Reducing energy losses & greenhouse gas emissions from substations

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Contents

1 Introduction

In substations, uncontrolled energy is typically consumed for heating and lighting, dehumidification and cooling equipment, oil pumps, air compressors and battery chargers to maintain secure network operation and resilience. The power supplies to substations are usually derived from secondary windings on 33 kV neutral earthing transformers. Presently, these supplies are unmetered and substation demand is therefore not accounted for separately, while still contributing to network transmission losses. This project is being undertaken for Scottish and Southern Electricity Networks in Scotland in order to establish potential energy efficiency improvements (e.g. better control of lighting and room heating, reducing internal/external lighting levels, improvement of building fabric thermal performance, onsite generation, etc) for implementation and requires reliable baseline losses and improved understanding of the “house load” flows within each substation to be established. In order to achieve this the Scottish Energy Centre (SEC) at Edinburgh Napier University are presently monitoring and metering substations energy demand at the Tealing 275kV site, in conjunction with conducting energy auditing and modelling of the site energy performance. This has been used to provide indications of the actual and potential energy performance of substation archetypes and scale across the network with a view to extending this work to cover the greater range of asset archetypes as part of a wider energy reduction strategy.

2 Energy Loss Assessment

2.1 Introduction

A typical substation site was selected by SSEN on which to base an analysis of losses in order to inform a wider strategy for substation loss reduction. Due to reporting requirements a methodology which involved the use of recorded real-time energy and temperature data in order to calibrate a dynamic simulation model of the substation buildings and extrapolate annualised output was adopted. It is recommended that further analysis of longer-term data be undertaken to provide a more accurate and refined model in order to assess a wider range of loss reduction opportunities.

2.2 Tealing 275kV Substation

Tealing 275kV substation is located to the North East of the city of Dundee and provides 275kV to 132kV network provision together with SVC equipment for grid stability. Site accommodation comprises three main building locations, which are identified on the satellite image in Fig. 1 below. A small heated workshop is located adjacent to the 275kV control building and included in the analysis.

Power monitoring equipment was installed in the each of the three buildings to monitor the following parameters:

SVC Buildings

Lighting Current

Air Conditioning Plant Current

Temperatures

275kV Control Building

3-phase DB Incomer Current

Lighting Current

Heating Current

Temperatures

Main Control Building

3-phase DB Incomer Current

Lighting Current

Heating Current

Temperatures

Data from each is transmitted via GSM to a Logic Energy LeNet cloud server portal from where 53 days of available data was presently available for this initial analysis. A typical output from this is shown in Fig. 2.

Fig. 1 Tealing Substation

Further to a site visit on 4th January 2018 to collect building and energy audit data models for each of the buildings were developed in Cadlink CYMAP building design software. The building models were then calibrated using the energy data gathered from the cloud portal in order to extrapolate the building energy demand over a yearly profile (using local weather data for Dundee) and to create a benchmark.

From this model, a range of lighting and building fabric interventions were applied, and subsequent energy and carbon reductions evaluated.

