EFFECTS OF SUPPLY-SECURITY-BASED DISTRIBUTION NETWORK RENOVATION ON CUSTOMER INTERRUPTION COSTS AND ALLOWED REGULATORY PROFIT IN FINLAND

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ABSTRACT

This paper considers development of customer interruption costs (CIC) in three Finnish rural area electricity distribution companies in the following 15 year time period that is the time span of the supply security development plans each Finnish distribution system operator (DSO) has prepared. Requirement for supply security plans are due to new legislation reform targeting secure electricity distribution in major storms.

The consideration shows that CIC reduce significantly, and thus so called quality incentive related to Finnish regulatory model provides quality bonus that increases allowed regulatory profit of the DSOs. Furthermore the effect of CIC development on the performance of economic regulation has been analysed.

INTRODUCTION

The paper studies the effects of supply security based electricity distribution network renovation on customer interruption costs (CIC) of rural area distribution system operators (DSOs) and furthermore the effects of CIC development on allowed regulatory profit of the Finnish DSOs according to Finnish regulatory model. Supply security requirements have been tightened in Finland, especially when the new Electricity Market Act 588/2013 was established [1]. A partial reason for new law was intensive discussion as consequence of several storms causing long customer interruptions in Finland especially during years 2010 and 2011 (Figure 1). In the act the maximum allowed duration of customer experienced interruptions were limited to 6 hours in urbanized areas and to 36 hours in other areas. Thus, DSOs have to develop their networks so that the limits do not exceed. The development of the network can reduce CIC significantly, and thus, the regulatory effects should be evaluated.

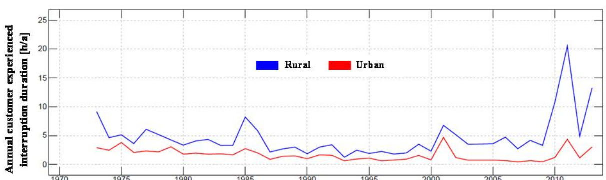

Figure 1. Statistics of customer experienced interruption durations in Finland [2].

Reduced customer interruption costs influence on allowed regulatory profit. In Finland the regulatory model, that evaluates the allowed profit of the DSOs, consists of different method blocks, of which one is so called *quality incentive* that considers development of CIC [3]. *Quality incentive* contains factors that effect on the quantity of the quality incentive, either bonus or sanction. For instance, at the present regulatory model the maximum volume of quality incentive is restricted to 20 % of the reasonable return on capital that depends on the calculatory net present value (NPV) of the network. Thus, there is an opportunity that the CIC can reduce so much that the quality bonus is permanently limited. The paper evaluates how the *quality incentive* behaves with the estimated development of CIC.

Background data of distribution networks

The study is based on real network data and long-term development plans of Finnish DSOs PKS Sähkönsiirto Oy (PKS Sähkönsiirto), Parikkalan Valo Oy (Parikkalan Valo) and Oulun Seudun Sähkö Verkkopalvelut Oy (Oulun Seudun Sähkö). Figure 2 shows the DSOs operating in Finland.

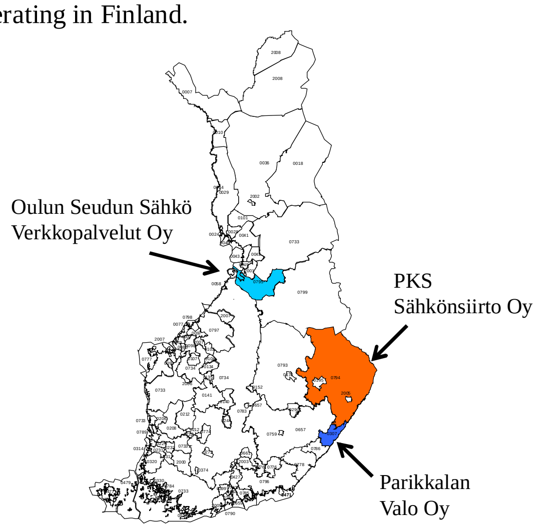

Figure 2. Finnish distribution system operators in the study.

