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Renewables Integration, Flexibility Measures and Operational Tools for the Ireland and N. Ireland Power System

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The Ireland and N. Ireland power system is pursuing ambitious renewable energy (mainly wind generation) targets for 2020. A range of system-wide initiatives are being developed as part of the DS3 (Delivering a Secure, Sustainable Electricity System) programme, and, in particular, a bespoke suite of ancillary services incentivising fast frequency response, dynamic reactive power and ramping margin, and other, (future) system needs. With approximately half of the wind generation connected at distribution level, network development at both distribution and transmission levels is a key challenge for both the transmission system operators (TSO) and distribution system operators (DSO): a wide range of technical options are being examined, including undergrounding, HVDC connection and series compensation, supported by a public and stakeholder engagement programme. The experience gained is highlighted, while also indicating solutions and strategies which have been proposed, and ongoing challenges for the future.

Island of Ireland Power System

The island of Ireland has historically consisted of separate power systems in Ireland and Northern Ireland, with the respective transmission and distribution networks connected together by one double circuit 275 kV line and two 110 kV transmission lines. As a consequence, interconnecting power flows, individual system reserve policies and wind generation penetration levels, particularly against the possibility of a system separation event, have been of concern. Against this background, the All-Island Grid Study (AIGS) [1] was initiated by the governments of Ireland and N. Ireland to establish the available volume of renewable energy resources on the island, and the economic and operational impacts for their integration. Subsequent to the report's release in 2008, the Ireland government established a target of 40% of all electrical energy to be provided by renewable sources by 2020, and a similar target was later introduced in N. Ireland. Currently, there is 2,500 MW of wind generation connected in Ireland, 1,250 MW of which is connected to the distribution network, while 640 MW of wind capacity is installed in N. Ireland. In 2015, renewable sources, predominantly wind generation, supplied 25% of the island's electricity demand, the average windfarm capacity factor was 32.3%, while the instantaneous wind penetration peaked at 65+% on occasion, mainly during night periods, with excess (wind) power being exported to Great Britain. Figure 1 shows the gradual reduction in system inertia in recent years, as conventional (synchronous) generators are increasingly replace by non-synchronous (wind) sources. So, for example in 2012, periods of low inertia are mostly limited to summer weekends and the Christmas break, but by 2015, even winter weekdays can experience low inertia periods.

It is anticipated that ≈ 6 GW of wind generation is required to meet the 40% renewable energy target, with the 2010 National Renewable Energy Action Plan for Ireland indicating a strategy based on onshore wind generation, grid expansion and the growth of a micro-generation sector. The transmission system operator in Ireland, EirGrid, has developed the Grid 25 plan [2] to upgrade the transmission network for 2025, incorporating additional (wind) generation, predominantly located in more remote parts of the network. In recent years, the generation plant portfolio has evolved significantly, with both a significant net increase (29.4%) in installed plant capacity despite plant retirements, and a growing transition towards non-synchronous technologies: 19.4% (capacity) in 2010, and 42.7% in 2020. The conventional generators mainly utilise natural gas and coal, with a number of older oil plants due to retire. The majority of gas-fired plants are CCGTs and OCGTs, supported by a small number (350 MW) of peat-based generators employing indigenous fuel. The system also has 220 MW capacity of run of the river hydro, and a single pumped storage station (292 MW). A current-sourced converter (CSC) HVDC 500 MW cable links Northern Ireland to Scotland, and a voltage-sourced converter (VSC) HVDC 500 MW cable links Ireland to Wales, with further interconnections to mainland Europe under review.

Until 1995, the two systems operated separately, when the 275 kV (AC) interconnector was re-established, having been out of operation for the previous 20 years. Each system is required to be capable of operating independently, which has encouraged high flexibility in day-to-day operations, even before the emergence of wind generation on both systems. So, for example, certain CCGT and coal-fired plants on the system have been adapted to provide rapid reserve and unit response.

