THE IMPACT OF THE CHANGE IN THE CHARACTERISTICS ON THE COSTS OF HYDRO-GENERATORS

Convenor P Wegscheider (A)

INTRODUCTION

Due to organisational changes in the electricity supply industry it is becoming more and more important to specify exactly the interface between generating plant and the power system. There is a general wish to define more clearly the additional services required of the power system which are to be fulfilled by the generating units. It is also important to know the costs of the additional services.

The additional services mainly concern the contribution towards:

- steady state and transient system stability
- system voltage control and reactive power
- coping with system disturbances

With regard to hydro generators including the excitation systems the above mentioned additional services generally have impact on the following characteristics:

- power factor
- range of voltage short circuit ratio inertia
- transient reactance
- ceiling voltage of the excitation system exciter response

It would be interesting to know what the impact of the additional services is on the design and costs of the hydro generators if the characteristics required are different to the natural values. This would include the range in which the characteristics can technically be chosen depending on the type, rating and nominal speed of the generator. The question is where, in fact, the technical limitation in performance is. In what area are the natural values of the characteristics to be found if, apart from the standards, the values can be chosen according to the optimisation of the generator design? Optimisation, in this case, would mean the lowest manufacturing costs.

Concerning this subject two CIGRÉ studies were made in the 60's:

- One by Mr. J. CHATELAIN (Switzerland) published by CIGRÉ in 1962
  "Economic repercussions of the choice of parameters of salient pole machines".

- and the other by Mr. G. RUELLE (France) published by CIGRÉ in 1966
  "Influence des divers parametres dimensionnels sur le cout relatif des alternateurs hydrauliques".

The results in these studies are now some 30 years old and it seems to be advisable to update. The following investigation shows that a development in the design of hydro generators was already taking place. However, the fundamental statements in these studies are always still valid.

At the WG-meeting in May 1995 the above mentioned topic was proposed. As a basis for the impact study the main data and changeable characteristics of a hydro generator with an active power output of 100 MW and a medium nominal speed of 375 rpm were prepared. The natural value of the changeable characteristics and the possible requested range of the value were given

as a proposal in the paper as well. This paper was distributed to all members for their comments in Oct. 1995. The received replies were discussed in May 1996. The following draft summary was worked out from that.

SUMMARY

Answers were received from 6 countries. A survey of the countries as well as the number and kind of companies is shown on the following table.

Country	Number of replies	Kind of companies
Austria	1	Manufacturer
Canada	1	Manufacturer
France	1	Manufacturer
Russia	1	Manufacturer
Spain	1	User
Sweden	1	Manufacturer
Switzerland	1	Manufacturer

NATURAL VALUE OF THE CHANGEABLE CHARACTERISTICS

The natural value of the changeable characteristics depends essentially on the nominal speed (number of poles). There is, as well, a certain influence of the power output in the range of very large generators and of the general form of construction of the generator (for instance Bulb-generator).

In order to show the dependence on the nominal speed 3 different generators with the same active power output of 100 MW, but different nominal speeds were investigated. The medium nominal speed is represented by 375 min^{-1} (16 poles), the higher nominal speed by 750 min^{-1} (8 poles) and the lower nominal speed by 107.14 min^{-1} (56 poles).

The general form of construction and the main data of the hydro generators has been determined according to the following table.

Type of generator	Three-phase synchronous generator		
General form of construction	IM 8425 (W41) vertical shaft, combined thrust and guide bearing above the rotor, guide bearing below the rotor		
Cooling system	Air - cooled with re-cooling by water-air heat exchanger		
Standard	IEC 34		
Active power output	100 MW		
Nominal speed	375 min^{-1}	750	107.14
Number of poles	16	8	56
Trip-out speed	450 min^{-1}	900	160
Runaway speed	675 min	1420	220
Rated frequency	50 Hz		
Insulation class	F		
Temperature rise	Class B		
Excitation system	Static type		

The approximate natural values of the changeable characteristics depend on the nominal speed; respective numbers of poles are shown in following table