In the Finnish scale PKS Sähkönsiirto is rather big DSO (90 000 customers), Oulun Seudun Sähkö is medium size DSO (30 000 customers) and Parikkalan Valo is small size DSO (10 000 customers). The size of the company and the network structure partially determine with the geographical location the sensitivity and preparedness of the DSOs to face events causing customer interruptions that influence significantly on measured CIC. For instance, within the last 10 years several storms have struck on the network of Parikkalan Valo causing massive CIC for few years. The neighbouring DSO PKS Sähkönsiirto has also experienced many of the same storms but the bigger size has levelled the influences. At the same time the network of Oulun Seudun Sähkö has not suffered as much as the other DSOs in the study. The main reason for this is probably the geographic location of the company. Figure 3 presents actual customer interruption cost statistics in one of the considered DSOs, PKS Sähkönsiirto. The statistics show the nature of CIC that it may fluctuate significantly between the years as it has been occurred in year 2011.

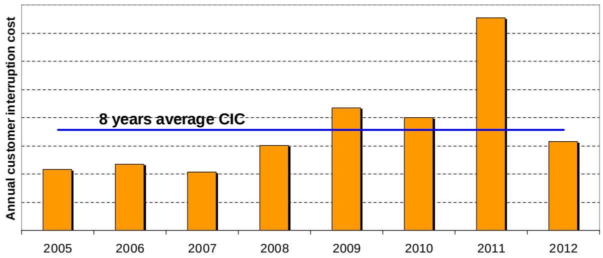

Figure 3. Customer interruption cost statistics in one of the analysed DSOs, PKS Sähkönsiirto Oy [4].

In each case the network renovation plan has made so that it fulfils supply security requirements in 2028. Even the time period seems to be rather long, massive and time consuming investments are needed.

Present state supply security of the DSOs varies considerably that affects the extent of the supply security investments. The study is based on actual distribution network models. The modelled networks consist of two or three substation areas containing the high-voltage/medium-voltage substation, medium-voltage network, medium-voltage/low-voltage substations and low-voltage network.

ECONOMIC REGULATION IN FINLAND

In Finland, the electricity distribution regulatory consists of different method blocks that are named to different incentives, which either increase or decrease the allowed revenue [3]. For instance, the model includes *quality incentive* that provides reward for DSO if reliability of supply improves, *efficiency incentive* that controls the improvement of network operational costs, *investment incentive* that increases the allowed revenue with the value of depreciation of network components, *innovation incentive*, *supply security incentive* and finally *reasonable return on capital* that determines profit that the present network asset provides for the DSO. The basic scheme of the Finnish regulatory model is presented in Figure 4.

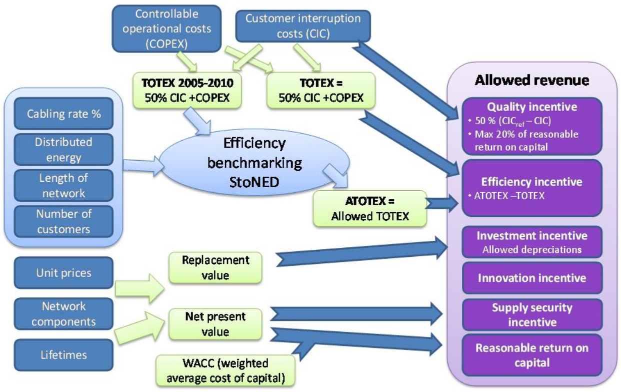

Figure 4. Description of Finnish regulatory model applied in 2012–2015.

Quality incentive

A quality bonus or a sanction is determined in the Finnish regulatory model by using customer interruption costs (CIC), which are calculated from unit costs and interruption statistics. The unit costs are based on a customer interruption cost survey published in 2005. Interruption statistics that are applied in the interruption cost calculation comprise sustained interruptions, consisting of both unannounced and announced interruptions, and momentary interruptions, including high-speed automatic reclosings (HSAR) and delayed automatic reclosings (DAR). Furthermore, sustained interruptions have been divided to unit cost of a number of interruptions (€/kW) and the duration of interruptions (€/kWh). The interruption unit costs applied in Finland are presented in Table 1.

