet model of selected algorithm

WP10 Transformers Develop spreadsheet model of selected algorithm

WP11 Switchgear / other plant Develop spreadsheet model of selected algorithm

WP12 Overhead Lines Establishing the key uncertainties

WP13 Underground Cables Establishing the key uncertainties

WP14 Transformers Establishing the key uncertainties

WP15 Switchgear / other plant Establishing the key uncertainties

WP16 Overhead Lines Establishing enabling equipment and systems

WP17 Underground Cables Establishing enabling equipment and systems

WP18 Transformers Establishing enabling equipment and systems

WP19 Switchgear / other plant Establishing enabling equipment and systems

WP20 Identification of key areas of concern / areas for further development. Workshop to share knowledge and seek feedback on acceptability criteria / final stage of project

WP21 Overhead Lines Establish and document current best practice. Update spreadsheet algorithm

WP22 Underground Cables Establish and document current best practice. Update spreadsheet algorithm

WP23 Transformers Establish and document current best practice. Update spreadsheet algorithm

WP24 Switchgear / other plant Establish and document current best practice. Update spreadsheet algorithm(s)

WP25 Hold workshop to disseminate project findings update spreadsheets & project report and hand over to enduring User Group. (User Group to adopt and own the Algorithms and parameters and ‘good practice methodology’).

(Where DCR = Dynamic Circuit Ratings)
4.3 Work Packages

**STAGE A**

The purpose of Stage A is to establish the objectives and success criteria for the project. It is therefore envisaged that during Stage A the members of the Dynamic Circuit Ratings Algorithms (DCRA) User Group will be appointed and it will be important for the successful contractor to facilitate engagement with the User Group and the DWG to ensure that their perceived barriers and risks are adequately addressed. The output of this stage will include a clear road map, which represents the minimum work required to ensure success of the project.

*Work Package WP1*

**Standards, current practice and constraints**

- Identify current practice within network operators worldwide, identifying reference documents.
- Identify any gaps.
- Identify relevant statutory or regulatory obligations.
- Identify activities in CIRED/CIGRÉ working groups and other standards bodies

**Existing ratings models**

- For overhead line ratings: (a) compare existing models, (b) assess suitability for the UK, (c) evaluate, e.g. consider inconsistencies in the CIGRÉ/Price methodology *(see section 2.1)*.
- For cable ratings: (a) compare existing models, (b) assess suitability for the UK, (c) evaluate.
- For relevant monitoring equipment, e.g. temperature measurement for overhead lines and cables: (a) compare equipment, (b) assess suitability for the UK (c) evaluate.

*Work Package WP2*

- Define the considerations that would enable adoption of dynamic ratings and how they are to be used ie ‘what for’ and ‘when’.
- Survey the members of the DCRA User Group to make explicit the success criteria for the project and what would be necessary for DNOs to implement a change in ratings methodology.
- Determine how system capacity would be assessed if dynamic circuit ratings were employed.
- Understand the difference between the rating that a planner would use when establishing a new section of network that was expected to last for some considerable number of years (in an economical and efficient way) and the that used by an operational engineer in the control room when he’d deciding whether a circuit can be used to provide emergency short term transfer / pick up capability. There is a need to ensure that the project does not produce a set of theoretical models that could not actually be used.
Definitions

- Define dynamic ratings at different levels, e.g. “basic dynamic circuit ratings”, “predictive dynamic circuit ratings”, “real-time dynamic circuit ratings”.

Work Package WP3

Risks and benefits - I

- Investigate the risks/benefits under different network scenarios.

For each scenario:

(a) how much extra can be achieved by the system using dynamic ratings?
(b) what is the risk of doing that?
(c) what is the cost/benefit?

For example:

- Dynamic circuit ratings could be used to allow the connection of loads that are known to be only used in the winter or at night without upgrading the grid.
- If loading the network more, e.g. to full capacity, is there enough leeway to manage N-1 and N-2 outages?
- Use of dynamic emergency ratings in N-1 situations could avoid network reinforcement (i.e. reinforcement required because static ratings would have been breached during N-1 conditions.)
- Dynamic circuit ratings could be used to maintain supply to a greater number of customers during N-2 conditions.

- Consider any asset and network risks associated with using particular ratings.