Changeable Characteristics	**Natural Values**		
	375 min^{-1}, 16 poles	**750 min^{-1}, 8 poles**	**107.14 min^{-1}, 56poles**
Rated power factor	1.0	1.0	1.0
Range of voltage regulation (% of rated voltage)	± 5	±5	±5
Short circuit ratio	0.9	0.75	1.0
Inertia	natural value	natural value	natural value
Transient direct-axis reactance saturated	0.30 pu	0.25 pu	0.35 pu
Ceiling voltage of the excitation system	1.4 U_{en}	1.4 U_{en}	1.4 U_{en}

The possible requested range of the change in the characteristics

Changeable Characteristics	**Range of the Change**
Rated power factor	Natural value : 0.75 overexcited
Range of voltage regulation	Natural value : +- 10%
Short circuit ratio	Natural value : 1.25
Inertia	Natural value : 50% more
Transient direct-axis reactance saturated	Natural value : 0.20 pu
Ceiling voltage of the excitation system	Natural value : 2.5 Uen

IMPACT OF THE CHANGE IN THE CHARACTERISTICS ON THE COSTS

The impact study was worked out for a 100 MW generator, as mentioned, with a medium nominal speed of 375 min^{-1} (16 poles) and the result is shown in the following charts. The impact on costs determined by Mr. Chatelain 34 years ago is included as a comparison in the Figures 1-6. The mean value line is the bold line in each chart.

The highest impact on the costs is the change in the power factor followed by the group of characteristics short circuit ratio, inertia, and transient reactance with approx. the half of impact on the costs. The lowest impact on the costs is the change in the ceiling voltage. It is practically negligible.

When the largest deviation is left out the remaining spread of the impact on costs is rather small. Differences that exist may be due to the traditional dimensioning practice of the companies. This will certainly also have relationships to the different companies' traditional markets.

According to Mr Chatelain's study it has to be taken into consideration that the impact on costs at each characteristic depends on the nominal speed and on the power output but with less influence. The higher the nominal speed the stronger the impact of the change in the characteristics on costs. The influence of the power output becomes less the lower the nominal speed. Mr. Chaterlain's study shows this influence very clearly at both important characteristics power factor and short circuit ratio. The relative values may be valid as always. Therefore, these influences are not to be investigated once more. The following proportional numbers, which can be estimated for a rough view of the conditions, result from the diagrams of the study.

	Proportional number of the impact on costs		
Hydro Generator	**Power Factor**		**Short Circuit Ratio**
750 min^{-1}, 8 poles			
⇧	1.02	Impact on costs times higher than 16 pole generator	1.09
375 min^{-1}, 16 poles			
⇩	0.95	Impact on costs times lower than 16 poles generator	0.95
107.14 min^{-1}, 56 poles			

CONCLUSION

Two CIGRÉ studies from the 60's exist about this topic. It appeared therefore to be advisable to update.

The impact of the change in the characteristics on the costs was investigated at a hydro generator with active power output of 100 MW and a medium nominal speed of 375 min^{-1}(16 poles). The result of the impact study is shown in Figures 1-6. The impact on the costs does not appear to be as great as 30 years ago. A development in the design of hydro generators was already taking place.

The influence of the different nominal speeds on the impact of the change in the characteristics on the costs is covered in the previous CIGRÉ study of Mr Chatelain. Proportional numbers which can be estimated for a rough view of the conditions were found.

An attempt has been made to determine the natural value of the changeable characteristics depending on the nominal speed and number of poles.

The shown impacts on the costs are only valid for hydro generators with a so called “normal" general form of construction and outside the range of very large generators. Considerable higher impacts are to be expected for instance, with bulb generators and generators in the range of load limit. That is shown in a previous CIGRÉ study by Mr Ruelle. The present contribution should be understood as a help in more accurately assessing additional services required of the power system which are to be fulfilled by the generating units.