Operating as a synchronously-isolated island network, the system operators in both parts of the island (EirGrid, Ireland, and SONI, Northern Ireland) have always placed great importance on reserve requirements, reliable delivery, and performance monitoring of all generating units. Reserve targets are shared in proportion to system size between the two jurisdictions, with demand-based sources and the two HVDC interconnectors supporting conventional generation technologies. Alternative (flexibility) sources are also beginning to emerge, including batteries, large-scale flywheels and compressed air energy storage. Reserve policies for loss-of-load (high frequency) events are also under review, particularly for scenarios when one of the HVDC interconnectors is forced offline when in export mode, likely to be associated with periods of high wind penetration.

The two systems are overseen by separate regulators, but the TSOs form part of one larger group, with EirGrid owning SONI. Similarly, each system has distinct distribution system operators (DSO), although again ESB (Electricity Supply Board) Networks in Ireland is the owner of NIE (N. Ireland Electricity) in N. Ireland. The TSOs have a common aim to achieve consistent planning and operational policies, and, in this regard, a 380 kV (AC) interconnector between the two systems is planned for by 2020. This measure would enable both systems to operate as a single synchronous system, with the restrictions imposed by a single 275 kV interconnection being removed.

Impacts of Wind Generation

The 40% renewables target for 2020, mostly expected to come from wind generation, is bringing a number of challenging issues to the fore: what are the operational and stability limits associated with high penetrations of non-synchronous generation? how can and should generators, and/or other sources, be incentivised to supply flexibility services to the system? how should the transmission and distribution networks develop to accept more distributed generation sources? what monitoring tools are necessary to control and co-ordinate a power system with an increasing share of (non-synchronous) generation connected to the distribution network?

Facilitation of Renewables Studies

Subsequent to the All-Island Grid Study, the Facilitation of Renewables (FOR) studies examined the stability implications of a power system with high penetrations of non-synchronous generation sources, including windfarms and HVDC interconnections [3-4]. Ten distinct studies were completed, covering transient, small signal, voltage and frequency stability analysis for system non-synchronous penetrations (SNSP) levels upto 100%. SNSP is defined as the ratio of non-synchronous generation (wind and HVDC imports) to the sum of demand and HVDC exports. Particularly for frequency stability, it was shown that the security of the system could be adversely affected for SNSP levels beyond 50%, assuming only compliance with existing grid code regulations in Ireland and N. Ireland. It was further suggested that a 75% SNSP level was achievable, subject to enhanced generator performance monitoring, resolving high rate of change of frequency (RoCoF) protection and stability issues, and other measures. EirGrid and SONI then introduced the DS3 (Delivering a Secure Sustainable Electricity System) programme to deliver upon the 75% SNSP target, consisting of 11 workstreams, under the pillars of system performance, system policies and system tools.

Wind Curtailment and Network Constraints

With rising wind penetration levels, operational and technical limits have increasingly been approached, particularly during periods of high wind generation and/or low demand. Active (MW) and reactive (MVAr) power setpoints are regularly sent to windfarms as part of normal procedures, but, curtailment and constraint instructions may also be issued. In Ireland, the term curtailment has a specific meaning, referring to the dispatch-down of (wind) generation due to system security, rather than local, concerns. Five security limits are specified: operating reserve, including high frequency (load rejection) reserve; approaching system stability boundaries (low synchronous inertia, transient stability, etc.); exceeding the SNSP operational limit; steady-state and dynamic voltage control capability; load rise ramping. Most of these limits can be associated with maintaining a minimum number of synchronous (conventional) generators online in strategic locations, with the effect that windfarms may need to reduce their production, particularly at night and/or low demand periods, to maintain system balance. If the HVDC interconnectors are importing power at high levels to Ireland at such times, then the TSOs can enact countertrading arrangements, which provides a limited ability to reduce imports and hence the requirement for wind curtailment. If curtailment is required, a hierarchy has been defined, in consultation with the two regulators, regarding which generation technologies are curtailed first: wind generation falls towards the bottom of this list, such that it is the last to be curtailed. Distinct from curtailment, local network issues, e.g. load carrying capacity of individual lines being exceeded, voltage stability limits being approached, line outages (due to maintenance, line upgrades or recent faults), may require the dispatch down of generation, known in Ireland as constraining off. One of the major objectives of the Grid25 programme is to strengthen the network in those critical and constrained locations, such that the number of constraint instructions tends towards zero. In 2015, 5.1% of the available wind energy was dispatched down, with approximately 36% (by energy) due to constraints and 64% due to curtailments. Of the two actions, curtailment instructions occur with much more frequency, particularly in the early morning and mid-afternoon, with constraint instructions being much less dependent on the time of day, being mainly associated with lines outages as part of network upgrading and uprating.