  - This needs to be assessed in a qualitative manner which is then quantified in terms of cost.
  - When considering the cost, consider the cost to whom? The DNO, the connecting party, the general customer base. Consider capex and opex. Are there any financial implications at the DNO/National Grid interface? How should the benefits be measured? Is it the benefit to the connected, existing customers, DNOs, UK plc?
  - There would continue to be a need to design networks that are compliant with N-1 and N-2 scenarios – the question is how much capability does a network have to cater for outages that are beyond the planning standards and should dynamic circuit ratings be used when establishing whether a network is N-1 and/or N-2 compliant. There is a linkage here to standard P2/6 which requires cyclic ratings to be used.
  - If dynamic circuit ratings have been used to design the network under N-1 and N-2 conditions, there would be less capacity available to cater for N-3 conditions.

Determine the impact on losses, long term system capacity and general asset management (i.e understanding system behaviour).

Road map - I

- Consider how dynamic circuit ratings should actually be used by the industry, for example:
- Is the first step a set of “advanced” tables similar to P17 and P27 but with, say, three or four different ratings for each of the present ratings?
- What are the alternatives to tables?

- Prepare a road map for moving from the P17/P27 type tables towards the alternative(s)?

- Explore the linkage to DWG PG2 P05 (Active network management – Commercial barriers and opportunities)

- Prepare and hold a workshop with the User Group members to ensure that their concerns and issues are included within the road map.

*Work Packages WP4, WP5, WP6, WP7*

**Algorithms and parameters - I**

- Identify algorithms which need to be in the public domain

- For algorithms already in the public domain:
  - Assess whether the basic equations are sufficient for each algorithm or whether the full algorithm is needed.
  - Identify and list the key parameters in the algorithms
  - Propose typical figures for fixed-value parameters

- For algorithms not in the public domain: prepare a plan for bringing these into the public domain.

**Plan to verify methodology**

- Plan how sufficient confidence would be gained to allow the adoption of the proposed algorithms.
Stage A report

- The Stage A deliverable will be a report describing the results of the analysis carried out in this stage. The report will include:
  - Review of existing ratings models
  - Road map for moving from existing P17/P27-type tables
  - List of key parameters for algorithms already in the public domain
  - Plan for bringing other required algorithms into the public domain
  - Recommended algorithms for each equipment type
  - Plan for verifying algorithms
  - Risks/Benefits under different network scenarios
  - Consideration of interactions with existing network systems and equipment
  - Specification for a method to identify sites for dynamic ratings

STAGE B

This is the main work content of the project, delivering spreadsheet models for typical types of distribution system equipment. Application scenarios will be developed for the dynamic rating models to ensure all risks and benefits are identified. The contractor will engage with the DCR Algorithms User Group and DWG to facilitate their views to ensure that the project addresses their issues.

Work Packages WP8, WP9, WP10, WP11, WP12, WP13, WP14, WP15

Development of spreadsheet models

- Produce spreadsheet models.
- Identify and list the key parameters in the algorithms.
- Evaluate sensitivities of the parameters and therefore identify any key uncertainties.
- With the knowledge gained, evaluate and review the practicalities of applying the algorithms in planning and operational scenarios.

Work Packages WP16, WP17, WP18, WP19

Existing network systems and equipment

- Consider network planning and modelling tools, how they will interact with any developed ratings tool, and what environmental assumptions should be used.
- Load management: determine whether existing network management systems have facilities for network reconfiguration when operating with dynamic circuit ratings.
- Study the impact of using dynamic circuit ratings on other equipment, e.g. switchgear.

  - This should be expanded to consider the capability of existing modelling tools (which are basically snapshot analysis) to accommodate more than one rating. There is very likely to be a new suite of modelling packages needed.
- In addition to environmental assumptions, there is a wider task to consider the new suite of variables that will be required including environmental ie load profiles, voltage profiles, load
management schemes, information re the capability of National Grid plant. There will be a need to collect and store (and potentially state estimate) some of this data.

**Specification for method to identify sites**

- Prepare a specification for a method which could identify points on the network where dynamic circuit ratings would be beneficial as part of normal operation (with the intention that measurements would then be made at these points).

**Communications**

- Consider the communications needed for dynamic circuit ratings and assess the suitability of existing communications.

**Risks and benefits - II**

- Review the risks, cost and benefits in light of the enhanced understanding.

**Work Package WP20**

**Workshop**

- Prepare a plan for the workshop(s) which will explain the thinking to the industry, for example: show how to work out risk, demonstrate an algorithm/spreadsheet, and elicit objections and criticisms leading to acceptance by the industry.