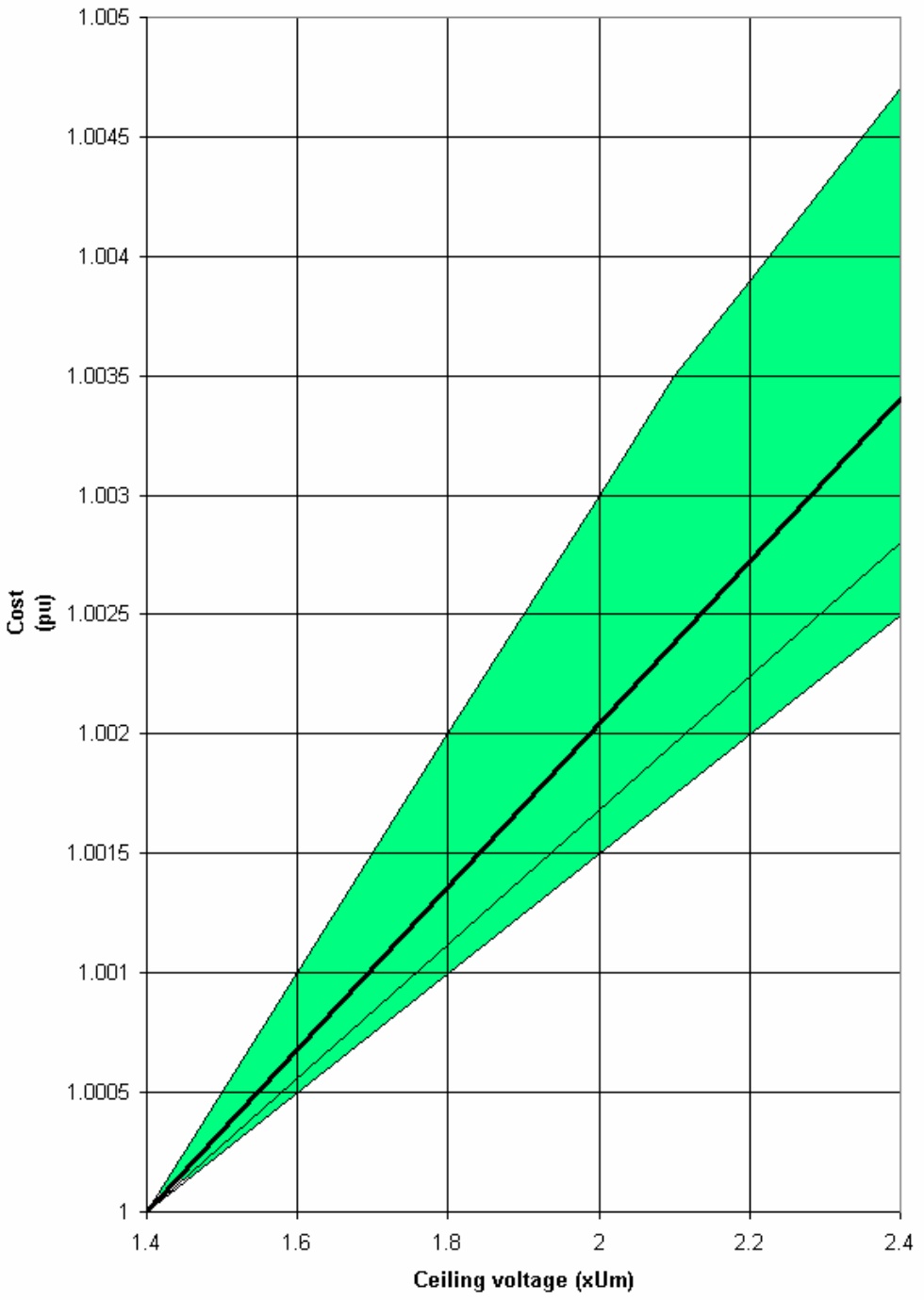

Figure 1 The impact on the change in ceiling voltage on the costs of the hydro generator 100 MW 375 rpm