Generation Connection Planning and TSO/DSO Interactions

Given that approximately half of existing and future windfarms are to be connected to the distribution network, strong DSO/TSO interactions are a key component to the planning and operation of the existing and future system. While several areas of mutual interest have been identified, a major focus is on the connection of new installations. Large-scale, i.e. exceeding 0.5 MW, renewable generators, whether connected to the transmission or distribution network, must submit a connection application through a 'gate' process, which closes at a particular time, rather than individual applications being considered in order of submission. Upon gate closure, all viable applications are processed as a single batch, with applications in similar locations grouped together to form specific clusters, to be reviewed collectively in detail by the TSO and DSO. The impact on the local network is studied, identifying cost-effective strategies to connect the grouped asset to the network. Such measures may include connecting a number of neighbouring windfarms at a higher voltage level [5].

In addition to the above, discussions regularly take place on matters involving the transmission and distribution grid codes, particularly relating to system frequency and voltage control. The former includes the provision of operating (primary, secondary and tertiary) reserves, and the configuration of switchable, distribution-connected loads, activated through frequency sensitive relays. Given the low inertia of the system, high RoCoF events are of concern, which may lead to maloperation of anti-islanding protection schemes for embedded (mostly wind) generation. Alternative, locational dependent, protection arrangements are under study. The latter includes management of reactive power, involving co-ordinated control of embedded generators, and appropriate operation of transformers and other network devices. For example, synchronous compensators, formed from existing plant, or dedicated new facilities, are being studied for various system-support roles in defined locations, e.g. voltage support, fault level provision, synchronous inertial source. Data communications between the TSO and DSO are also seen as being a key element of real-time operations and long-term planning, e.g. network topology, regional demand forecasts, planned maintenance procedures. Increasing periods of curtailment and/or network constraints have necessitated the introduction of congestion management strategies, including automated load shedding arrangements, and co-ordinated special protection schemes (SPS).

System-Wide Initiatives

The major conclusion from the AIGS and FOR studies was that the 40% renewable targets for Ireland were achievable, but only if major technical, economic and environmental challenges were addressed, with success dependent on the full participation and co-operation of all market players and the general public. The location of windfarms and the routing of new overhead lines represent issues common to many power systems, but public discussion on technical topics such as synchronous inertia, anti-islanding protection, voltage stability, reactive compensation, etc. has become necessary to explain and understand operational and planning decisions. Consequently, a range of initiatives have been introduced to identify the best technical and economic solutions, to gain consensus on the way forward, and to communicate the decisions made to a range of different audiences.

DS3 Programme

The DS3 (Delivering a Secure, Sustainable Electricity System) programme [6] was introduced by EirGrid and SONI to implement those measures necessary to achieve the 2020 renewable targets. While resolving technical issues is at the core of the programme, multi-dimensional factors are recognised, Figure 2, including the design of financial incentives for enhanced plant performance, and the development of operational policies and system tools to increase the realisable flexibility from conventional and renewable generation sources [6]. As Figure 2 also shows, the SNSP limit was temporarily raised to 55% in October 2015 for the upcoming winter period, with the change being made permanent in early 2016. Similar raised SNSP trial periods are planned for successive years. The capability standards for all generators are also being updated to make them (relatively) future proof against anticipated flexibility needs. A range of stakeholders have been integrated into the programme: regulatory authorities, distribution system operators, conventional and renewable plant owners, governmental departments, in both N. Ireland and Ireland.