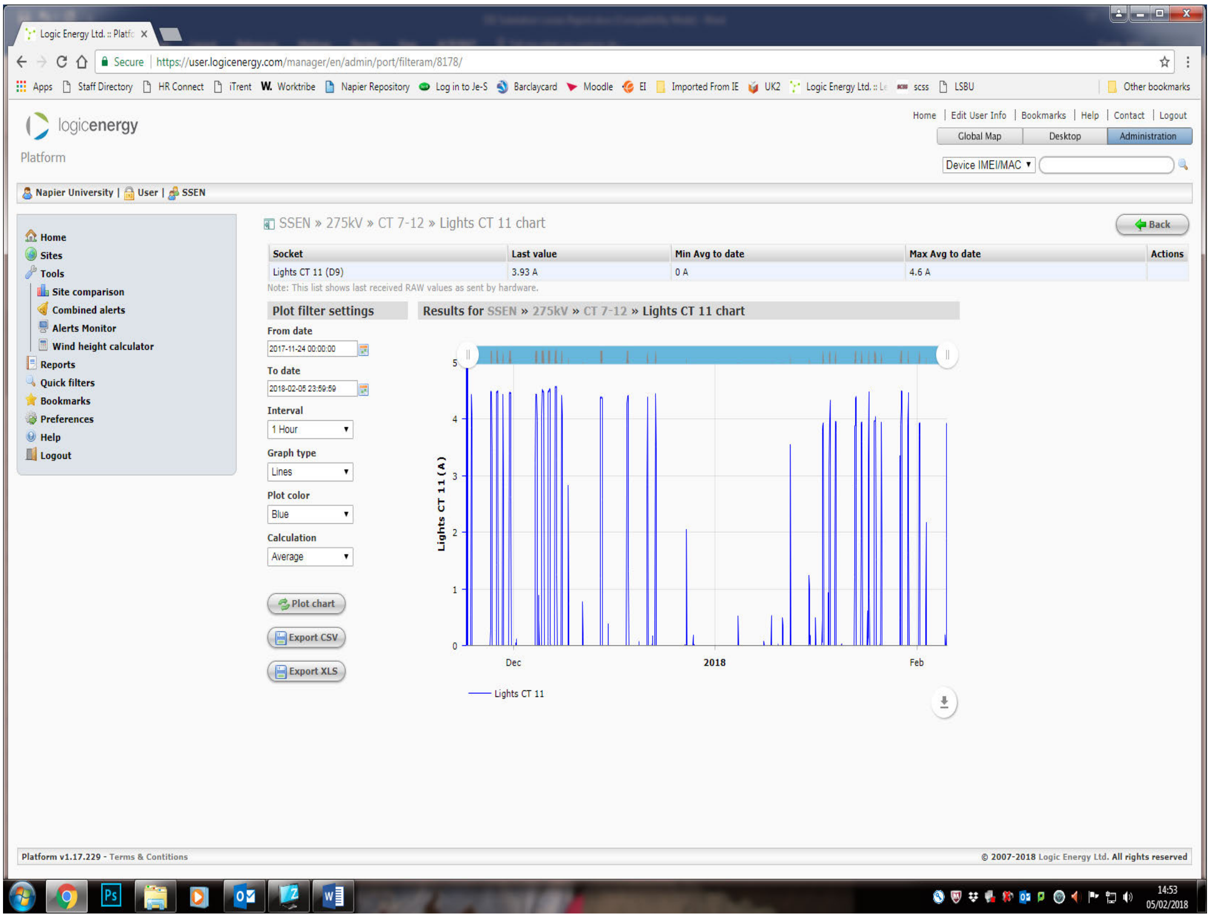

Fig. 2 Logic Energy Data Portal

2.3 Energy Benchmarking

Three dimensional models for each of the site buildings were developed using the survey dimensional and fabric construction data. A floor plan of the Main Control and 275kV building layout is shown in Fig. 3.

Fig. 3 Main Control and 275kV Building Floor Plan

Building fabric, occupancy, heating, and lighting profiles were then attributed to the model and an energy analysis conducted using local weather data in order to arrive at an annual energy profile for the building. Actual recorded temperatures for each zone in the buildings were then applied and the predicted energy consumption for the month of January compared with that recorded by the data logging equipment. The model was thus calibrated and an annualised energy consumption for the building created per Fig. 4.