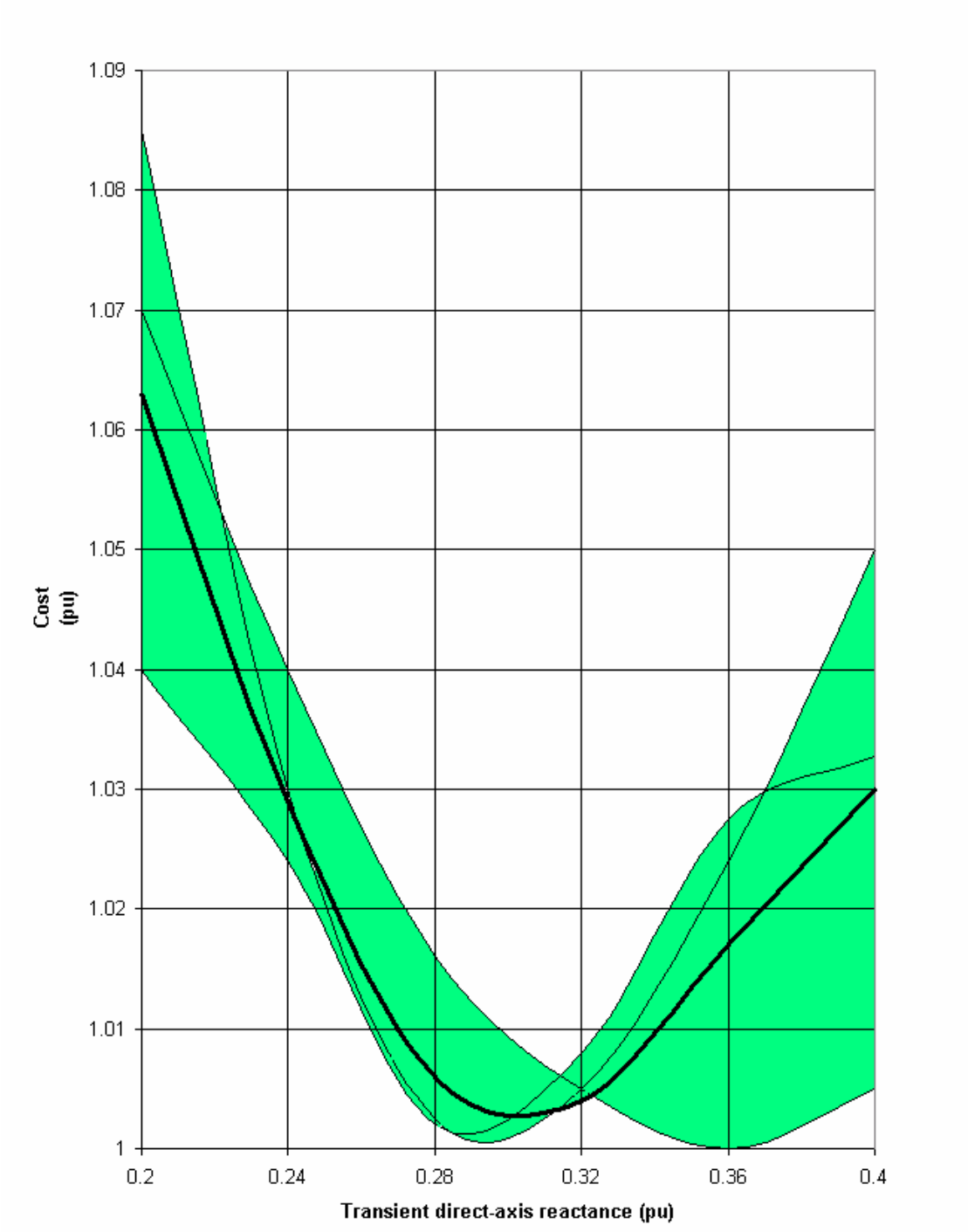

Figure 2 The impact of the change in the transient direct axis reactance (saturated) on the costs of the hydro generator 100MW 375rpm