A current focus of the DS3 programme is the delivery of a bespoke suite of ancillary services for the Irish power system, incorporating individual services such as synchronous inertial response, fast frequency response (similar to emulated inertial response in other systems), post-fault active power recovery (enhanced active power fault ride through capability from windfarms), dynamic reactive power and ramping margin (1,3, 8 hours). With 8 new products being introduced, the relative volumes of new and existing ancillary services needed to be defined, particularly at higher SNSP levels. However, with uncertainty as to how the system services market might develop, and the mix of technology providers also affecting the availability and requirement for different services, the TSOs considered two potential eventualities: an 'enhanced capability' strategy, whereby the majority of 'new' flexibility comes from existing generators, but with some additional capability from demand side response (DSR), windfarms and HVDC interconnectors, and a 'new providers' strategy, whereby new technology options become (more widely) available, e.g. batteries and flywheels, supported by a greater contribution from interconnectors, and less from wind farms and demand response. The structure and incentive mechanisms for the individual services has also received careful attention, with distinct approaches being implemented for the different flexibility products, based on anticipated volumes available, importance to system security, performance and scarcity needs, and the ability to supply multiple (linked) services. Figure 3 illustrates the changing landscape for ancillary services, ranging from present day arrangements (with 6 products) to the near 'flexible DS3' future (with 14 products, new products marked by *). It is intended that the payment pot for the existing services is largely unchanged, for the moment, but by 2020, for example, fast frequency response (FFR), fast post-fault active power recovery (FPFAPR) and dynamic reactive power (DRR) combined would account for 38% of the total, while existing services would contribute to less than half of the pot size.

Grid 25 Programme

Given that the windier regions of Ireland tend to be on the west coast, while the major load centres are on the east and south-west coasts, a natural consequence of higher renewable penetrations has been investment in the transmission and distribution systems. Network developments have involved significant public and governmental consultations, which, in some cases, has resulted in major changes to the originally proposed options selected. For example, for the Grid Link project, with the objective of transferring wind power from the south-west to the major loads in the East (Dublin), the installation of a new 380 kV line was rejected in favour of a 'regional' option, involving the installation of a new 380 kV cable and introducing series compensation to two existing 380 kV lines.

As part of a comprehensive review of network upgrade options, the TSOs investigated the viability of extensive EHV underground cabling for the combined transmission system of Ireland and N. Ireland [7]. The study addressed three fundamental questions: What is the impact on the transmission system of installing significant lengths of underground cables, either individually or in aggregate? Is it feasible to install a 380 kV cable interconnection, rather than an overhead line, between N. Ireland and Ireland? Is it feasible to underground part of the above overhead line interconnection? Reactive power management and assessment of resonance concerns formed a major part of the studies. Ultimately, for the fully undergrounded option, it was concluded that voltage control was best achieved for a 100% compensated cable, although voltage management issues could be seen during normal operation, light load conditions and with one end of the cable circuit tripped, particularly if some of the reactive compensation was offline. As a further study, the potential role for HVDC schemes on the transmission network was investigated [8], particularly in comparison to equivalent solutions based around 380 and 220 kV overhead lines. HVDC options were shown to be technically feasible, subject to the protection, telecommunications and control for the HVDC technologies, and their interactions with the rest of the system, being sufficiently robust. However, no significant technical advantages were seen for HVDC over HVAC.

Control Room Operational Tools

The entire network, incorporating Ireland and N. Ireland, can be operated and controlled by an Energy Management System in either jurisdiction. Additional functionality has been introduced to the control room to monitor and operate the windfarm portfolio, including WSAT (Wind Secure Level Assessment Tool) and a wind dispatch tool [9]. WSAT provides guidance to the system operator on the stability margin for the system, particularly with increased wind penetration levels. At its heart, the tool comprises TSAT (Transient Stability Assessment Tool) and VSAT (Voltage Stability Assessment Tool), Figure 4, both developed by PowerTech [6]. TSAT evaluates the rotor angle stability for 20 s after a disturbance, while VSAT assesses the voltage stability under quasi-steady-state conditions, i.e. 20+ s after a disturbance, once transient effects have decayed, including the activation of remedial action or special protection schemes. Incorporation of a frequency stability assessment tool is also planned.

