SP ENERGY NETWORKS

Flexible Networks for a Low Carbon Future

IPSA Developments

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1 Introduction

IPSA forms the primary network design analysis tool for a number of UK Distribution Network Operators, including SP Manweb, for the design, operation and planning analysis for their 11kV, 33kV and 132kV networks. IPSA+ engines are also embedded into custom analysis tools for long-term network planning and use of system charge calculations and are widely used in the UK as well as internationally.

TNEI provided a funding contribution to Flexible Networks from the IPSA development budget due to the alignment of this project with our strategic goals for the IPSA product. This was in the form of both development time on core features across the duration of the project, as well as the provision of three full feature software licences for use in the project.

A number of software modules were developed for the innovative techniques being trialled in Flexible Networks (asset dynamic thermal ratings, series voltage regulators), for improved network reliability modelling, and improved network model build as listed below;

- Asset dynamic thermal ratings models,
- Reliability analysis,
- Series voltage regulator model,
- Composite load model,
- GIS conversion model,
- Rapid input of load profiles.

IPSA software developments for this project are free to all IPSA users. Background and foreground IPR was managed in accordance with Low Carbon Network Fund governance default IPR conditions and TNEI will retain all IPR developed as part of IPSA.

The majority of models are already available in IPSA v2.5 with the remainder to be made available in IPSA 2.6.

2 Software Modules

Software modules developed in IPSA for Flexible Networks are described in detail below. For several modules, development time was also available from other innovation projects e.g. Western Power Distribution FALCON LCNF project, as the modules were a key feature of both projects and development time was substantial.

2.1 Dynamic thermal ratings

Dynamic thermal ratings (DTR) models for transformers, cables and overhead lines were implemented in IPSA. User defined input profiles can be incorporated for;

- Load
- Weather
  - Ambient temperature
  - Wind speed/direction
  - Solar irradiance

The network load flow uses the dynamic thermal rating for the asset where specified. The asset rating and conductor or hot spot temperature is provided as output.

The DTR models are provided in the form of a DLL file and are supplied as part of the IPSA install. A user defined field for enhanced thermal asset ratings is also available in IPSA as a selectable drop-down box for the rating.

2.1.1 Dynamic Transformer Rating model

The Dynamic Transformer Rating model is based on IEC 60076-7 and represents the thermal time constants of a transformer to determine when the transformer oil temperature exceeds the maximum allowable hot spot oil temperature. The model also estimates the insulation degradation due to oil temperature effects and determines the remaining transformer life. An overload is reported in IPSA if the rated hot spot temperature is exceeded.

2.1.2 Dynamic Cable Rating Model

The dynamic cable rating model is based on IEC 60287 and IEC 60853. The model calculates one continuous and cyclic cable rating from profile analysis and is implemented for single cables. It was tested for 11kV and 33kV single core, trefoil and flat laid. The number of cable overloads is determined by comparing power flow results to cable ratings.

Validation was undertaken as part of the Western Power Distribution FALCON innovation project by Aston University.

Mutual heating effects and the influence of cable ducts are on the future development plan.

2.1.3 Dynamic Overhead Line Model

The dynamic overhead line model was based on "Overhead electrical conductors – Calculation methods for stranded bare conductors IEC TR 61597". This incorporated consideration of load and a range of weather parameters on the conductor temperature and thus rating of overhead lines.

Validation was carried out using monitoring data collected as part of Flexible Networks.

2.2 Reliability Analysis

A reliability analysis engine was developed for IPSA that calculates customer interruptions (CIs) and customer minutes lost (CMLs). Automated contingency analysis functionality was also added to enable calculation for a number of N-1 branches.

Input data required for reliability analysis includes customer numbers for loads, and asset failure and repair rates, switching time, and repair time.

Loss of supply can be calculated based on definition of protection zones. Circuit breakers, isolators, fuses need to be added to the network.

