INITIAL ASSESSMENT OF REACTIVE POWER EXCHANGES AT UK GRID SUPPLY POINTS

Christos KALOUDAS
The University of Manchester – UK
christos.kaloudas@manchester.ac.uk

Luis F. OCHOA
The University of Manchester – UK
luis_ochoa@ieee.org

Ben MARSHALL
National Grid – UK
ben.marshall@nationalgrid.com

Shanti MAJITHIA
Energy & Climate Advisory Services – UK
shanti.majithia@hotmail.com

ABSTRACT

In 2011-2012, the UK transmission system operator, National Grid, reported more than 160 voltage excursions in the 400 kV system. Given its close correlation with the national decline in reactive power demand seen during minimum load (i.e., decline in Q/P ratio), it is crucial to understand the corresponding trends to identify cost-effective measures. Understanding the Q/P ratio trends is also of importance to distribution network operators due to the forthcoming European Demand Connection Code that will potentially enforce distribution operators having reactive power exchanges at the interface with transmission, i.e., at the Grid Supply Point (GSP), limited across normal operation, with the design of new networks requiring no export or reactive power during minimum load,. This work presents a thorough analysis of the Q/P ratio trends at GSPs across Great Britain considering yearly and half-hourly demand data from 2005 to 2012 provided by National Grid. In addition, indices are proposed to identify critical GSPs based on the level of reactive power decline and relative size.

INTRODUCTION

National Grid, the UK transmission system operator, has reported 165 voltage excursions in the 400 kV system within 2011-2012 [1]. This number is far larger than the corresponding ones of previous years and has lead to increasing levels of constraint action on the transmission system, both of network availability and of bringing on otherwise unavailable generation where possible in an attempt to mitigate the high voltage resulting upon the transmission voltage as a result of the reactive power export at the transmission/distribution interface. According to National Grid Ten Year Statement [2], the factors leading to voltage excursions may vary from the increased use of cables in transmission networks and the lack of voltage control at some transmission network areas to the reduction of reactive power (Q) demand during periods of minimum load. Focusing on the latter factor, National Grid has recorded nationwide a reduction of the Q/P ratio during minimum load [2]. Indeed, reactive power demand during minimum load decreased from approximately 7.5 GVAr nationwide in 2005 to 2.1 GVAr in 2013. The corresponding decline for active power demand was not proportional, decreasing from circa 22 GW to 18 GW.

National Grid combines different voltage control techniques to maintain statutory voltage levels in transmission networks. Power plants, particularly among those operating in the South, are used to absorb reactive power during periods of minimum demand and the switching of circuits is used to decrease injection of reactive power from capacitive lines [2]-[3]. Shunt reactors and Static VAR Compensators (SVCs) are also used to absorb reactive power during minimum demand [2]-[3].

It is crucial for National Grid to understand the trends of the decline in reactive power demand during minimum load to identify cost-effective measures and responsibilities for ongoing planning and operational management in voltage control practices. The understanding of these trends is also of importance to Distribution Network Operators (DNOs) as they also are seeing real voltage containment challenges within their networks with the additional technical challenges of complying with the forthcoming European Demand Connection Code [4], which limits exchanges of reactive power between transmission and distribution operationally and requires new distribution networks to be designed to not export reactive power at the transmission/distribution interface for loadings up to the 25% of the peak MW load at that interface.

Grid Supply Points (GSPs) are the interface of transmission and distribution networks in the UK. The reasons behind a possible trend for GSPs to present less inductive or even more capacitive behavior during minimum load may vary. Industrial recession, the extended installation of cables in some distribution networks, extensive use of equipment with less inductive or even capacitive power factor (i.e., lighting devices) and distributed generation are some of the possible factors influencing this trend.

This work presents a thorough analysis of the Q/P ratio trends during minimum load at GSPs across all license areas of the 6 DNOs operating in Great Britain (ENWL, NP, SPEN, SSE, UKPN, WPD). Ranking indices are also proposed to identify critical GSPs based on the level of reactive power decline and relative size.