The WSAT stability assessment studies are initiated every half hour based on real-time system snapshots from the EMS. The base case can then be adjusted, by scaling the wind generation in major (50 MW) or minor (20 MW) steps, while also reducing the conventional generation output (according to a defined merit order) in order to better define the (wind) stability limit. A similar process can be followed to scale the load in locations susceptible to voltage collapse. For each modified case, the stability is assessed for both N and N-1 conditions, and any breaches indicate the secure wind level for the existing system conditions. The system operator must then evaluate the results, taking actions as appropriate, which may involve constraining or curtailing wind generation.

Given the high instantaneous SNSP levels at certain times it has also become necessary to implement a wind dispatch tool which can control windfarms in real-time, most importantly during a system contingency, or at other times when system security is threatened. Curtailment and constraint instructions can be applied concurrently or separately, based upon the current output (MW) of each windfarm and the required system-wide curtailment and/or constraint volume. Due to the system's priority dispatch policy, some windfarms are given a higher operational priority, with curtailment instructions recognising their individual controllability status. Regional constraints are also automatically applied to neighbouring windfarms. Once normal conditions are re-established the dispatch tool gradually relaxes the curtailment / constraints on individual windfarms in order to lessen system frequency (step) transients.

Generation Scheduling

The Single Electricity Market (SEM) operates across both N. Ireland and Ireland, as a dual currency, gross mandatory pool energy only market. In parallel, both TSOs implement a reserve constrained unit commitment (RCUC) to determine an indicative operational schedule (IOS) for all generating plant and demand-side units for a 30 hour ahead optimisation horizon. Within the RCUC tool, each power system is recognised as a separate area with distinct system data, wind production forecasts and load forecasts employed. Two independent wind forecasts are used, which are later 'blended' together by the TSOs based on system risk levels, system demand levels and previous individual forecaster performance for similar meteorological conditions. When determining the IOS schedule, various operational constraints are considered, including system energy limits, voltage support requirements and regional transmission constraints. The latter are represented through time-dependent, unit-specific generating station limits, known as transmission constraint groups (TCGs), which are based on extensive operational experience. Consequently, generating units are scheduled to respect the TCGs, for a congestion-free schedule, without the need to explicitly model the network. The schedule co-optimises energy and reserve (considering primary, secondary, tertiary and negative (high frequency) reserve categories), with the impact of the optimised schedule on replacement, substitute and contingency reserve targets also considered.

Future developments to the RCUC procedures are envisaged, with a revised implementation of the SNSP metric under consideration, recognising that at raised demand levels higher SNSP values may be less onerous (from a system stability perspective) to the system. Additionally, (minimum) synchronous inertia based constraints are under review [10], with an inertia monitor being a first step in that direction to warn the system operator when online inertia levels are approaching a threshold level.

Future Initiatives

A range of other initiatives are also in progress, with the most important being the introduction of a new electricity market (iSEM - Integrated Single Electricity Market), due to go live in 2017. A comprehensive programme of performance testing is underway for all generating units and interconnectors, dynamic line rating equipment and phasor measurement units are being installed for live evaluation, and the new suite of ancillary services, under interim arrangements (to confirm issues such as plant capability and service measurability), will contract for services from October 2016, before enduring arrangements are later obtained. The SNSP upper limit is also due to be raised to 60% on a trial basis for the 2016/17 winter period. Also, the government of Ireland released a white paper on energy in late 2015, which outlines its vision to transform Ireland's fossil fuel-based energy sector into a clean, low carbon system by 2050: offshore wind energy, growth of biomass and solar installations, energy storage, and interconnections to continental Europe are seen as part of this future. An unexpected recent addition to this list is Brexit (will the UK leave the EU, and on what terms?), which may or may not impinge on the operation of the all-island power system ...