- Hold workshop with aim of improving success of project and adoption of algorithms:
  - Explain project stages and share knowledge gained so far
  - Seek feedback from stakeholders
  - Seek guidance on resolving outstanding areas of concern
  - Clarify actions required to complete project

**Stage B report(s)**

- The Stage B deliverables will be a report (or reports) describing the results of the analysis carried out in this stage, together with any relevant model(s) or tool(s) in line with the IPR statement. The report(s) will include:

  - Documentation of algorithms
  - List of key parameters for algorithms required for the road map
  - Documentation re execution of the road map
  - Documentation of method to identify sites
  - Plan for the delivery solution
  - Plan for adoption

**STAGE C**

This stage is largely to disseminate the work carried out to a larger audience. It will document and publish the algorithms, hand over the spreadsheet models, document outstanding issues and recommend future work. This will be explained and handed over to the User Group.

**Work Packages WP21, WP22, WP23, WP24**
Algorithms and parameters – II

- If necessary, update Algorithms & Parameters in light of feedback on Stage B report.
- Execute plan to bring identified algorithms into the public domain.
- Propose typical figures for all parameters.
- Confirm and/or update the road map from these findings.

Road Map - II

- Implement the road map for moving from the P27 type tables towards the alternative(s), for example: develop advanced ratings tables and/or algorithms or spreadsheets.

\[\text{Work Package WP25}\]

Plan for delivery solution

- Plan a route for implementation of the techniques, tools and reference documentation developed in the project that would achieve the project objectives, i.e. enable network planners to determine seasonal (static) and real-time (dynamic) ratings for future low carbon networks designs. The delivery solution would include:

  \[
  \text{Acceptance at project workshop(s)} \downarrow \\
  \text{Report back to DWG} \downarrow \\
  \text{ENA Engineering Recommendation} \downarrow \\
  \text{User Group, Tools, etc}
  \]

- Identify the most appropriate party to implement the various stages of the plan.
- Hold final workshop to share knowledge with the industry and confirm how the User Group will take the algorithms forward.
- Revise spreadsheets, report, conclusions and list outstanding material issues following feedback from the workshop.

Stage C deliverables

- The Stage C deliverables will be:
  - The planned workshop(s).
  - Revisions arising from the workshop(s), after which it would be the responsibility of a User Group to take the work forward.
  - Spreadsheet models.
  - Stage C report.

4.4 IPR

Owing to the funding of the work via the public purse it is proposed that the contractor's underlying algorithms and documented, modifiable spreadsheets would be in the public domain.
If the contractor is proposing not to put the spreadsheets and/or algorithms in the public domain, they should explain how the project objectives will be met.

4.5 Success Criteria

Success criteria for the project, bearing in mind that the aim is to maximise the connection of sustainable generation technologies, are:

- Is the validity of the chosen algorithms clear?
- Is the relationship between the risks, benefits and costs of moving towards the proposed dynamic ratings solutions clear?
- Is the documentation for the techniques/tools clear?
- Is appropriate language used to take DNO planning engineers forward with using the techniques, e.g. will they get an understanding of what is behind the ratings?
- Are planning engineers comfortable with using the advanced tables and/or tools?
- Does the information that planning engineers have available at the desktop enable the application of the new methodologies?
- Is the path for a step-by-step implementation process for dynamic ratings clear?
5 Table of Standards

The Table of Standards and Recommendations (Table 1 below) lists the standards and recommendations known to be used in the UK, Europe and the US for each of cables, overhead lines and transformers.

Table 1: Standards and Recommendations

<table>
<thead>
<tr>
<th>Standards etc used in the UK</th>
<th>Overhead Lines</th>
<th>Cables</th>
<th>Transformers</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Standards</strong></td>
<td>ENA TS 43-122 (static probabilistic ratings)</td>
<td><strong>Standards:</strong></td>
<td><strong>Standards:</strong></td>
</tr>
<tr>
<td><strong>Recommendations</strong></td>
<td>ENA ER P27 (static probabilistic ratings, based on the ACE 104&quot; standard)</td>
<td>IEC 60287 = BS 7769 (steady static ratings)</td>
<td>IEC 60076-7 (continuous or cyclic load and emergency ratings)</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>Standards etc used in Europe</strong></td>
<td><strong>Standards:</strong></td>
<td><strong>Standards:</strong></td>
<td><strong>Standards:</strong></td>
</tr>
<tr>
<td></td>
<td>IEC 60287 (steady static ratings)</td>
<td>IEC 60076-7 (continuous or cyclic load and emergency ratings)</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td>IEC 60853 (cyclic and emergency static ratings)</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>Standards etc used in USA</strong></td>
<td>IEEE 738-1993</td>
<td>ANSI/IEEE C57.91 (1995)</td>
<td>---</td>
</tr>
</tbody>
</table>

Switchgear ratings at reduced ambient temperature are covered in ENA ER S33 (1982) but these recommendations are not now widely used by DNOs. The new international standard IEC IEC62271-1 (replacing IEC60694) will include switchgear ratings.
6 Literature Review

A review of the literature was carried out to provide a background to existing methodologies for
determining the static and dynamic ratings of distribution equipment and to focus areas of exploration
for the main project.