First, yearly demand data provided by National Grid from 2005 to 2012 is used to rank how critical is each GSP across different DNO areas. The proposed indices are adopted to select the top 10 critical GSPs per DNO (60 GSPs in total). Next, the analysis is carried out on the selected GSPs using half-hourly demand data provided by National Grid from 2009 to 2012.

Seasonal analysis results are obtained allowing a better insight in the decline trend of Q/P ratios and reveal the adequacy of using the proposed indices for the selection of critical GSPs. Specifically, critical weeks of low Q/P ratios are identified per season and the decline trend of Q/P ratios from 2009 to 2012 for these weeks is presented. Further analysis using ordinary linear regression to approximate Q/P ratios for summer and winter weeks from 2009 to 2012 are obtained, indicating a dominant decline trend of Q/P ratio.

Finally, the correlation of periods of low Q/P ratios with the appearance of maximum voltages at 132 kV buses of GSPs (most distribution networks 'start' at this point) is examined from a time perspective. Given the existing headroom (i.e., taps) for voltage regulation at GSPs, results show that, to date, the declining trend of Q/P ratios has limited correlation with the recorded maximum voltages at 132 kV busbars. This, however, could significantly change in the near future.

CRITICAL GRID SUPPLY POINTS

In this section the proposed indices for the selection of critical GSPs across all DNOs operating in Great Britain are described. Due to the different geographical characteristics and different mixes of domestic and industrial customers per DNO, the analysis is conducted independently for every DNO area.

Proposed Indices to Identify Critical GSPs

To select the critical GSPs, a total number of 336 GSPs across all 6 DNOs in Great Britain are first examined using P and Q data recorded by National Grid from 2005 to 2012. Each P-Q set corresponds to the average yearly value of the three minimum load (active power) conditions of the system. Using this data, the following three normalised indices ranging from 0 to 1 are proposed:

- Q/P 2012 index: A value of 1 accounts for the most critical GSP exhibiting the lowest Q/P ratio in 2012.
- Q/P decline index: This index takes into account the decrease of Q/P ratio from 2005 to 2012. For this index, a value of 1 accounts for the most critical GSP in terms of exhibiting the most significant decrease of Q/P ratio during the last 7 years.
- P index: This index takes into account the relative size of each GSP during minimum load (within the DNO). A value of 1 accounts for the largest GSP in terms of highest demand of active power.

These three indices are then combined into a triple index which considers them all using a 1/3 weighting factor for each of them. The 10 GSPs with the highest triple index are selected for each of the 6 DNOs.

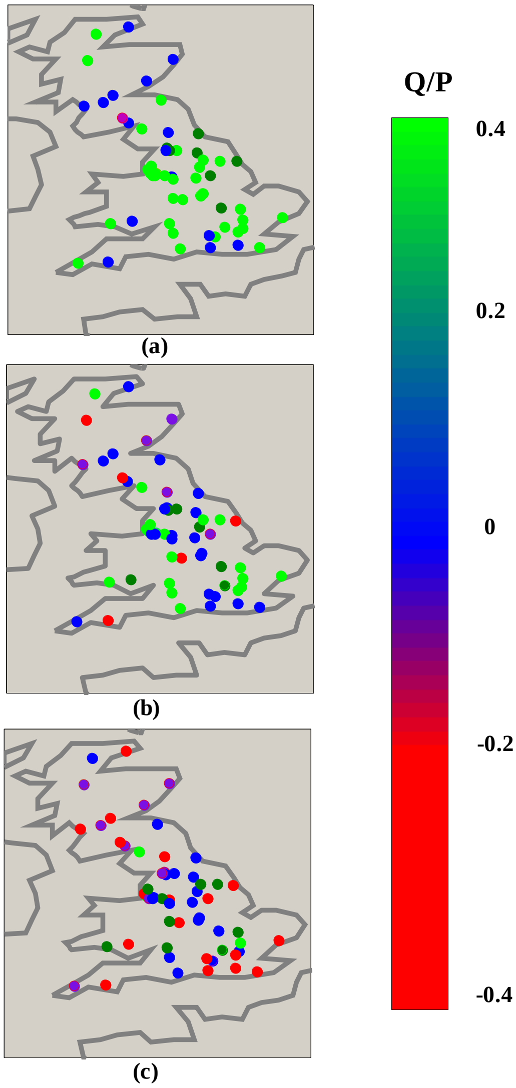

Fig. 1. Reactive power to active power ratios (Q/P ratios) during minimum load across Great Britain for a) year 2005, b) year 2010 and c) year 2012.