Table 1. Interruption unit costs applied in the Finnish regulatory model in the monetary value of 2005 [3].

Unannounced interruptions		Announced interruptions		HSAR	DAR
[€/kW]	[€/kWh]	[€/kW]	[€/kWh]	[€/kW]	[€/kW]
1.1	11	0.5	6.8	0.55	1.1

The bonus or sanction is calculated from the actual annual customer interruption costs that are compared with the reference level of customer interruption costs (CIC_{ref}) based on a historical average of customer interruption costs. The quality bonus is calculated so that the actual CIC are subtracted from the reference level. Because of the symmetry of the bonus system, the bonus can be either positive or negative (sanction).

$$\text{Quality bonus} = \left(CIC_{\text{ref}} - CIC\right) \cdot 50\,\% \,. \tag{1}$$

The CIC in year t are calculated in the value of year k using actual interruption values based on actual interruption statistics

$$CIC_{t,k} = \frac{W}{8760}\begin{pmatrix} c_{\text{u}} \cdot n_{\text{u}} + c_{\text{a}} \cdot n_{\text{a}} + c_{\text{ud}} \cdot d_{\text{u}} + \\ c_{\text{ad}} \cdot d_{\text{a}} + c_{\text{hsar}} \cdot n_{\text{hsar}} + c_{\text{dar}} \cdot n_{\text{dar}} \end{pmatrix} \cdot \frac{CPI_{k-1}}{CPI_{2004}}, \tag{2}$$

where

$CIC_{t,k}$	customer interruption costs in year *t* in the value of year *k*
W	annual distributed energy of the DSO (kWh/a)
c_u	unit cost for unannounced interruption (€/kW)
c_a	unit cost for announced interruption (€/kW)
c_{ud}	unit cost for unannounced interruption duration (€/kWh)
c_{ad}	unit cost for announced interruption duration (€/kWh)
c_{hsar}	unit cost for high-speed autoreclosing (€/kW)
c_{dar}	unit cost for delayed autoreclosing (€/kW)
n_u	customer's average annual number of interruptions weighted by annual energies, caused by unannounced interruptions in the 1–70 kV network in year *t*, number
n_a	customer's average annual number of interruptions weighted by annual energies, caused by announced interruptions in the 1–70 kV network in year *t*, number
d_u	customer's average annual duration of interruptions weighted by annual energies, caused by unannounced interruptions in the 1–70 kV network in year *t*, hour
d_a	customer's average annual duration of interruptions weighted by annual energies, caused by announced interruptions in the 1–70 kV network in the year *t*, hour
n_{hsar}	customer's average annual number of interruptions weighted by annual energies, caused by high-speed automatic reclosings in the 1–70 kV network in year *t*, number
n_{dar}	customer's average annual number of interruptions weighted by annual energies, caused by delayed automatic reclosings in the 1–70 kV network in year *t*, number
CPI_{k-1}	consumer price index in year *k*-1
CPI_{2004}	consumer price index in year 2004

In the regulatory model, the CIC affect the quality bonus so that todays' interruption costs are compared with the historical average of interruption costs, which are the reference level for the present actual interruption costs. The reference level of the CIC is calculated as

$$CIC_{\mathrm{ref},k} = \frac{\sum_{t=2005}^{2010}\left(CIC_{t,k}\cdot\left(\frac{W_k}{W_t}\right)\right)}{6}, \tag{3}$$

where

$CIC_{\mathrm{ref},k}$	reference customer interruption costs for year *k*
$CIC_{t,k}$	actual customer interruption costs in year *t* in value of year *k*
W_k	annual supplied energy in year *k* (kWh/a)
W_t	annual supplied energy in year *t* (kWh/a)

Restriction of quality incentive

In the present regulatory model the influence of the quality incentive is limited in two ways: first, only 50 % of the difference between the actual and reference CIC is included in the quality bonus, and secondly, the maximum of the bonus or sanction is limited to 20 % of the reasonable return on capital that defines the floor or top of the quality bonus. Thus, if the allowed return on capital is close to zero for some distribution company, the quality bonus or sanction is also limited to zero.