Overhead lines

The level of development of dynamic rating systems for different network components varies from
overhead lines, where complete systems are available, to cables where country specific models are at
best in the process of demonstration.

The theory of the thermodynamic behaviour of overhead lines is well developed but there have been
few practical measurements at the distribution level to verify the theory.\textsuperscript{9,10}

There are a number of different techniques and measuring devices, eg for conductor temperature, sag
and tension.\textsuperscript{7,8,11,12} Although originally developed for transmission lines, sag and tension monitors
can be used at any voltage level. Indirect methods of measurements using weather readings have also
been used effectively at the transmission level in many countries.\textsuperscript{13}

Full dynamic thermal ratings with real-time monitoring has only been developed in the last 5 years
but has been used in a number of countries\textsuperscript{14,15} yielding increases of 5-30\% compared to the original
static rating capacity.\textsuperscript{8,14}

Cables

A number of measurement techniques and models have been developed. Some models are designed
for static ratings but could be upgraded for dynamic ratings.

EA Technology\textsuperscript{6} has developed a modelling package for cables, CRATER, that calculates static
ratings, cyclic ratings at maximum conductor temperature and distribution ratings (see also section
2.3.1). Monitoring of cables is also built into the software developed by EPRI\textsuperscript{7,8} for dynamic thermal
circuit ratings for calculating continuous ratings and emergency ratings (see also section 2.3.2).

Cable temperature can be measured very accurately using fibre optics laid with the power cable\textsuperscript{16,17}
but retro fitting is prohibitively expensive. Setting thermocouples at strategic points along the cable
can be retro fitted more easily - the relationship between the change in surface temperature of the
cable and the conductor temperature for a step change in current is given in IEC 60853-2.\textsuperscript{18}

A dynamic ratings model for distribution cables that predicts increases in capacity for emergency
operation has been developed by Helsinki University. In the Netherlands, dynamic rating systems
have been developed by KEMA and NUON Tecno.\textsuperscript{20,21} An on-line dynamic cable rating system (DCRS) has been developed by the Energy System Research Center in the USA.\textsuperscript{22}
Transformers

Desk top case studies of the models and measurements required for dynamic ratings are detailed in a conference paper \(^\text{23}\). At 33kV and above, monitoring of transformers is standard and therefore to achieve dynamic ratings this information would need to be incorporated into appropriate software to calculate real-time ratings. Work on modelling transformer capacity, ambient temperature and demand has been carried out at EDF \(^\text{24}\).

The dynamic rating of a transformer is governed by the hot spot temperature, which needs to be measured or modelled. Some new transformers have a hot spot probe to measure the temperature directly \(^\text{25,26}\).

Although there are many models to determine the temperature and deterioration of transformers with different loading and under different weather conditions, there are few dynamic rating systems available \(^\text{23,25,26}\). The EPRI model can incorporate transformers \(^\text{7}\).
7 References

1. Report on the derivation of overhead line ratings applicable to high voltage distribution systems, British Electricity Board ACE Report No 104 (1986)

2. The thermal behaviour of overhead conductors, Électra, no 144 (October 1992), pp 107-125 [Section 1: Mathematical model for evaluation of conductor temperature in the steady (or quasi steady) state (normal operation), Section 2: Practical application of mathematical model for evaluation of conductor temperature in the steady state]

3. British Standard Electric Cables – Calculation of the Current Rating Section 1.1 General BS 7769 Section 1.1:1997


5. CYMCAP software website: [www.cyme.com/software/cymcap](http://www.cyme.com/software/cymcap)

6. EA Technology’s Strategic Technology Programme (STP): Overhead Networks, Cable Networks, Substations, Networks for Distributed Energy Resources


9. Examination of the continuous and short-term thermal capacity of overhead lines, RL Jackson CF Price CIGRE Symposium Brussels 1995 210-02 Item 2.1

10. Statistical approach to thermal rating of overhead lines for power transmission and distribution, CF Price RR Gibbon IEE Proceedings Vol 130 Part C No 5 September 1983


8 Acknowledgements

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Appendix I: Statement of Requirement for the Main Project
STATEMENT OF REQUIREMENT

The Development and Application of Dynamic Equipment Ratings

1. BACKGROUND

The aims of the Electricity Networks Strategy Group (ENSG) are to identify and co-ordinate efforts to address the technical, commercial and regulatory issues in electricity transmission and distribution networks in transition to a low-carbon future. In achieving this it will provide advice to DTI, DEFRA and Ofgem (the electricity regulator) on any actions required to assist the integration of generation onto the utility electrical networks. The ENSG has established and will co-ordinate the Transmission and Distribution Working Groups to build on the earlier contributions of the Transmission Issues Working Group and Distributed Generation Coordinating Group.