Initial Analysis on Q/P Ratio Trends

Using the yearly demand data provided by National Grid, the trends of reactive power demand for the 60 selected critical GSPs have been investigated. Fig. 1 depicts the Q/P ratios during minimum load across the top 10 GSPs per DNO in Great Britain from 2005 to 2012. It is evident from these figures that the 60 critical GSPs have significantly changed their mostly inductive behaviour (i.e., absorbing reactive power from the transmission network) from 2005 to a more capacitive behaviour (i.e., injection of reactive power) or closer to unity power factor.

Having adopted the proposed indices to identify the critical GSPs across all DNOs in Great Britain using yearly data, half-hourly demand data also provided by National Grid for years 2009-2012 was used to refine the corresponding analysis. Using a similar approach to that of National Grid, the P, Q and Q/P ratios for the average of 3 minimum active power demand conditions are assessed for all critical GSPs. Fig. 2 and Fig. 3 show P, Q and Q/P results for a GSP in the South West of Great Britain during minimum load using yearly and monthly resolution. This GSP exhibits a maximum demand of 470-480 MW, whereas during minimum load conditions absorbs 120-230 MW. As it can be seen in Fig. 2, this GSP exhibits a continuous decline to even more capacitive yearly Q/P ratios.

The monthly analysis presented in Fig. 3 for the same GSP in 2012 reveals that reactive power injections occur in all months during minimum load conditions. However, in this case, Q/P ratios are influenced by seasonal load levels during minimum demand.

SEASONAL ANALYSIS

Since the performance of distribution networks during minimum load depends on seasonal circumstances, the analysis on the critical GSPs is carried out independently for every season. Weekly resolution is used on half-hourly demand data for years 2009-2012. Starting from 1st January (week 1), weeks 1-9 and 49-52 correspond to winter, weeks 10-22 to spring, weeks 23-35 to summer and weeks 36-48 to autumn.

Identification of Critical Periods

The critical periods per season are the weeks that exhibit the lowest inductive or even capacitive Q/P ratios during minimum load for years 2009 to 2012. Having calculated the Q/P ratios for every week, the 4 weeks with lowest Q/P ratios per season are recorded for every GSP. This process is followed for each of the years 2009 to 2012 and each of the selected 60 critical GSPs. Based on the recorded 4 critical weeks per GSP per season, a comparison among all 60 critical GSPs is carried out for all the years simultaneously. The 3 most frequent weeks are then identified and shown in Table I.

Taking into account the difference of Q/P ratio values from 2009 to 2012 for the identified critical weeks included in Table I, it is possible to assess the corresponding trend in Q/P ratios. Table II summarizes the proportion of GSPs that during the identified critical weeks exhibit in 2012 a lower inductive or even more capacitive Q/P ratio compared to the corresponding of 2009. All weeks have more than 65% of the GSPs with declining Q/P ratios.

Linear Regression Analysis

Taking into account all weeks per season from 2009 to 2012, the declining trend of Q/P ratios during minimum load is examined in this section. Each season consists of 13 weeks, thus a total of 52 weeks per season for each of the analysed years (2009 to 2012). A linear regression analysis was carried out using the least squares approach to fit the weekly Q/P ratios. Fig. 4 and Fig. 5 show the linear fitting of the calculated Q/P values during summer weeks for a London area GSP during winter weeks and a GSP in East Midlands (central Great Britain), respectively. A declining trend of seasonal Q/P ratios from 2009 to 2012 is evident in both cases.

Fig. 6 shows the corresponding linear fittings derived for winter weeks of years 2009-2012 for all 10 critical GSPs of a DNO that operates in the south of Great Britain. All examined GSPs, apart from one, present a declining trend of Q/P ratios during minimum load.