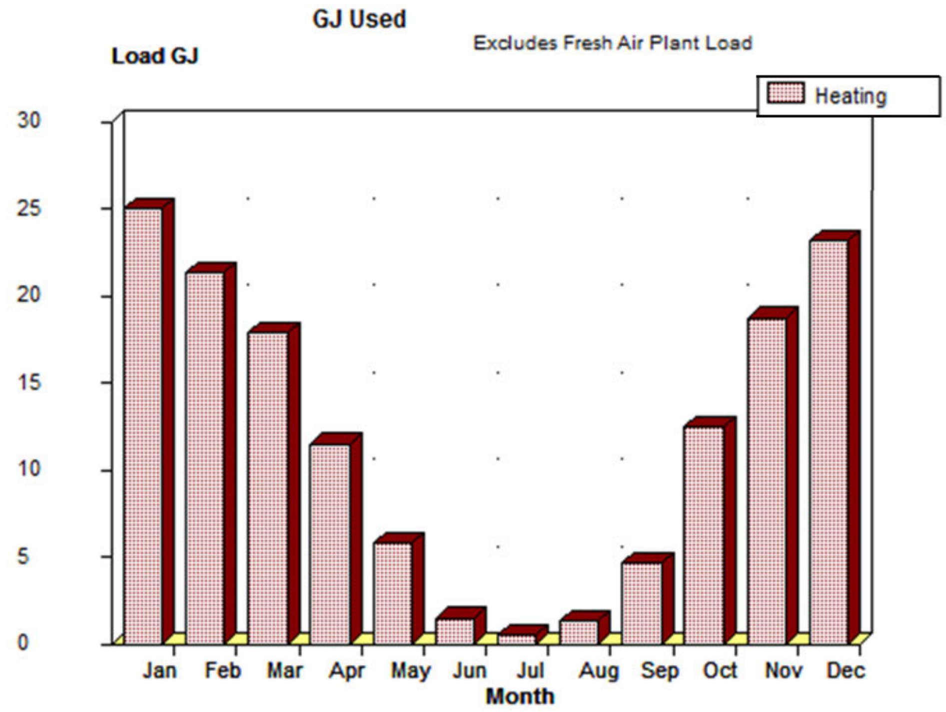

Fig. 4 Energy Consumption Profile for 275kV building

Results from the data analyses of energy consumption for each of the buildings are presented in Table 1 below:

Building	Floor Area	Modelled Energy Consumption
	(m^2)	(kWh/annum)
275kV	169	39,994
Workshop	36	18,332
Main Control	470	133,718

Table 1 Annual energy consumption for each modelled building

A range of fabric intervention measures appropriate to the construction form were applied and the reduction in energy consumption calculated. A simple cost benefit analysis for each intervention measure could then be derived and aggregated to provide a realistic overall energy reduction metric for this substation archetype.

Using this benchmark data, a range of substation archetypes across the SSEN network were analysed to provide an indication of potential loss reduction in this sector.

3 Energy Saving Measures

3.1 Introduction

A limited portfolio of intervention measures were analysed in this study; including lighting replacement, lighting control, and building fabric measures. Further analysis over a longer time period will enable other intervention measures such as wider control strategies and onsite generation to be investigated in respect of carbon mitigation. The intervention measures adopted for the Tealing substation archetype are discussed as follows.

3.2 Intervention Measures

3.2.1 Lighting

The majority of artificial illumination used in the buildings is provided by fluorescent T8 luminaires; with a mixture of High Frequency or Switch Start control gear depending on age. Opportunities exist for replacement with modern LED lamps and or fittings to provide savings in energy consumption of up to 60% depending on the type and age of luminaire. Most of the lighting in intermittently accessed rooms of the building was noted to be switched off at the time of the building survey, however some areas with higher staff throughout may benefit from the introduction of occupancy detection controls.

Utilising energy consumption data collected from the Logic Energy portal the aggregated energy consumption for artificial lighting was estimated to be 4,910kWh per annum which, at a cost hurdle rate of [redacted]MWh costs some [redacted]per annum. Replacing all 106 luminaires with modern LED equivalents (depending on technology chosen) is estimated to cost [redacted] providing, in simple payback terms, a 30year return on investment.

3.2.2 Building Fabric

A number of fabric intervention measures have been selected for the site, based on the building age and construction form/archetype. These include:

Location	**Intervention Measure**
Roof/loft	270mm Mineral fibre or equivalent
Roof/exposed metal	Sprayed insulation
Wall	External cladding
Windows	Secondary glazing

Alternative measures such as internally applied insulation were considered but the number of appliances fixed to walls and proximity of control cabinets to walls would cause significant disruption and reduced access resulting from internal volume reduction, such that they were not deemed tenable for this site.

One topic raised during discussion with the network operators was the safe distances and type of material utilised when undertaking such works (scaffolding, cladding) etc. This would require to be assessed by SSEN in conjunction with potential contractors and might reflect on pricing for the work.

For clarity, when considering the material intervention for the Main Control building, the spray insulation and mineral wool insulation are considered as separate interventions. Meaning, if a room had an exposed metal deck roof then the spray insulation was considered, if a room had a flat ceiling then mineral wool was considered. For the dynamic simulation model, only one roof intervention was applied to a room depending on its ceiling and roof arrangement.

A summary of the fabric intervention measures applied to each of the buildings is provided in Table 2 below.

