DISTRIBUTION NETWORK LOSSES AND REDUCTION OPPORTUNITIES FROM A UK DNO'S PERSPECTIVE

Sarat Chandra VEGUNTA
S&C Electric Europe Ltd – UK
sarat.vegunta@sandc.com

David HAWKINS
LIG Consultancy
Services LLP – UK
davehawkins@iee.org

Frank CLIFTON, Alistair STEELE, Stewart A REID
Southern Electric Power
Distribution plc – UK
frank.clifton@sse.com

ABSTRACT

This paper provides, from a Distribution Network Operator's (DNOs) perspective, a review of various distribution losses reduction opportunities and technologies and their applicability to today's UK distribution networks. The paper evaluates some of these losses reduction technologies by desktop studies on a typical distribution network in Southern Electric Power Distribution's (SEPD).

INTRODUCTION

Electrical losses represent about 6% of the total energy transmitted in the UK distribution system [1]; these losses currently cost about £1 billion a year and account for 1.5% of all greenhouse gas emissions in the UK [2]. DNOs in the UK are obliged to design and operate their networks efficiently [3][4], reduce the cost of electricity distribution to customers, and participate in reducing the carbon footprint of their operations in order to help the UK reach its carbon reduction targets by 2020.

Traditionally, DNOs in the UK have reduced losses through long-term asset management, replacing end of life assets with energy efficient models; with the introduction of the EU's Ecodesign Directive 2009/125/EC in 2009 [4], this has become mandatory for utilities. In addition, the UK's gas and electricity regulator 'Ofgem', recognizing the importance of network loss reduction, has included a new obligation from April 2015 for DNOs to reduce losses to "as low as reasonably practical".

This paper provides a review of various distribution losses reduction opportunities and technologies, and their applicability to today's UK distribution networks.

LOSSES REDUCTION OPPORTUNITIES

A brief commentary on various losses reduction methods is included below.

Losses Reduction Management and Policy

DNO electrical losses management and policies are driven by both internal and external factors. The internal factors include aspects such as providing the best value to stakeholders (e.g. customers, shareholders [5]) and sustainability (accounting for economic, social, and environmental factors) [6]-[8]. External factors include complying with statutory obligations [3], and local and international plant design standards [4]. These policies drive both non-technical and technical approaches to electrical losses reduction.

A wide variety of other reduction strategies are also currently employed today by the DNOs. These include training of utility staff, customers, and general public in the use of electricity and practical ways to reduce consumption [9]; promotion of sustainability and environmental conservation [9]; raising awareness of related utility service offerings to customers [10]; implementation of low losses asset procurement strategies [4]; etc. These approaches are complimentary to DNO's technical losses reduction approaches applied in operations, design, major projects, and network reinforcements [11].

Feeder Tie Open Point Optimisation

Optimal feeder sectionalising, or load balancing between feeders, is one of the cheapest losses reduction measures [11]. This is currently achieved by DNOs in the UK by selection of 11 kV feeder open points assessed using internal power flow studies, engineering judgement, and accounting for variation in seasonal load and load growth. Currently there are no examples in the UK where this is implemented to periodically reconfigure the network (e.g. every half hour) through a centralised (or local) losses reduction optimisation algorithm; however, similar schemes in combination with other network aspects are proposed in several studies (e.g. [12]-[14]).

SEPD studies in [15] show that a dynamic tie open-point optimisation scheme, when solely applied to reduce network losses, may be expensive and may have limited return on investment. This is due to tie open-point circuit breakers wearing out often, and therefore requiring replacement every few years.

Conservation Voltage Reduction

According to 2010 US DOE's Smart Grid report in [17], "End-use energy consumption has been shown to drop when the electric service voltage is reduced. This strategy, termed conservation voltage reduction (CVR), occurs primarily because the energy consumption of certain end-use loads such as incandescent lights and certain electronics go down as the voltage is decreased."

A field study in [18] involved studying 31 feeders at 10 different substations and 11 utilities in the Pacific

Northwest region. The study showed that a 1% change in distribution line voltage provided a 0.25% to 1.3% change in the end-user energy consumption, and that voltages could be reduced from 1% to 3.5%. A review work undertaken in [18] suggests that the CVR and advanced voltage control scheme together when applied universally in the US could deliver a 2% reduction in 2030 electricity demand. According to reference [17], however, "Accurate determination of the CVR effects on any given feeder must include analysis of the electrical load as well as the design of the distribution system. The design of the distribution feeders includes everything from line and cable types, line and cable configurations, use of voltage correction capacitors, and use of tap-changing voltage regulators for transformers. Thus, extrapolating the CVR results to estimate the national potential is difficult."