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Biographies

Damian Flynn is an Associate Professor in Power System Operation and Control at University College Dublin. He received M.Eng. and Ph.D. degrees in Electrical & Electronic Engineering at The Queen's University of Belfast in 1991 and 1994, before being appointed as a lecturer in 1995, and later a senior lecturer. In 2009 he joined the Electricity Research Centre at UCD. His research interests include power system analysis and control, and the integration of renewable generation into electrical networks.

Michael Power has B.E. (Electronic) and M.Eng.Sc. degrees from UCD. He has over 30 years experience of power system operation with ESB and EirGrid. He joined the Electricity Research Centre (ERC) at UCD in 2009 as a Charles Parsons Award Researcher. He is a Fellow of CIGRÉ, the International Council on Large Electric Systems, and was awarded a CIGRÉ Technical Committee Award in 2004 for contributions to System Control and Operation. He is a senior member of the IEEE.

Mark O'Malley received the B.E. and Ph.D. degrees from University College Dublin, Ireland, in 1983 and 1987, respectively. He is a Professor of electrical engineering in University College Dublin and is director of the Electricity Research Centre, with research interests in power systems.

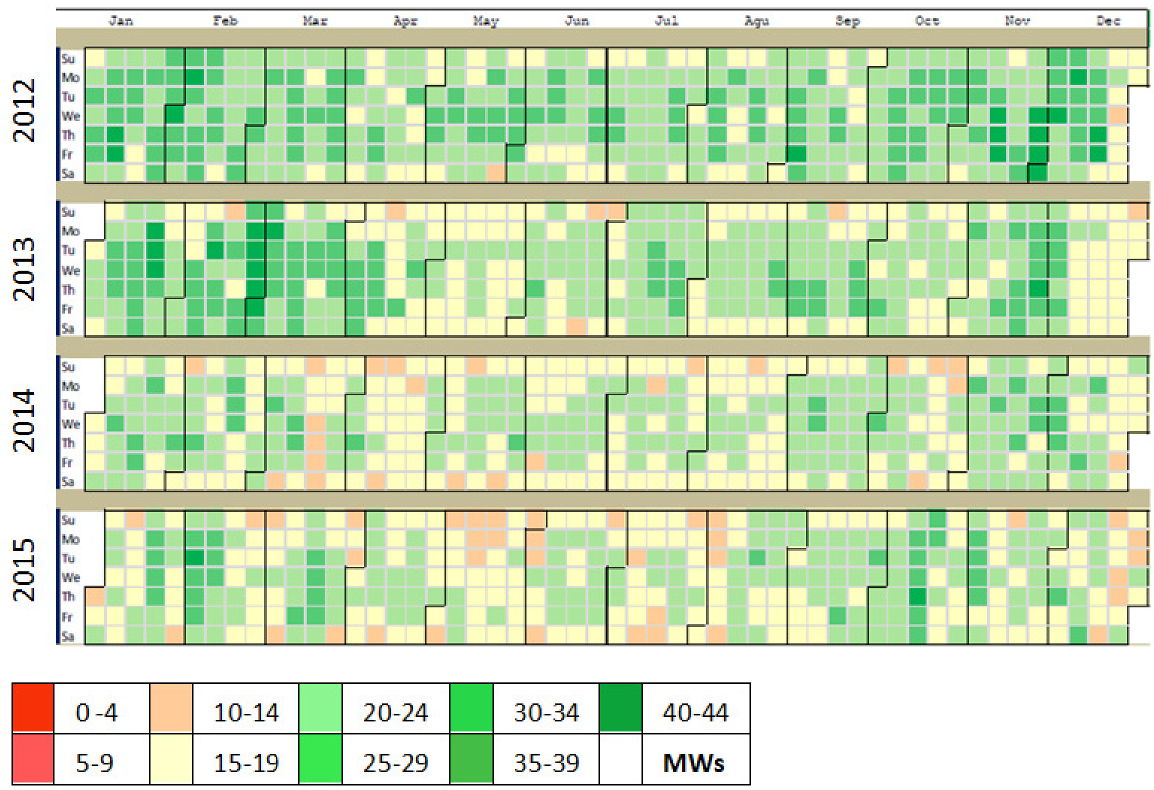

Figure 1: System synchronous inertia levels (2012-2015) [6]