Building	Intervention	Saving	Cost Saving	Unit Cost	Area	Total Cost	Payback	CO_2 Saving
		kWh/yr	£/yr	£/m^2	m^2	[redacted]	[redacted]	Tonne
275kV	Roof Insulation - mineral wool	12,860	[redacted]	[redacted]	169	[redacted]	[redacted]	4.52
	External Wall Insulation	11,236	[redacted]	[redacted]	157	[redacted]	[redacted]	3.95
			[redacted]	[redacted]		[redacted]	[redacted]	
Workshop	Spray roof Insulation	5,700	[redacted]	[redacted]	33	[redacted]	[redacted]	2.00
	External Wall Insulation	5,000	[redacted]	[redacted]	62.5	[redacted]	[redacted]	1.76
			[redacted]	[redacted]		[redacted]	[redacted]	
Main Control	Spray roof Insulation	3,864	[redacted]	[redacted]	45.5	[redacted]	[redacted]	1.36
	Roof Insulation - mineral wool	37,835	[redacted]	[redacted]	424.5	[redacted]	[redacted]	13.30
	External Wall Insulation	23,572	[redacted]	[redacted]	278.4	[redacted]	[redacted]	8.29
	Secondary Glazing	639	[redacted]	[redacted]	18.6	[redacted]	[redacted]	0.22

Table 2 Fabric intervention measures

3.2.3 Controls

The energy audit of the site, in conjunction with the monitored Logic Energy data, showed that a number of artificially lit zones across the site experience intermittent access and usage. These areas might benefit from the introduction of occupancy detection controls which, according to Good Practice Guide 312, can deliver saving of up to 50% in energy consumption. It is estimated that installing occupancy detection equipment in the SVC buildings, main control room and relay room could potentially deliver savings of up to 3,150kWh per annum at a cost of [redacted] Estimated costs for installing occupancy detection (depending on rewiring costs) is in the order of [redacted] providing a simple payback of 5.3 years.

Further control strategies could be applied to the heating systems in buildings in order to provide both comfort control for occupants as well as suitable environmental conditions for electrical control equipment and appliances. It was noted that many electrical heaters were operated on manual (hand) control, despite many having time controls fitted, and were thus operating 24hrs per day. Further analysis would be required in order to calculate the potential savings for applying close control to the different heating systems and significant potential exists to implement some form of building energy management control through the Logic Energy LeNet system in order to achieve this.

3.3 Alternative Technologies

An area that has not been explored in this study is the opportunity to adopt or apply alternative technologies for loss reduction in substations. These include onsite generation (e.g. solar PV) and the utilisation of rejected heat from site equipment for the heating of buildings.

The installation of solar PV technologies on substation sites (notably atop suitably oriented buildings) has the potential to displace locally that provided from the network. The main control building and 275kV building at Tealing for instance have approximately 510m^2 pitched roof area facing SSE. Depending on structural and any other site safety restrictions with regard to installation of such equipment, there exists a potential to install up to 50kWp of solar PV, which could potentially generate some 40,000kWh per annum depending on technology employed. An associated carbon reduction of 14tCO_2 might also be realised.

National Grid, in association with Siemens, have recently installed a 400kV transformer in north east London which has the potential to recover up to 1MW of waste heat from synthetic ester insulation via heat exchangers for the local community. Such technologies might be adopted when specifying new plant such that recovered heat could be utilised to mitigate losses.

4 Results

This study has reviewed the current energy usage patterns at Tealing Substation and identified a range of intervention measures suitable for the building archetypes on the site; these have included artificial lighting controls and luminaire replacement and a range of building fabric upgrades to mitigate electrical energy usage on site. A summary of the proposed measures are presented in Table 3 below together with indicative intervention costs and likely payback; based on the Ofgem investment hurdle rate of [redacted]

Table 3 Summary of cost savings calculated for intervention measures

The results from the study identify a hierarchy of intervention measures in respect of cost benefit and, following discussions with SSEN staff, identified lighting controls and roof insulation measures as being a priority target for investment. Utilising the above data a metric for application across a similar range of substation archetypes can be approximated to 161kWh/m^2 in achievable savings and 56kgCO_2/m^2 carbon reduction potential.