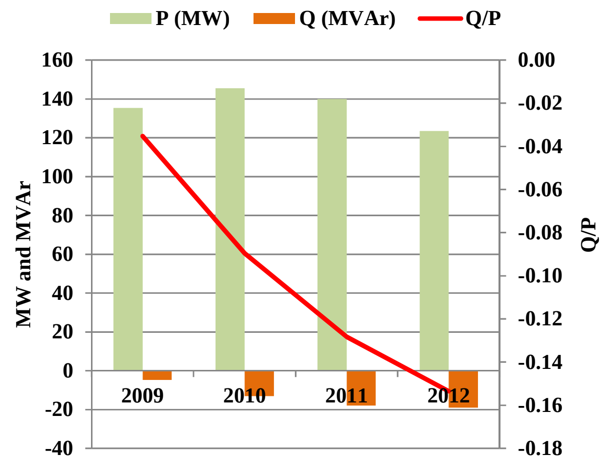

Fig. 2. Yearly analysis results for a GSP in South West of Great Britain.

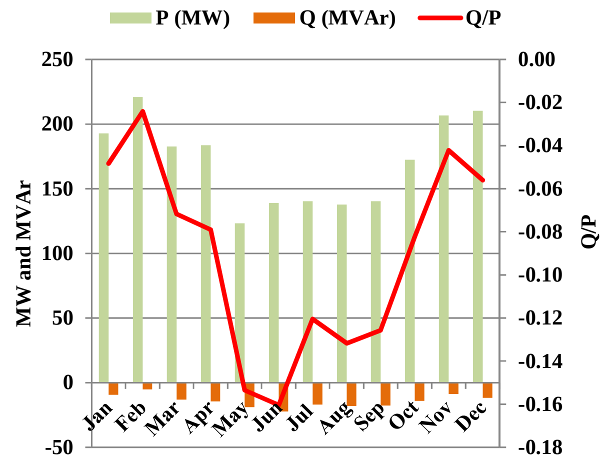

Fig. 3. Monthly analysis results for a GSP in South West of Great Britain for year 2012.

Table I Selected critical weeks per season

Season	Weeks
Winter	*1, 50, 52*
Spring/Autumn	*21, 22, 37*
Summer	*24, 25, 31*

Table II GSPs with reduced Q/P ratios from 2009 to 2012

Winter		Spring/Autumn		Summer	
week	GSPs(%)	week	GSPs(%)	Week	GSPs(%)
1	*80.0*	21	*65.0*	24	*73.3*
50	*76.7*	22	*68.3*	25	*73.3*
52	*90.0*	37	*71.7*	31	*78.3*

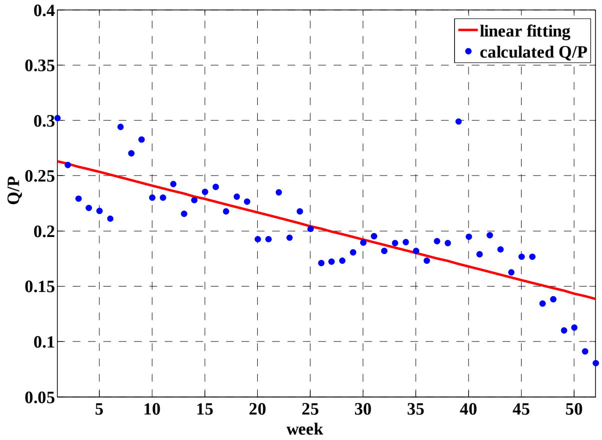

Fig. 4. Fitting of weekly Q/P ratios of a London area GSP during summer for years 2009-2012.

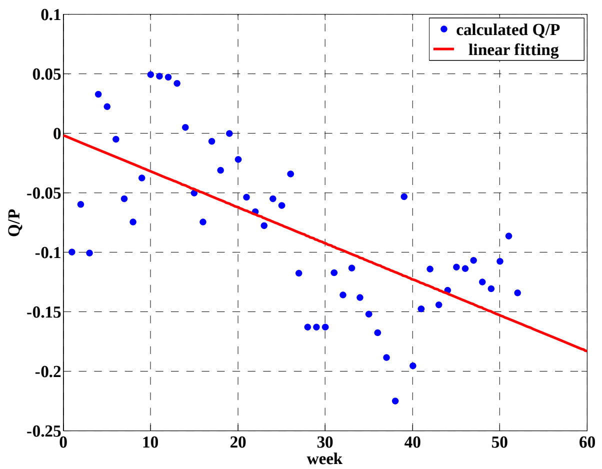

Fig. 5. Fitting of weekly Q/P ratios of a GSP in East Midlands during winter for years 2009-2012.