An ESB Networks published paper in [19] has identified a CVR factor (dP/dV) of 0.35 for domestic load that consisted of significant lighting. At the time of this study, the majority (around 92%) of domestic lighting identified by ESB Networks was incandescent rather than CFL or LED, neither of which are voltage dependent. Practical studies to confirm the appropriate CVR factors for SEPD/UK customer and load groups are required quantify the benefits offered by CVR.

Transformer Auto Stop-Start

Utility distribution transformers (ranging from tens of kVA to tens of MVA) typically have efficiencies higher than 98% [20]; the remainder of the transformer's transfer energy (i.e. less than 2%) is lost as transformer fixed (or iron) losses and variable (or copper) losses. The peak transformer efficiency [20] "…occurs when load loss and no-load loss are equal."

Although transformers are efficient at higher load factors, the average annual load may be much lower, leading to overall copper losses being lower than overall iron losses. This phenomenon was observed in several feeder losses evaluation studies: SEPD commissioned 'Isle of Wight Network Losses Study' [15] [16], EPRI's 'KCP&L Green Circuits Analysis' in the USA [21], Power System Engineering, Inc. study [22]. In [15], for example, among nine 33/11 kV substations during the year 2012, the demand at five substations is less than 40% of their firm capacity for about 95% of the time, the demand at two other substations is less than 40% for about 40% of the time, and the demand at the remaining two substations is less than 50% for about 40% of the time. In addition, transformers may suffer internal core damage, due to close-up feeder faults. Damage may include shorting of laminations, disfigurement of laminations causing increased flux infringement, etc., leading to increase in transformer iron losses; this is reported in [23].

Switching off one of a pair of under-utilised distribution transformers was suggested by ESB Networks in [11], which observes that, "Such switching is usually only practical in SCADA or remotely controlled stations, where the cost of carrying out the switching is minimal". Although, variants of Stop-Start schemes have been applied before to Arc Furnace switching applications [24], the Auto Stop-Start application for the purpose of distribution transformer losses reduction has not been found in the UK or elsewhere in the world.

SEPD's commissioned network losses reduction study in [15] indicates about 9% reduction in overall 11 kV network losses (with inclusion 33/11 kV primary and secondary LV transformer losses) could be achieved through the use of a transformer Auto Stop-Start scheme.

Alternative (Meshed) Network Topology

The primary benefit of the Alternative Network Topology (or network meshed topology) is the maintenance and/or improvement of network reliability. According to The Brattle Group report in [25], "… distribution systems are frequently radial in design, whereas transmission systems are normally meshed." Network meshed topologies are also typically applied to high load-density urban distribution networks, and radial topologies to lower load-density rural distribution networks.

In an urban meshed networks, according to [25], the "Network systems are designed with redundant supply paths, although lines to individual customer premises are typically stand-alone." This enables utility's personnel to visually identify the fault location, identify the best fault isolation switches, isolate the fault, and re-establish supply to customers. Although, the manual procedure to restore electrical supply may be long, it reduces the number of customers without supply following a system fault.

The secondary benefit achieved using network meshed topology is the reduction in an overall network impedance, and as a consequence [26][27], it reduces the overall network losses and voltage drop, maintains higher fault levels, improves network power quality, etc.

With advancements in switching technology and new control algorithms (e.g. S&C's IntelliRupter® PulseCloser and IntelliTEAM II™ Automatic Restoration System [28][29], distributed automation using reclosers and sectionalizers [30]), networks are able to deploy co-ordinated distributed intelligence, enabling fast automated fault isolation and sectionalizing schemes; this significantly reduces the electrical supply restoration time following a fault. Some of these technologies are currently deployed as part of a technology demonstration project at the SEPD Isle of Wight region in the UK [28]. At the completion of the project pilot, SEPD in [28] has concluded that "…the technological benefits of pulseclosing and economic benefits of reducing CML were repeatedly demonstrated."

Reactive Power Compensation

Where there are low power factors, DNOs typically install reactive compensation equipment to improve local or overall network power factor, which consequently reduces the network current flows. As "All current flow causes losses both in the supply and distribution system" [31], such installations may help reduce the network electrical losses.