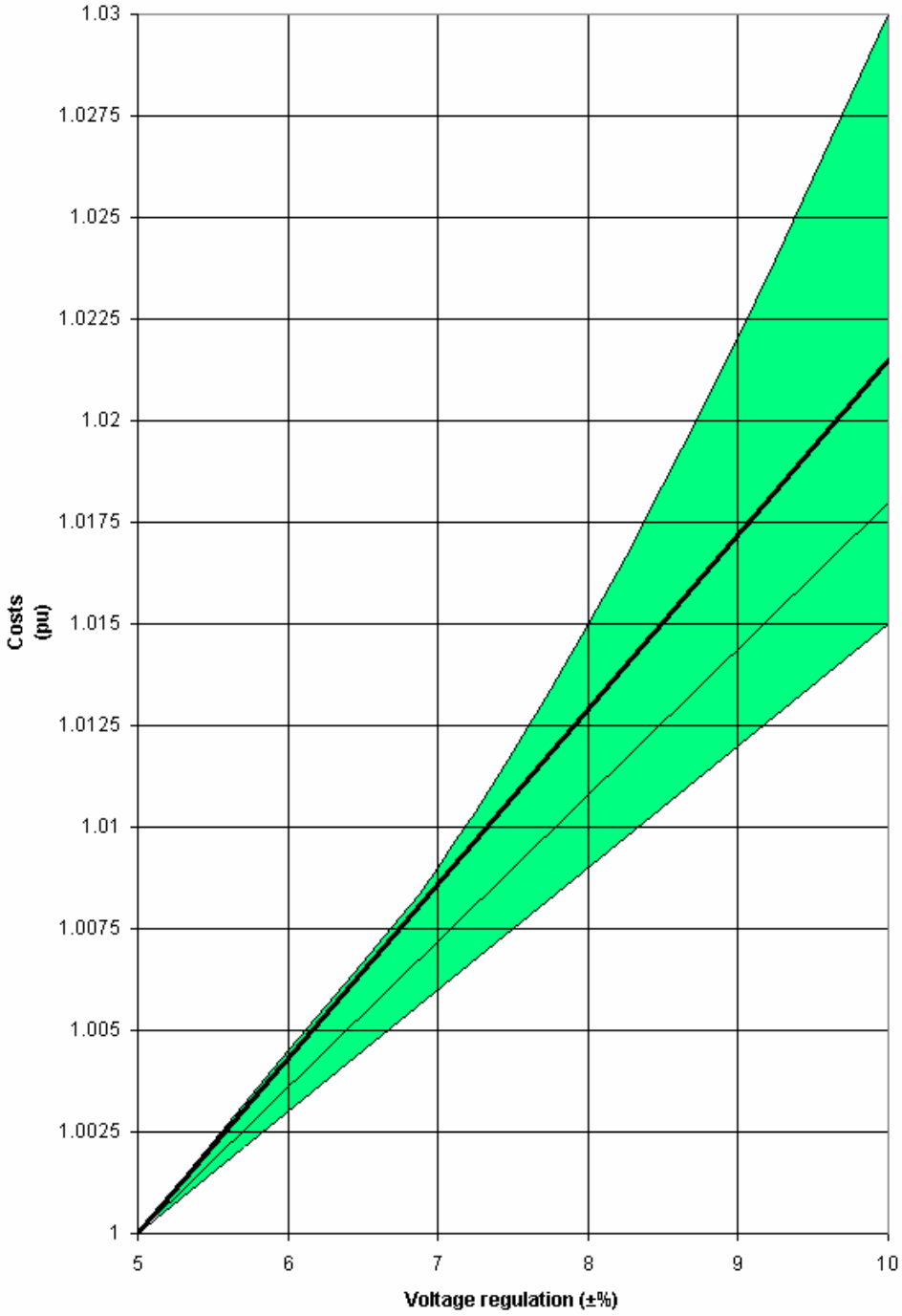

Figure 3 The impact of the change in the voltage regulation on the costs of the hydro generator 100 MW 375 rpm