The reasonable return on capital is basically calculated from the net present value of the network (NPV). In that case the NPV is multiplied by allowed rate of return that is the percentage of weighted average cost of capital (WACC). The equations related to calculation of restricted maximum quality incentive are as follows:

$$\text{Reasonable return} = NPV \cdot WACC \tag{4}$$

$$\text{Restriction} = \text{Reasonable return} \cdot 20\%. \tag{5}$$

Because of the connection of quality bonus to return on capital, quality bonus is dependent on WACC. Figure 5 presents development of WACC that determines the return on capital. The figure shows, that allowed rate of return (WACC) has been around 3%, since year 2013. It can be observed that the effect of WACC can be essential on achieved quality bonus, because when WACC is low, maximum possible quality bonus is also low.

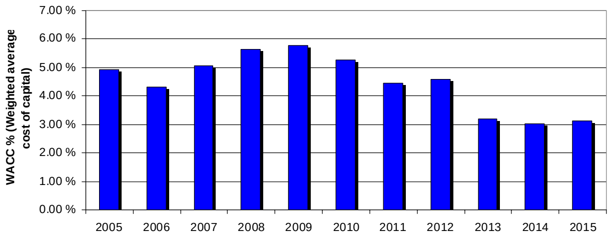

Figure 5. Development of WACC within years 2005–2015 in economic regulation of Finnish electricity distribution.

Assessment of quality incentive

Figure 6 presents different parameters affecting quality incentive (reference of CIC, estimated annual CIC, top of quality bonus and floor of quality bonus). The floor and top of quality bonus are calculated:

$$\text{Floor} = CIC_{\mathrm{ref}} - \text{Restriction} \tag{6}$$

$$\text{Top} = CIC_{\mathrm{ref}} + \text{Restriction} \tag{7}$$

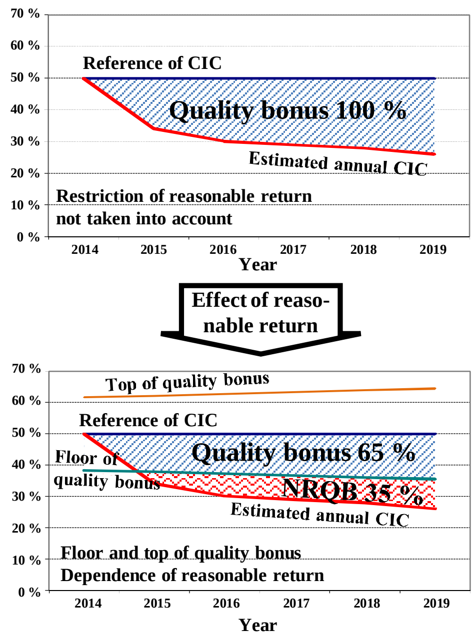

Figure 6. Example where part of quality bonus is not realized (area NRQB) because of restriction.

The figure illustrates an example, where the quality bonus is restricted as consequence of reached maximum bonus. In this case the annual CIC crosses the floor level of quality bonus. It can be observed, that the amount of quality bonus is 65% of the difference between reference and annual CIC that leaves 35% for the not realized quality bonus that is a considerable proportion.

DEVELOPMENT OF CUSTOMER INTERRUPTION COSTS

Development of customer interruption costs (CIC) have been analysed with real electricity distribution networks of three Finnish DSOs, which are PKS Sähkönsiirto, Parikkalan Valo and Oulun Seudun Sähkö. In each modelled network the analysis is based on long-term development strategies, which objectives are to fulfil the requirements of the law and authorities that means in case of most DSOs considerable improvement in electricity supply security. For instance, the development plans aim to reduce effects of storms on weather sensitivity. That means often either transition of the present overhead lines from the forest next to roadsides or cabling of present overhead lines. Also the network strategies include wide utilisation of network automation that typically provides fast impact on CIC. Thus, trend of customer interruption costs is estimated to be decreasing in the near future, which can be observed in Figure 7 that shows the estimated CIC development in the case DSOs.