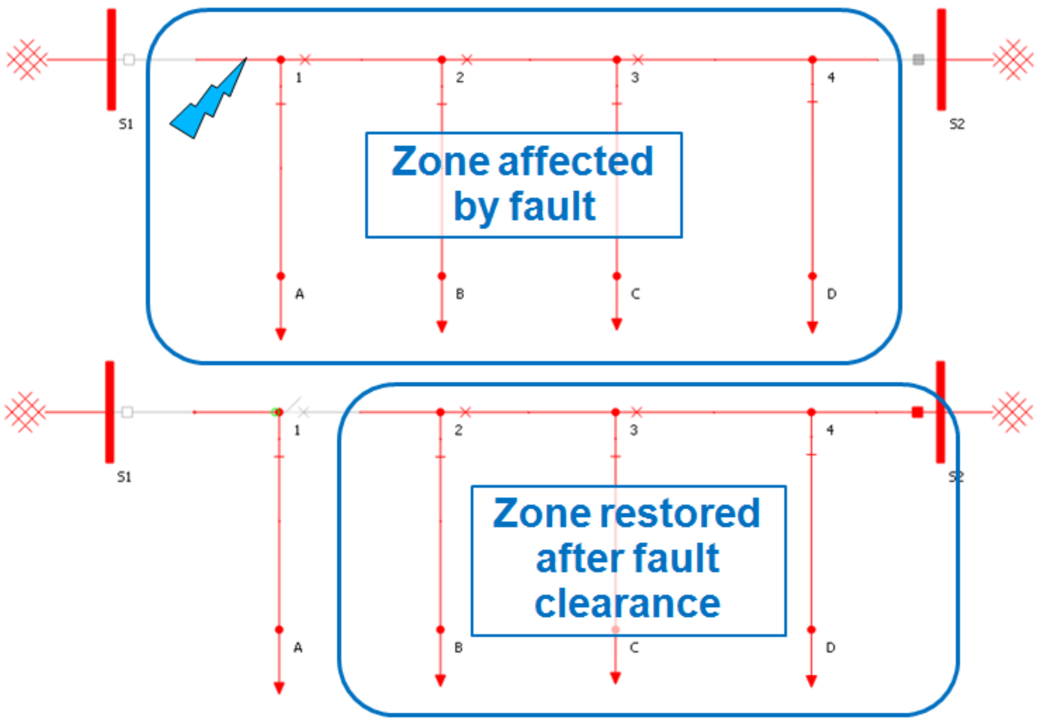

Figure 2-1 Protection zone definition in IPSA

A partial restoration feature is on the future development plan.

2.3 Series voltage regulator model

A series voltage regulator model was developed that covers the majority of potential applications. It can be added to an existing network branch. Inputs include voltage rating, load current, rated power, regulation range and impedance. The model was validated in detail with monitoring data from testing of an 11kV Automatic voltage regulator (AVR) at the Power Networks Demonstration Centre.

The following control modes are available. Please note that for the purposes of this model, when operating in the forward direction the source (S) bushing is located upstream and the load (L) bushing is located downstream. Conversely, in the reverse mode, the source (S) bushing is located downstream and the load (L) bushing is located upstream. Thus the denotation is based on physical location rather than power flow direction as shown in Figure 2-2.

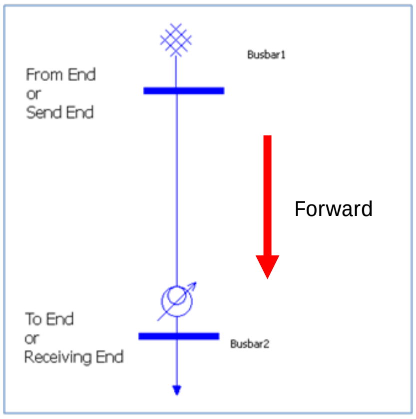

Figure 2-2 Series voltage regulator definition in IPSA

2.3.1 Forward Locked Mode

The transformer tap changer operates to maintain the Load busbar voltage equal to the target voltage. The tap changer only operates when the direction of active (MW) power flow is from the Source to the Load side. The tap changer does not operate when the active power flow is in the reverse direction or below 0.001 times the System base MVA.

2.3.2 Reverse Locked Mode

The transformer tap changer operates to maintain the Source busbar voltage equal to the target voltage. The tap changer only operates when the direction of active (MW) power flow is from the Load to the Source side. The tap changer does not operate when the active power flow is in the forward direction or above 0.001 times the System base MVA.

2.3.3 Neutral Reverse

The transformer tap changer operates to maintain the Source busbar voltage equal to the target voltage. The tap changer only operates when the direction of active (MW) power flow is from the Load to the Source side. The tap changer returns to the nominal position when the active power flow is in the forward direction or above 0.001 times the System base MVA.

2.3.4 Co-generation Mode

Provides a compounded voltage control for the tap changer. The target voltage is adjusted by a compensation voltage calculated from the compounding impedance multiplied by the power flow. Different compounding impedances are used for the forward and reverse directions. Only the forward target voltage is used.