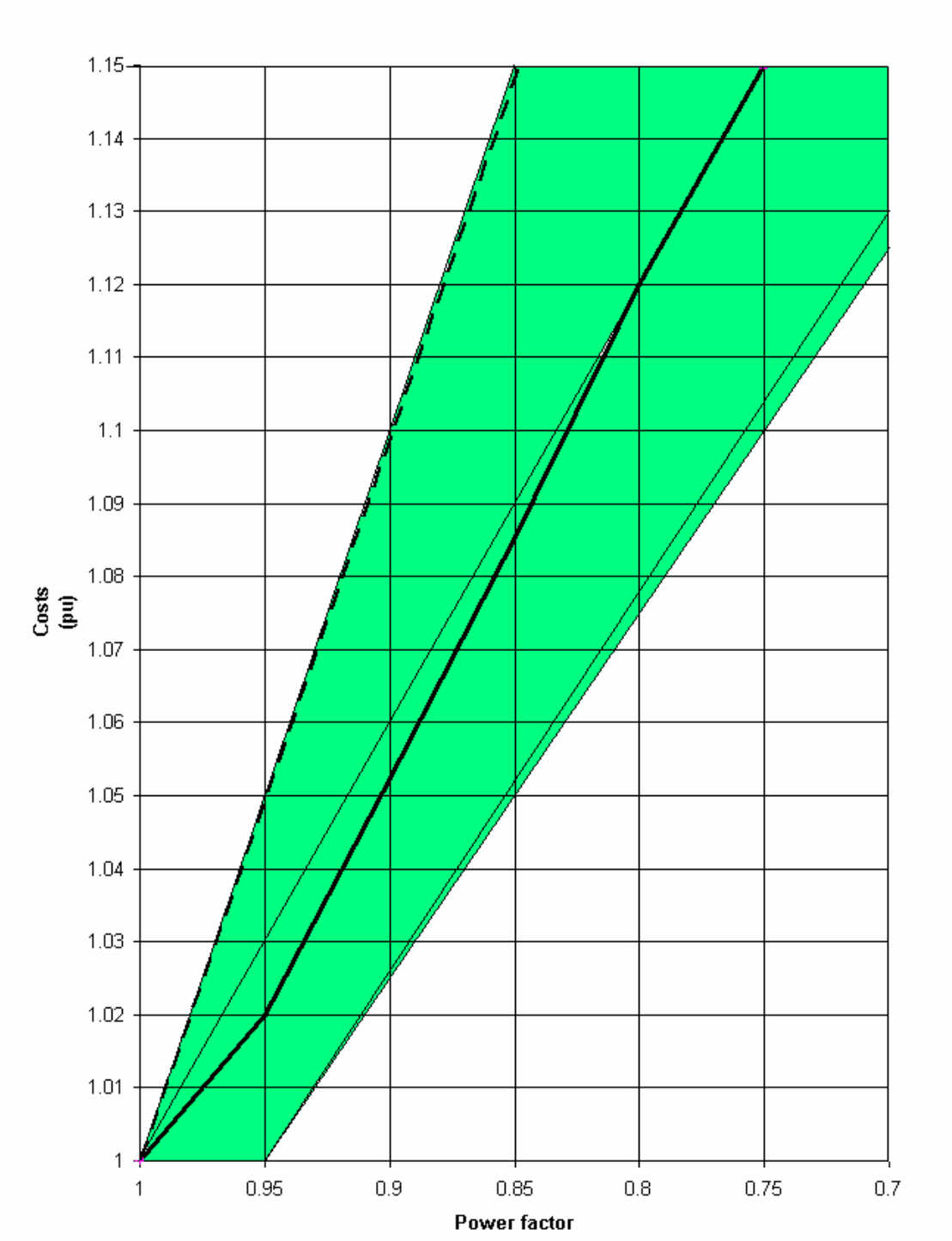

Figure 4 The impact of the change in the power factor on the costs of the hydro generator 100 MW 375 rpm