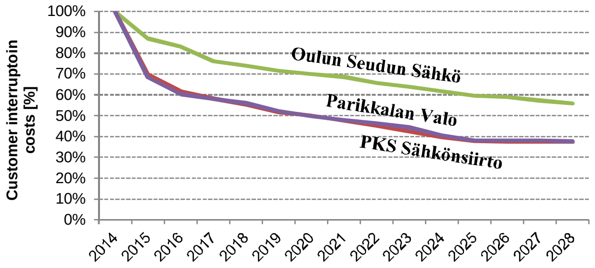

Figure 7. Estimated development of customer interruption costs of considered Finnish DSOs.

The CIC curves are almost similar in two of the DSOs, in which the value of year 2028 is about 40% of the present CIC (100%). In the case of the third DSO the CIC do not reduce as much as in the two others but however the CIC is about 55% of the present CIC value at the end of consideration period.

Assessment of regulatory quality incentive

Development of quality bonus within the next 15 years is considered with the networks of Finnish DSOs with the scheme of present regulatory model. The base parameters affecting this consideration are the weight of CIC that influences on quality bonus i.e. reference of CIC and actual CIC. In the present regulatory model 50% of CIC is taken into account in *quality incentive*. Other important parameters are the maximum percentage of allowed reasonable return on capital, allowed rate of return (WACC) and length of calculation period affecting reference of CIC. These parameters determine together the floor level of quality bonus. In the present regulatory model the maximum impact of quality bonus is restricted to 20% of return on capital, WACC is around 3% that is assumed to remain same through the consideration period and calculation period of CIC reference is 6 years that remains constant each four year period that has been the length of previous regulation periods. The CIC reference of the first years has been calculated from the present state annual estimate (CIC of 2014) in the case of PKS Sähkönsiirto and Oulun Seudun Sähkö because the actual CIC of the modelled network is not known. In the case of Parikkalan Valo, the CIC history of the modelled network is known, and it is used to determine the CIC reference for the first years (2014–2019). Figure 8 illustrates the development of quality bonus in the near future with the estimated annual CIC that describes the CIC with 50% probability.

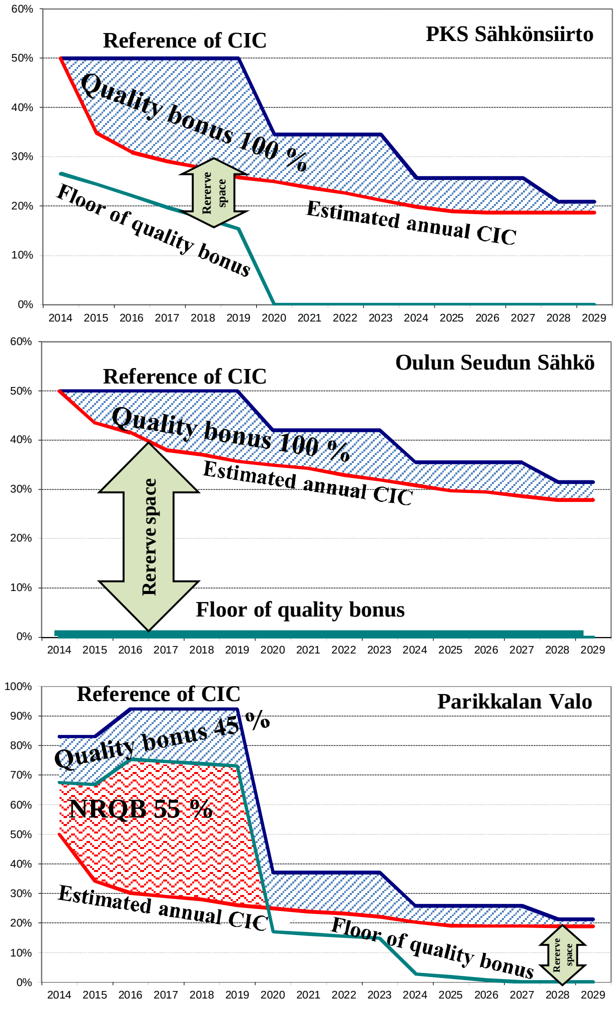

Figure 8. Estimated quality bonus of three Finnish DSOs with the present regulatory model, where 50% of CIC is taken into account in regulatory model and floor of quality bonus is 20% of reasonable return on capital.