2.3.5 Normal Bi-Directional

Provides a compounded voltage control for the tap changer. The target voltage is adjusted by a compensation voltage calculated from the compounding impedance multiplied by the power flow. Different compounding impedances and target voltages are used for the forward and reverse directions.

2.3.6 Reactive Bi-Directional Mode

Provides a compounded voltage control for the tap changer. The target voltage is adjusted by a compensation voltage calculated from the compounding impedance multiplied by the power flow. Different compounding impedances and target voltages are used for the forward and reverse directions, however the forward direction is set to the direction of the reactive power flow.

2.4 Composite Loads

2.4.1 ZIP Model

A ZIP (impedance-current-power) model was developed that enables representation of mixed constant power, current and impedance load characteristics and corresponding influence on network voltage.

Total load is split between constant impedance, constant current and constant power as required by the user. Load profiles can be input and a separate real power and reactive power response can be defined in a single load.

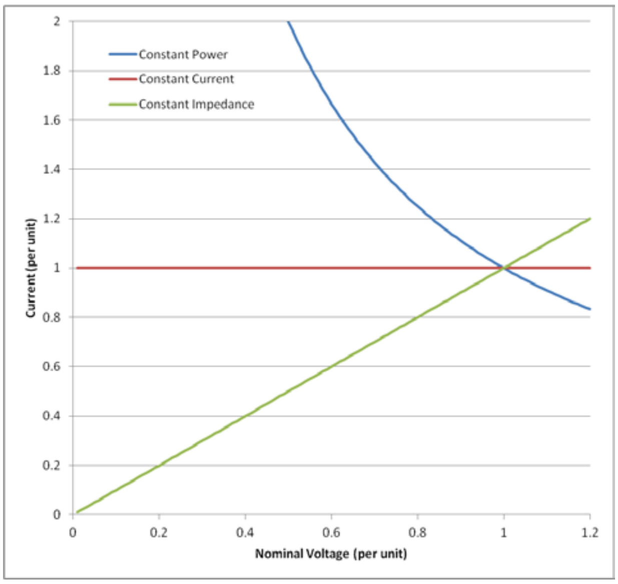

Figure 2-3 Representation of ZIP model

University of Strathclyde recommended that SPEN should model network loads on a constant current basis[1], except where knowledge of particular load behaviour dictates otherwise, based on a detailed assessment of load modelling for Flexible Networks. In IPSA, this can be achieved through use of the ZIP load model, configured to act as a constant current load.

The addition of customer numbers to ZIP loads to enable reliability modelling and the addition of fault backfeeds to ZIP loads to enable fault modelling is on the future development plan.

2.5 GIS conversion model

A script was developed and tested for conversion of GIS data to IPSA models at HV and LV. This enabled the creation of a detailed network model with no aggregation of loads required, thus preserving the full network topology. More rapid model build and refresh (if the network configuration changes) is then possible. The script is bespoke to the formatting of the GIS software output but could form the basis of future development to import a range of GIS formats.

Asset ratings were incorporated during network model build via a separate lookup table. Generic assumptions were made where conductor details were not available in GIS. A number of modifications were recommended following a detailed performance assessment and implemented in a beta version of the script to improve model representation. A simple validation "toolkit" is on future IPSA development plans.

This approach was found not to be suitable for LV network model build due to a large number of busbars and circuits (often of very short length) created and significant amount of manual correction of connectivity.

A more efficient process is proposed for LV networks that involves manually tracing an image of the LV network in IPSA using the facility to include a map of the network from Arcview/GIS in the background. This is suitable for modelling LV networks in low volumes.

2.6 Rapid Input of Network Load Profiles

IPSA now allows rapid input of network load profiles on a half-hourly or hourly basis for demand or generation loads. A load profile template is defined that can be applied to a single load or a group of loads. Multiple load flow studies can be run for a network with different load profiles defined. Load profiles are also required for asset dynamic thermal ratings models.

Outputs from IPSA such as busbar voltage and network asset loading can also be plotted as a daily profile.

[1] University of Strathclyde, Flexible Networks - Technical Note on Modelling of Load, January 2015.

2.6.1 Generation and Demand Profiles

The development of a set of generic PV generation profiles based on analysis of monitoring data from Flexible Networks was evaluated for use in modelling embedded solar PV on LV networks. However, there are some good freely available web based software such as PV-GIS that can provide daily solar irradiance profiles by day and month for any specified co-ordinates. It is recommended that solar irradiance is then converted into PV generation profiles using the simple “rules-of-thumb” outlined in “Improved Characterisation of PV Capacity at LV” for input into the IPSA model as a load profile.