There is a variety of reactive power compensation equipment available today; they range from simple passive equipment to advanced customer power devices [32]. Deployment and control of these devices in the network could be local and standalone, or be part of the overall distribution network multi-parameter (power factor, voltage, losses, etc.) optimisation and co-ordinated control (e.g. [34][31][32]); the devices may also be placed strategically to enable such control (e.g. placement of distribution capacitors, DSTATCOMs, etc.)

Currently, the average power factor at SEPD substations is better than 0.96; the opportunity for the use of reactive power compensation to reduce network losses was therefore not considered in its losses reduction studies detailed in [15][16].

Energy Storage

Currently, energy storage solutions are primarily employed to: provide fast frequency response support to the grid [33][35], act as a back-up supply to a site during loss of mains, reduce network reinforcements, enable grid stabilisation by accommodating distributed generation (e.g. wind and PV) [33][36], provide power flow peak shaving and congestion management, etc.; with reduction in network losses achieved consequentially of its primary application.

For energy storage to be effective in power flow peak shaving application, which enables consequential reduction in electrical losses, some level of feeder load forecasting is needed. Currently, there are distribution load forecast algorithms that are employed currently in the US (such as EPRI's Artificial Neural Network Short Term Load Forecaster (ANNSTLF) [37]) that have shown to maintain the load forecast errors to less than 2%.

SEPD's network losses reduction study in [15] has shown that energy storage purely from an electrical losses reduction point may not be cost effective.

Distributed Generation

Embedded generation's impact on the local and overall network electrical losses depends on several factors, such as its proximity to load and level of consumption, spillage of excess generation to other network voltage levels, network circuit conductor sizes and selection criteria, etc.

Studies conducted by Strathclyde University for the Electricity Network Strategy Group on some of these aspects in [13] have shown that the embedded generation may enable a reduction in losses when network load is greater than about 70% of its peak value. SEPD's network losses reduction study on the Isle of Wight 11kV network in [15] and [16] has shown a similar result that the embedded generation may increase 11kV network electrical losses; however, the system wide electrical losses (400kV to LV) may reduce.

Network Reinforcements

ESB Networks, has upgraded much of its MV network from 10 kV to 20 kV over the last 15 years and has reported in [34] that "The costs of 20kV conversion were little more than those of rebuilding in 10kV, yet the voltage drop was halved, thermal capacity doubled and losses reduced by 75%." Upgrade costs, were reported in [38]: "From 2007 -'10 incl. the cost of the programme for renewing and upgrading existing network plus construction of new lines and transmission /distribution stations is in excess of €2.5 billion."

There is some history in the UK of network voltage upgrade work [39][40] – almost the entire earlier 6.6 kV underground network has been upgraded to 11 kV between the 1960's and the present date. In many cases, it was found to be economically 'fortunate' that the 6.6 kV cable was capable of reliable operation at 11 kV.

A network voltage upgrade can provide significant reduction in losses; while its deployment may be expensive, disruptive, and time consuming the benefits of an increase in capacity for new load and generation connections may suit the future low-carbon customer.

SEPD's network losses reduction study in [15] has shown that "Although, the intervention offers significant savings in network losses savings compared to any other considered intervention," and "the upfront high investment outweigh any cumulative benefits offered for remainder of the assessment period, with no expected ROI [Return On Investment]."

CONCLUSIONS

With the growing need for lower electrical losses, driven by carbon reduction targets, rising electricity prices, and regulatory obligations, traditional DNO methods will have to be complimented by alternative methods that are able to deliver significant loss reductions while providing return on investment within reasonable time scales.

A broad set of network losses reduction methods and opportunities were reviewed and applicability of some was evaluated using a section of SEPD's own network.

Among the losses reduction methods summarised in this paper, the use of transformer auto stop-start and alternative network topology methods (and their combination where appropriate) were found to provide significant loss reductions. Further studies and field trials are recommended to confirm their applicability in practice.