Four GSPs exhibit a less inductive behaviour in 2012 approaching zero Q/P values compared to winter weeks of previous years. Additionally, five GSPs tend to be more capacitive having even lower negative Q/P ratios.

Following the same approach, for all selected critical GSPs across Great Britain for years 2009-2012, 83.3 % and 85 % of the GSPs exhibit a declining trend in Q/P ratios during winter and summer weeks, respectively. This dominant declining trend of Q/P ratios reveals that the proposed indices were sufficient in identifying critical GSPs across different DNO areas.

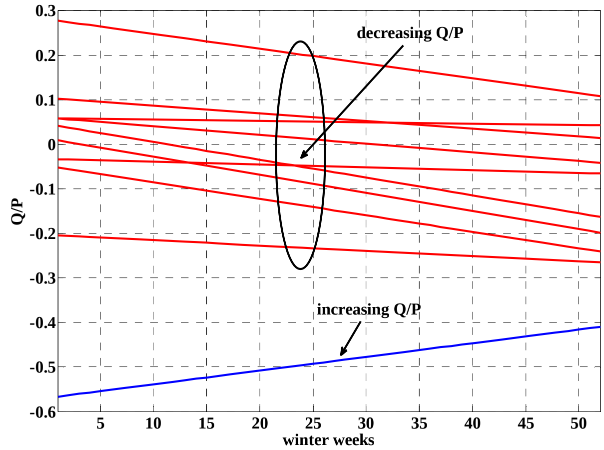

Fig. 6. Linear fitting approximations of Q/P ratios of all 10 selected GSPs of the same DNO (South of Great Britain). Results during winter weeks of years 2009-2012.

Table III. Top 10 weeks of a GSP in London area

Criterion	Top 10 Weeks
Min Q/P	*24, 28-29, 39-43, 51-52*
Max Voltage for SGT1	*1-6, 12-15*
Max Voltage for SGT2	*3, 8 ,12, 15-18, 20-22*
Max Voltage for SGT3	*1-6, 24-29*
Max Voltage for SGT4	*3, 12-13, 15-18, 20-22*
Max Voltage for SGT5	*3, 12-13, 15-18, 20-22*

CORRELATION WITH VOLTAGE

In this section, the correlation between voltage magnitudes at 132 kV buses of GSPs with the corresponding Q/P ratios during minimum load is examined from a time perspective (most distribution networks in the UK cover the circuits from the 132 kV buses of GSPs downstream). Half-hourly voltage data at 132 kV buses of all 400/132 kV and 275/132 kV supergrid transformers (SGTs) of the 60 critical GSPs have also been made available by National Grid.

Table III shows the top 10 weeks during 2012 for a London area GSP that exhibit the lowest Q/P ratios during minimum load and the maximum voltages at the 132 kV buses of the corresponding SGTs. The examined GSP consists of five SGTs and has an 800-900 MW demand during peak load. From a time perspective, results indicate there is no correlation between Q/P ratios and the appearance of maximum voltages (the lowest Q/P ratios appear after week 24 and maximum voltages before week 22 for all SGTs).

Fig. 7 shows the maximum voltages of 132 kV buses of SGT2 and SGT3 of the same London area GSP during 2009 and 2012 using weekly resolution. From a time perspective, there is no correlation of maximum voltages for adjacent SGTs with the top 10 weeks found to have minimum Q/P ratios.

Similar results to Table III and Fig. 7 that indicate no correlation of minimum Q/P ratios and maximum voltages have been obtained for the rest of GSPs. Consequently, the voltage magnitudes at the 132 kV busbars cannot be directly correlated with the GSP reactive power demand during minimum load. This is consistent with the fact that voltage regulation, by means of on-load tap changers at SGTs, is still effective (i.e., there is headroom in terms of taps).