Through the Distribution Working Group (DWG) a number of work programmes have been established. Work programme 2 of the DWG is focussed on the technology, tools, techniques, processes and standards that will be required to construct power systems that are compatible with the developing trends in low-carbon energy technology. For the DWG work programme 2 this proposed study will aim to implement the project scope defined in section three below. The full DWG specification for this project, of which this study forms part, can be found on the ENSG web site.

It is well known that equipment ratings can vary continuously in response to changes in the environment particularly ambient temperature. For example, overhead line ratings are based on a ‘design temperature rise’ above ambient and a line route will be constructed to achieve minimum ground clearance when subjected to its assumed ‘seasonal’ environmental conditions. In operation, the actual seasonal environmental conditions may lead to a higher than anticipated temperature rise making the rating of the overhead line lower. To avoid infringing minimum overhead line ground clearances there would be a need to reduce the loading on the line and this may require the disconnection of load or generation. The assigned static ratings of switchgear, cables and transformers are similarly based on assumed environmental conditions that may be exceeded.

Assigning lower static ratings to equipment would impose an economic and environmental cost as more circuits and transformers would be required. There would however be potential benefits in terms of improved supply security, and reduced losses.

The industry guidance on the ratings of electricity distribution equipment have their routes in R&D that, in some cases, was carried-out several decades ago. With the current and future needs of the various industry stakeholders this guidance now needs to be reviewed. It should be appreciated that EPRI have considerable relevant expertise in this area. The output of this

1 See the ENSG web site www.ensg.gov.uk
2 See http://www.ensg.gov.uk/index.php?article=72
project will be a reference document and models to enable network planners to determine seasonal (static) and real-time (dynamic) ratings.

In conjunction with active network management techniques and by allowing network capacity to be fully utilised the deliverables of the project will facilitate the development of a low carbon economy as it will enable a more cost effective connection of sustainable generation technologies.

2. THE AIM OF THE STUDY

To develop practical and enduring modelling tools for the planning of electrical networks utilising static and dynamic equipment ratings to maximise the connection of sustainable generation technologies.

3. SCOPE OF WORK

Innovative proposals are sought, and it is proposed that the project is divided into three stages:

A. Establish the requirements for the dynamic modelling of network infrastructure. Review the literature and establish the methodologies for determining the dynamic rating of distribution plant. Critically appraise the functionality of any existing models that provide dynamic rating data.

B. Based on the findings of the above, and if not already available, develop user-friendly dynamic rating models, to include an appraisal of their limiting conditions.

C. Hold a workshop to disseminate the modelling tools developed, gather feedback and modify tools if appropriate

In implementing these stages the project will:

- Identify current practice within network operators worldwide, identifying reference documents, current assumptions and tools.

- Identify any gaps in this understanding and knowledge.

- Identify any constraints imposed on the network operators by relevant statutory or regulatory obligations.

- In agreement with the project steering group define the industry agreed approach to the assessment of circuit ratings.

- Consider any asset and network risks associated with using particular ratings.

- Consider network planning and modelling tools and how they will interact with any developed ratings tool. What environmental assumptions should be used by these planning standards.
Consider the interaction of these rating tools with network control and monitoring systems.

4. ADDITIONAL COMMENTS

- A Distributed Working Group project steering group will be appointed to direct the project.
- In the process of undertaking the work, it may be necessary for discussions to be held with DNOs and distributed generation developers. The project steering group should be invited to these meetings.
- The proposal should include costs for a ‘kick off’, delivery of the stage A report, delivery of the stage B report, and final report meetings (4) in London.
- Contractors should be able to demonstrate why their organisation has the relevant expertise to undertake the project.
- For stage C of the project, the proposal should include costs (provided separately) for one workshop (50 delegates) to be held in London or Birmingham.
- Bidding contractors may submit joint proposals, however these must be led by a single organisation.

5. TIMESCALES

The study is required as soon as possible and the bid should include the best project start and delivery time that will not compromise the quality of the deliverable.

6. DELIVERABLES

The deliverables from the project will be:

- A report describing the results of the analysis carried out in stage A of the study.
- A report describing the results of the analysis carried out in stage B of the study.
- Implementation of the Workshop.
- Revision of the work carried out in stage B with a draft and then final report.