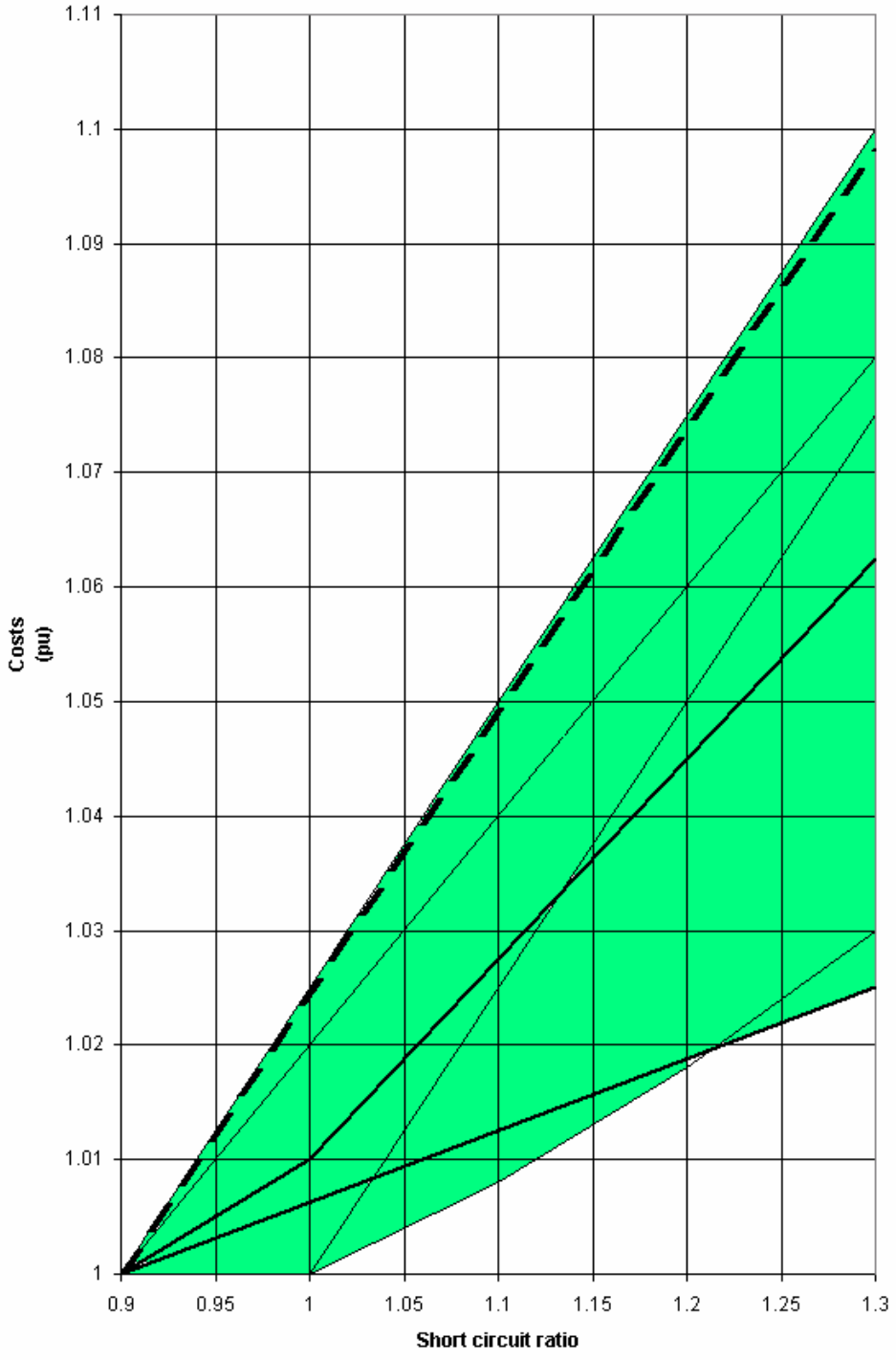

Figure 5 The impact of the change in the short circuit ratio on the costs of the hydro generator 100 MW 375rpm