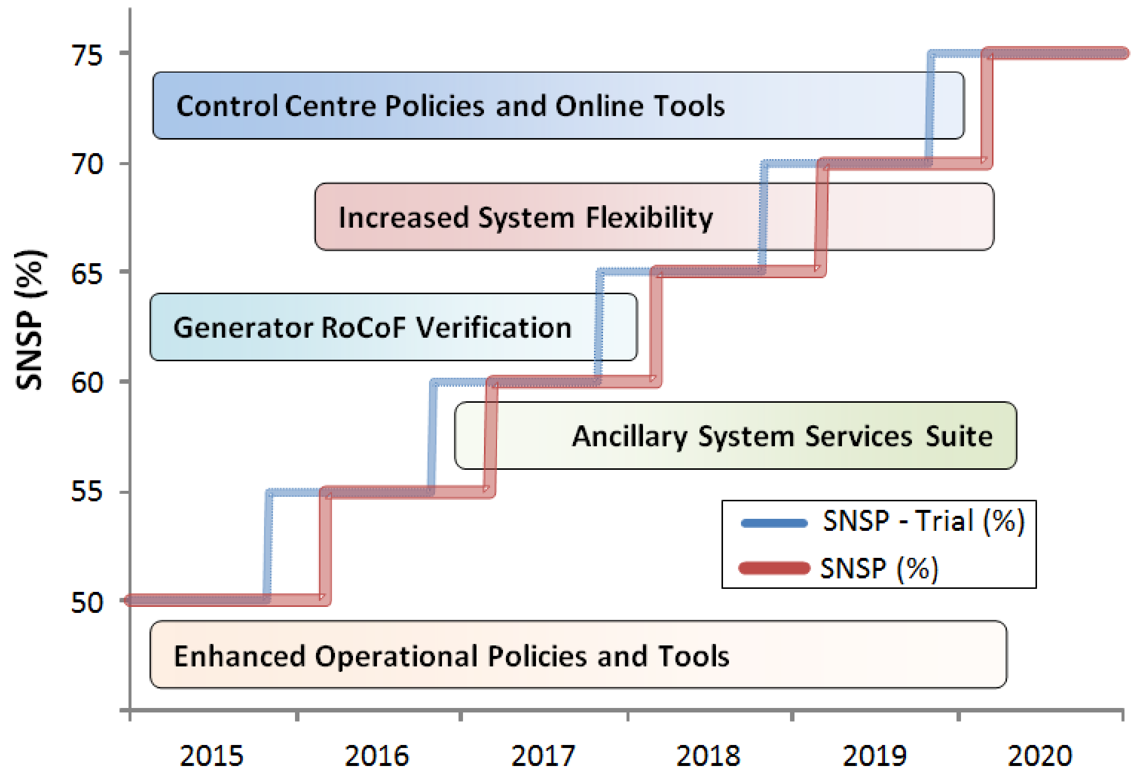

Figure 2: DS3 Operational Planning Outlook

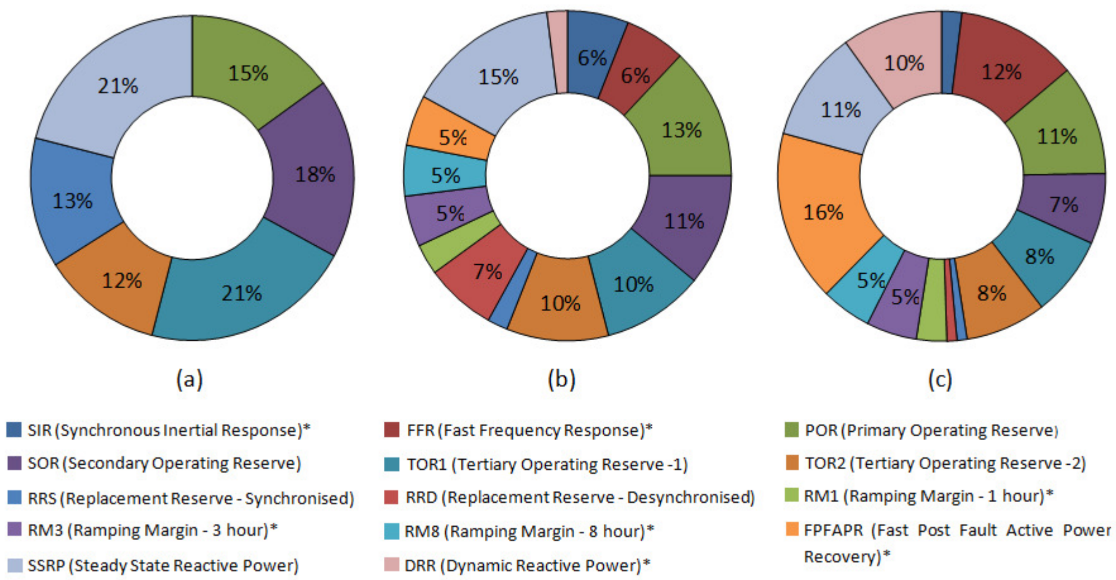

Figure 3: Relative Importance of System Services (a) Current payments, (b) 2016 (DS3) system needs (c) 2020 (DS3) system needs

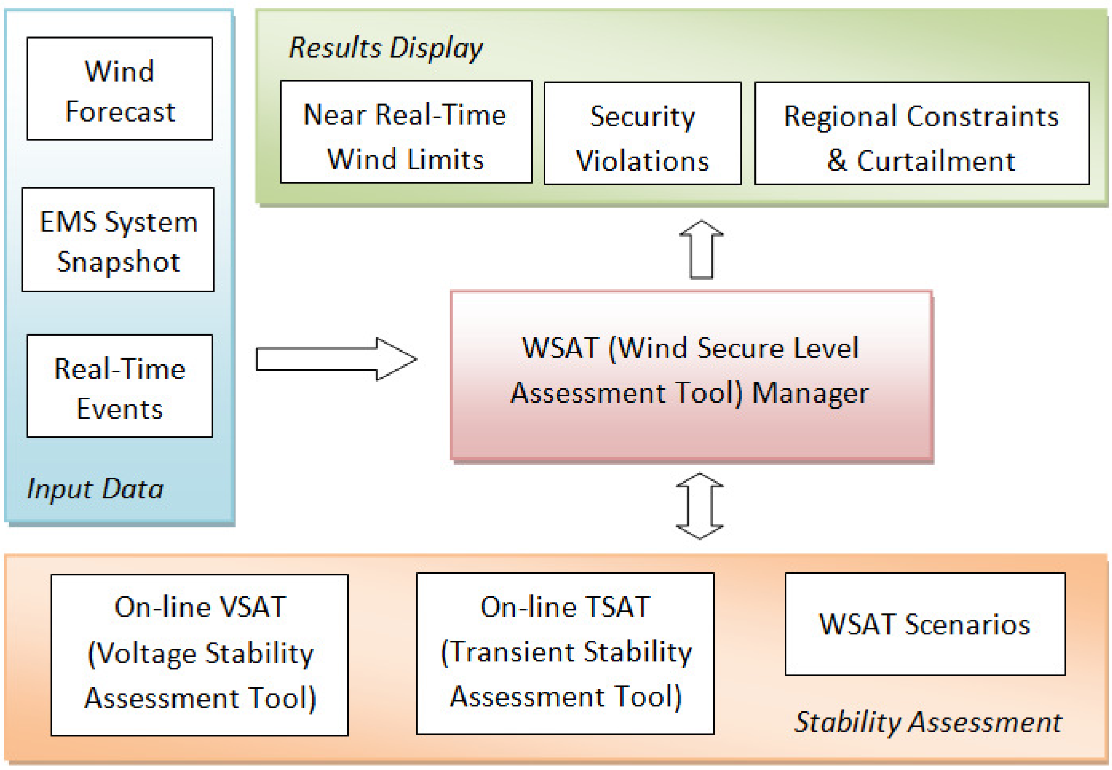

Figure 4: (WSAT) Wind Secure Level Assessment Tool