REFERENCES

[1] "Electricity Distribution Units and Loss Percentages Summary - Factsheet," Ofgem, London, UK, Aug. 2010.
[2] "Electricity Distribution Price Control Review Final Proposals – Incentives and Obligation," Ofgem, London, UK, Doc. No. 145/09, 7th Dec. 2009.
[3] Great Britain, Electricity Act 1989, Part 1, Chapter 7. 1989.
[4] "Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products," Official Journal of the European Union, L 285, pp. 10-35, Oct. 2009.
[5] "Price controls explained – Factsheet 117," Ofgem, London, UK, Mar. 2013.
[6] "RIIO-ED1 Business Plan," Scottish and Southern Energy Power Distribution Ltd, Perth, UK, Mar. 2014.
[7] "Strategy Decision for the RIIO-ED1 Electricity Distribution Price Control – Outputs, Incentives and Innovation," Ofgem, London, UK, Rep. 26a/13, Mar. 2013.
[8] "The Carbon Plan: Delivering our Low Carbon Future," Great Britain, Department of Energy & Climate Change (DECC), London, UK, Dec. 2011.
[9] "About Your Energy Booklet," Southern Electric Power Distribution Ltd. [Online].
[10] "Being Green," SSE plc, Perth, UK. [Online].
[11] Tobin, N.P.; Lyons, M., "Practical electricity distribution system loss reduction," The energy efficiency challenge for Europe: Proceedings of the 1993 ECEEE Summer Study, Rungstedgard, Denmark, 1-5 Jun. 1993.
[12] Sedighizadeh, M.; Dakhem, M.; Sarvi, M.; Kordkheili H.H., "Optimal Reconfiguration and Capacitor Placement for Power Loss Reduction of Distribution System using Improved Binary Particle Swarm Optimization," International Journal of Energy and Environmental Engineering, Springer-Verlag GmbH, Berlin, Germany, vol. 5, iss. 1, Apr. 2014.
[13] "Automation to Optimise Network Configuration in Real Time – To Optimise DG Contribution and Reduce Losses", Institute for Energy and Environment at University of Strathclyde, Glasgow, UK, Contract No. DG/CG/00096/00/00, URN No. 07/1653, Nov. 2007.
[14] Dahalan, W.M.; Mokhlis, H., "Network reconfiguration for loss reduction with distributed generations using PSO," 2012 IEEE International Conference on Power and Energy (PECon), vol., no., pp.823-828, Dec. 2012.
[15] Vegunta, S. C.; Hawkins, D.; Barlow, M. J., "Isle of Wight Network Losses Reduction Study – Phase 1 Studies," S&C Electric Europe Ltd., Manchester, UK, Rep. 200729-02-RevC, Oct. 2013.
[16] Vegunta, S. C.; Hawkins, D.; Barlow, M. J., "Isle of Wight Network Losses Reduction Study – Phase 2 Studies," S&C Electric Europe Ltd., Manchester, UK, Rep. 200729-03-RevB, Oct. 2013.
[17] Pratt, R.G.; Kintner-Meyer, M.C.W.; Balducci, PJ.; Sanquist, T.F.; Gerkensmeyer, C.; Schneider, K.P.; Katipamula, S.; Secrest , T.J., "The Smart Grid: An Estimation of the Energy and CO2 Benefits," U.S., Department of Energy, Washington, DC, USA, Rep. PNNL-19112, rev. 1, Jan. 2010.
[18] "Distribution Efficiency Initiative," Northwest Energy Efficiency Alliance, Portland, Oregon, USA, Dec. 2007. Available: https://www.leidos.com/NEEA-DEI_Report.pdf. Last accessed on 12th Jul. 2014.
[19] Diskin, E.; Fallon, T.; O'mahony, G.; Power, C., "Conservation Voltage Reduction and Voltage Optimisation on IRISH Distribution Networks", CIRED Workshop, Lisbon, Portugal, pp. 1–4, Paper no. 0264, May 2012.
[20] "Review of Minimum Energy Performance Standards for Distribution Transformers," Commonwealth of Australia, Barton, Australia, May 2011.
[21] Arritt, R.F.; Grady, W.M.; Forsten, K.; Brooks, D.; Short, T., "KCP&L Green Circuits Analysis," Electric Power Research Institute (EPRI), Palo Alto, CA, USA, Rep. 1020143, Apr. 2011.
[22] Triplett, J.; Rinell, S.; Foote, J., "Evaluating distribution system losses using data from deployed AMI and GIS systems," 2010 IEEE Rural Electric Power Conference (REPC), Orlando, FL, USA, pp.C1, C1-8, 16th-19th May 2010.
[23] Griesacker, W.F.; Thierry, J.L., "Magnetic Core Issues in Power Transformers and Their Diagnostics," 81st International Conference of Doble Clients, Doble Engineering Company, Boston, MA, USA, 6th-11th Apr. 2014.
[24] "Power/Vac® – Product Family Application Guide," GE Consumer and Industrial, Houston, Texas, USA, Publication No. GET-6600G, Aug. 2011.
[25] Hesmondhalgh, S.; Zarakas, W.; Brown, T., "Approaches to Setting Electric Distribution Reliability Standards and Outcomes," The Brattle Group Ltd., London, UK, Jan. 2012.
[26] Vybiralik, Frantisek; Tlusty, J., "Increasing of the Capacity of Low-Voltage Networks with Higher Exploitation of their Components," 16th