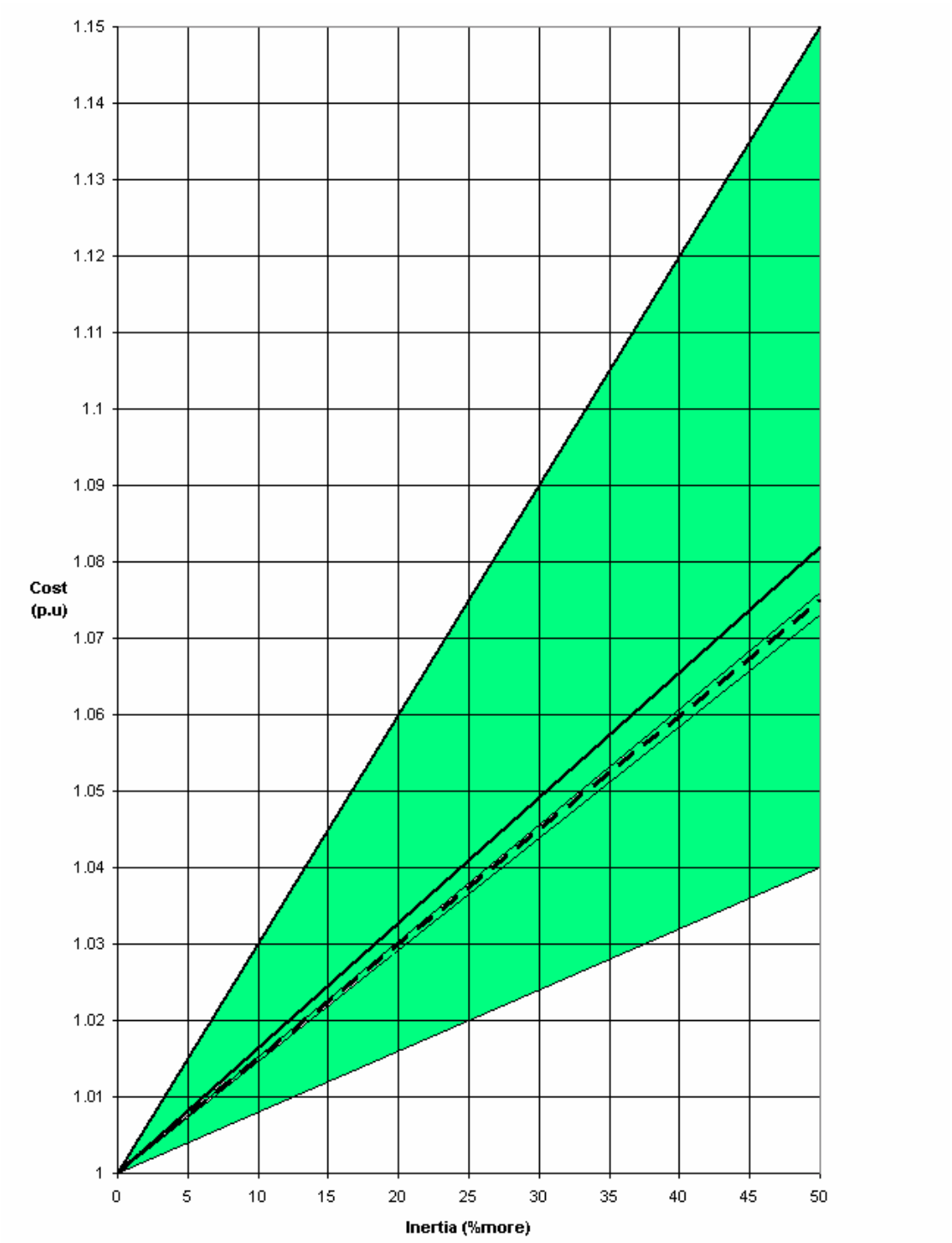

Figure 6 The impact of the change in the inertia on the costs of the hydro generator 100 MW 375 rpm

Disclaimer