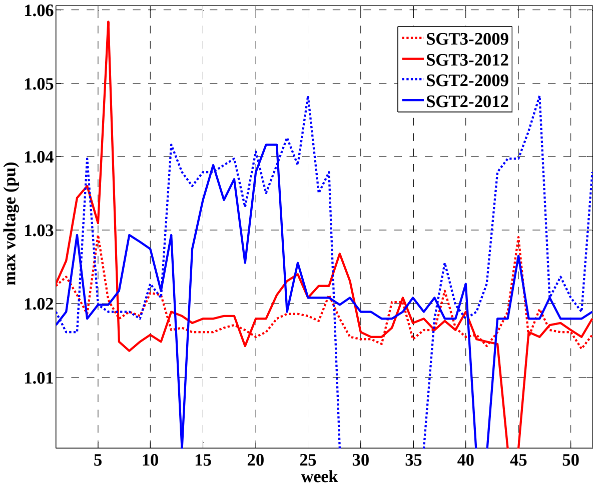

Fig. 7. Maximum voltages at 132kV buses of two supergrid transformers of a GSP in London area.

CONCLUSIONS

In this paper, an initial assessment of reactive power exchanges during minimum load at the Grid Supply Points (GSPs), the interface between transmission and distribution networks in the UK, was carried out. Yearly and half-hourly demand data provided from National Grid for years 2005-2012 was analysed. The trends of Q/P ratios at GSPs across all Distribution Network Operators (DNOs) in Great Britain were thoroughly investigated. Indices were also proposed to identify critical GSPs based on the level of reactive power decline and relative size.

The initial analysis of GSPs across Great Britain revealed that the declining trend of Q/P ratios is significant and not particularly localised. In addition, from 2005 to 2012, many GSPs are no longer absorbing reactive power during minimum demand but injecting to the transmission network, thus worsening the problem.

The proposed indices were used to identify the top 10 critical GSPs for each of the 6 DNOs operating in Great Britain. A more detailed seasonal analysis of the critical GSPs, including critical weeks from 2009 to 2012 and a linear regression analysis, revealed the strong declining trends of their Q/P ratios, thus confirming the adequacy of the indices. Consequently, further studies and modeling can be carried out on the selected GSPs in order to understand the factors affecting the reduction in reactive power demand during minimum load.

In terms of voltages at the transmission-distribution interface (132kV busbar), no correlation was found between maximum voltages and the corresponding Q/P ratios during minimum demand. This is consistent with the fact that voltage regulation, by means of on-load tap changers at SGTs, is still effective (i.e., there is headroom in terms of taps). This, however, could significantly change in the near future with even further declines in the Q/P ratios and limited resources to manage voltages in the transmission network.

ACKNOWLEDGEMENTS

This work has been funded by National Grid and the 6 DNOs in Great Britain: Electricity North West Limited (ENWL), Northern Powergrid (NP), Scottish Power Energy Networks (SPEN), Scottish and Southern Energy (SSE), UK Power Networks (UKPN) and Western Power Distribution (WPD), through the “Reactive Power Exchange Assessment and Characterisation (REACT)” project. In addition, the authors would like to thank the support of National Grid for making available the corresponding data.

REFERENCES

[1] National Grid, “National Electricity Transmission System Performance Report 2012-13”. [Online]. Available: http://www2.nationalgrid.com/WorkArea/

[2] National Grid, “2013 Electricity Ten Year Statement”, Nov. 2013. [Online]. Available: http://www2.nationalgrid.com/UK/Industry-information/Future-of-Energy/Electricity-ten-year-statement/Current-statement/

[3] National Grid, “The Grid Code”, *Issue 5*, *Revision 6*, Dec. 2013. [Online]. Available: http://www2.nationalgrid.com/UK/Industry-information/Electricity-codes/Grid-Code/

[4] ENTSO-E., “Draft Demand Connection Code”, 2012. [Online]. Available: https://www.entsoe.eu/resources/network-codes/demand-connection/