International Conference and Exhibition on Electricity Distribution, 2001. Part 1: Contributions (CIRED), Paper No. 482, vol.5, pp.5, 2001.

[27] Gonen, T., Electric Power Distribution Engineering, CRC Press, Boca Raton, FL, USA, Jan. 2006, pp. 335-337.

[28] Baker, J.; Meisinger, M., "Experience with a distributed-intelligence, self-healing solution for medium-voltage feeders on the Isle of Wight," 2nd IEEE PES International Conference and Exhibition on Innovative Smart Grid Technologies (ISGT Europe), 2011, vol., no., pp.1-4, Dec. 2011.

[29] McCarthy, C.; Jayantilal, A.; Edmonds, M.; Boardman, E., "Smart Distribution through Layered Intelligence for Next Generation Self-Healing Distribution Networks," 22nd International Conference on Electricity Distribution (CIRED), Stockholm, Sweden, Paper No. 0514, 10th-13th Jun. 2013.

[30] Goodin, R.E.; Fahey, T.S.; Hanson, A., "Distribution Reliability using Reclosers and Sectionalisers," ABB, Inc., Lake Maryu, FL, USA, Document No. 1VAL2601-WP, rev. A, 1999.

[31] Ware, J., "Power Factor Correction," IEE Wiring Matters, Herts, UK. [Online]. pp. 22-24, Spring 2006. Available: http://electrical.theiet.org/wiring-matters/18/power-factor.cfm?type=pdf. Last access on 15th Jul. 2014.

[32] Dixon, J.; Moran, L.; Rodriguez, J.; Domke, R., "Reactive Power Compensation Technologies: State-of-the-Art Review," Proceedings of the IEEE, vol.93, no.12, pp.2144,2164, Dec. 2005.

[33] "Electrical Energy Storage – White Paper", International Electrotechnical Commission (IEC), Geneva, Switzerland, Dec. 2011.

[34] Niall, K.; Walsh, A., "Maximising Benefits to Customers from Distribution Losses Management – An ESBN Perspective," 21st International Conference on Electricity Distribution (CIRED), Frankfurt, Germany, pp. 1-4, Paper no. 1143, 6-9 Jun. 2011.

[35] "Electricity Energy Storage Technology Options – A White Paper Primer on Applications, Costs, and Benefits", Electric Power Research Institute (EPRI), California, USA, Rep. 1020676, Dec. 2010.

[36] Strbac, G.; Aunedi, M.; Pudjianto, D.; Djapic, P.; Teng, F.; Sturt, A.; Jackravut, D.; Sansom, R.; Yufit, V.; Brandon, N., "Strategic Assessment of the Role and Value of Energy Storage Systems in the UK Low Carbon Energy Future," Imperial College London, London, UK, Jun. 2012.

[37] Khotanzad, A.; Afkhami-Rohani, R.; Lu, T.; Abaye, A.; Davis, M.; Maratukulam, D.J., "ANNSTLF-a Neural-Network-Based Electric Load Forecasting System", IEEE Transactions on Neural Networks, vol.8, no.4, pp.835-846, Jul. 1997.

[38] "Our Infrastructure," ESB Networks Ltd., Dublin, Republic of Ireland. [Online] Available: http://www.esb.ie/esbnetworks/en/about-us/our_networks/. Last accessed on 12th Jul. 2014.

[39] Hawkins, D.; Currie, B.; Davidson, E.; McNeill, N.; Gooding, A., "Task 3.4: Review of Enablers, Solutions and Top-Down Modelling in TRANSFORM," Smarter Grid Solutions Ltd., London, UK, Rep. 200109-05C, Feb. 2013.

[40] Stokes, G., Handbook of Electrical Installation Practice, Blackwell Science Ltd., Oxford, UK, ed. 4, 2003.