SSEN provided a list of transmission substations across which this metric was applied in order to gain an estimated quantification of losses reduction potential. A visual inspection of the buildings at the Tealing site, plus information provided by SSEN indicate that the 275kV and main control buildings were constructed circa

1960. Furthermore, the survey indicated that the walls were constructed of two layers of brick separated by an air cavity. This method of construction became common after the 1920s. It wasn't until the mid-1970s when levels of prescribed wall insulation were standardised, to conform to these standards a dense block inner leaf replaced the brickwork. Wall insulation standards improved significantly during the 1980's, when the inner blockwork was replaced by lightweight blockwork and the addition of insulation material was included into part of the air cavity.

The SSEN transmission substation database shows that 53 sites, excluding the Tealing site, have an estimated age of between 1930 and 1970; this dataset is divided as follows: 1930s n=2, 1940s n=0, 1950s n=23, 1960s n=28. These dates where assigned to the sites by SSEN based upon the earliest recorded procurement date of the equipment housed within those sites.

A desktop study, using Ordnance Survey's Digimap Roam tool, located 37 of the 53 transmission substations. The 37 sites held a total of 85 individual buildings, (mean = 2.3 buildings), the map in Fig. 5 illustrates the geographical spread of substation buildings which were investigated as part of this study. Google Street View images provided visual evidence to classify 47 (55%) of the 85 buildings as having a similar archetype which conforms to the age and era defined by SSEN, and therefore representative of the 2 control buildings at the Tealing site. Deeper observations indicated that the remaining buildings where added or heavily refurbished after 1970 and as such, they are considerably less likely to be architecturally representative of the 2 control buildings at the Tealing site. Therefore, the other 45% of buildings on these other sites were removed from the study.

Fig. 5 Geographical location of substations considered representative of those buildings at the Tealing site (Ordnance Survey Digimap.edina.ac.uk/roam 2018)

The total floor area (m^2) for each representative building was measured digitally using the Ordnance survey. The representative buildings ranged in size from $48m^2$ to $1716m^2$, with a total floor area of $13,131m^2$ (mean = 253 m^2, standard deviation = $284m^2$).

When normalised by the total floor area the baseline (without energy reduction interventions) energy consumption (lighting and heating) for the 275kV and main control buildings is $282kWh/m^2$/annum. If, all of the interventions for lighting and heating are applied to both of these buildings this would reduce the total energy consumption by 51% (to $137kWh/m^2$/annum).

The combined floor area for the 47 representative buildings plus the 2 Tealing buildings provides an estimated total floor area of $13,770m^2$. Extrapolating the baseline energy consumption data for the 2 Tealing site buildings over the total floor area provides an estimated 3.89GWh/annum for energy consumed by these buildings (including the 2 buildings at the Tealing site).

Applying the calculated 51% savings, as discussed for the 2 Tealing site buildings, to the extrapolated total energy consumption for all of the representative buildings reduces the 3.89GWh/annum consumption to 1.89GWh/annum.

These values are dependent on each building's operation; the set point temperatures assigned to the installed heating system; the building fabric and the presence and frequency of human visitors. The nature of this extrapolation considers the 47 buildings across the other sites to be operating under the same conditions as those at the Tealing site.

5 Conclusions

This study has reviewed the current energy usage patterns at a typical transmission network substation (Tealing) by utilising measured electricity consumption for building services provision (heating and lighting) and using this to calibrate building models in order to estimate the effects of applying intervention measures to mitigate energy losses. A narrow window for data capture and analysis in order to meet reporting deadlines has limited the study and it is recommended that a longer-term analysis of data be performed across a greater sample of sites in order to gain a statistically representative and more complete understanding of uncontrolled losses on such sites.

The study findings show that readily available intervention measures can be applied in order to achieve savings of up to 40,754kWh per building (averaged over n = 49) which, extrapolated across the SSEN network portfolio, could amount to potential losses reductions approaching 2.0GWh per annum, providing a cost saving of [redacted] per annum and an associated carbon reduction of 702tCO_2. It is therefore hoped that this study will help support the decision-making priorities for reduction of losses and environmental impacts within the network.

By applying the more readily accessible intervention measures, identified as lighting control and roof insulation, as a first stage in losses reduction then savings in the order of 1.24GWh (32%) might accrue with an associated cost saving of [redacted] and a carbon reduction potential of 434tCO_2 realised.

Bibliography

Good Practice Guide 312, The Government's Energy Efficiency Best Practice programme, BRECSU, 2001.