It can be observed that in the case of PKS Sähkönsiirto and Oulun Seudun Sähkö quality bonus is not restricted because of the empty space between the curves of *Estimated annual CIC* and *Floor of quality bonus*. Oulun Seudun Sähkö forms a special case where the floor level is at zero that indicates low importance of CIC in the distribution business. This means that even the annual CIC would be zero that means no interruptions; the quality bonus can still be earned 100%. When the floor level is not zero, there is a risk that quality bonus is restricted, because the actual annual CIC can fluctuate significantly depending on weather related and other interruptions (see Figure 3). It can be noticed that in case of PKS Sähkönsiirto fairly a minor decrease in annual CIC can cause crossing of the floor level, because at the first years the quality bonus floor seems to remain fairly close to estimated annual CIC.

In the case of Parikkalan Valo the proportion of quality bonus is only 45% and proportion of not realised quality bonus (NRQB) is the rest 55% of the difference between reference and annual CIC. It can be noticed that, already at the beginning of the consideration period at year 2014, the reference of CIC is considerably higher than the estimated CIC. This is consequence of extremely high CIC at year 2010 caused by severe storms. With the present regulatory model the effect of the storm remains in the CIC reference to the end of the next regulatory period that is the end of year 2019. The high proportion of not realised quality bonus means that before 2020 the *quality incentive* of regulatory model does not give any incentive to decrease CIC. The consideration shows that already the present estimated annual level of CIC provides the maximum quality bonus because of the restriction of quality incentive.

Discussion

The considered case examples of the Finnish DSOs show that the effect of quality incentive is highly dependent on the floor or the top level that is determined by the reasonable return on capital that restricts the amount of incentive (bonus or sanction) to 20% of the reasonable return. With the present regulatory model the restriction cuts even 55% of the quality bonus (the difference between annual CIC and reference of CIC) in case of Parikkalan Valo. On the other hand the extremely high CIC reference indicates that CIC reference may fluctuate significantly as consequence of single year high CIC caused by major events. Thus, if the proportion of not realised quality bonus increases as it seems to be the case of Parikkalan Valo, there can be situation when improving of quality does not give reward. This is not the aim of *quality incentive* in economic regulation.

CONCLUSION

Development of customer interruption costs and its regulatory effects has been studied in case of three Finnish DSOs. The study shows that CIC is estimated to decrease considerably next 15 years to that in the year 2028 the CIC is from 40% to 55% of the present state of CIC. In the studied cases the regulatory effect was totally different in each considered DSOs. It seems that in one of the cases development of CIC can be fully earned. In the second case DSO, the development of CIC seems to provide full quality bonus with the estimated CIC. However, the annual fluctuation of CIC can be considerable, that indicates that there is high risk that in a good year part of quality bonus is not realised. The case of the third DSO shows that the high CIC reference causes a situation where it the quality bonus is restricted at the beginning of the consideration period. Thus, improvement in supply reliability does not provide quality bonus in the next years. However, the study shows that even small changes in the regulation can have significant influences on the behaviour of *quality incentive*.

REFERENCES

[1] Finnish Electricity Market Act 588/2013.

[2] Finnish Energy Industries. 2014. Keskeytystilasto 2013 [Outage statistics 2013], (in Finnish), Finnish Energy Industries, Helsinki. Version 2014-06-13.

[3] Energy Authority of Finland (EA). 2011. Sähkön jakeluverkkotoiminnan ja suurjännitteisen jakeluverkkotoiminnan hinnoittelun kohtuullisuuden valvontamenetelmien suuntaviivat vuosille 2012–2015 [Guidelines for assessing reasonableness in pricing of electricity distribution network and high voltage distribution network operations for 2012–2015], (in Finnish), www.energiavirasto.fi, accessed 7 November 2014.

[4] Finnish Energy Authority, *Electricity distribution network Statistics from years 2005–2012*), www.energiavirasto.fi.