ASSESSMENT OF SHORT CIRCUIT POWER LEVELS IN HV AND MV NETWORKS WITH RESPECT TO POWER QUALITY

V. ALLEGRANZA, A. ARDITO, E. DE BERARDINIS
CESI
Milano
ITALY
ardito@cesi.it

M. DELFANTI
Politecnico di Milano
ITALY
maurizio.delfanti@polimi.it

L. LO SCHIAVO
Autorità per l'Energia Elettrica e il Gas
ITALY
lloschiavo@autorita.energia.it

ABSTRACT

The Italian Regulator (AEEG - Autorità per l'energia elettrica e il gas) is paying great attention to voltage quality and has started up a research task in the framework of the Public Interest Energy Research Project named "Ricerca di Sistema" (Italian Ministry for Productive Activities Decree of 28 February 2003) aimed to the monitoring of representative portions of the MV network.

Moreover, the Italian Regulator has requested the calculation of the minimum short circuit power (hereinafter, S_{sc}) levels on the EHV and HV transmission network (Resolution n. 250/04), as S_{sc} represents a meaningful and synthetic parameter for the robustness of the electric network if related to the customers characteristics in terms of disturbing emissions.

A simple method to correlate rapid voltage changes caused by rapid variations of loads (f. i. motor starting) with S_{sc} in the connection site has been set up. Based on this method, a criterion for the classification of HV and MV customers and substations is proposed: this criterion leads to a direct correlation between the customers and substation rated power and S_{sc} in the point of common coupling (PCC).

An example of the application of the methodology to the real short circuit power data coming from HV networks is also reported.

INTRODUCTION

The power supply quality is attracting growing attention from regulators in the international context. As far as electric systems are concerned, customer requirements are getting harder to meet, especially in highly industrialized countries. On the other hand, distribution networks are increasingly characterized by potentially disturbing loads at any voltage level (f.i. due to the massive development of power electronics). Load requirements are getting huger, with reference to both the continuity of the power supply (the most important parameter in an economic sense) and to the voltage waveform [1]. As in case of the continuity of power supply, the level of voltage quality is determined by the interaction between the distribution networks and the customers connected.

In the first case (i.e. continuity of power supply, on which the Italian regulator was mainly focused so far), the situation has considerably improved thanks to the interaction between distributors and customers towards a better network management (operating strategies, network automation, protections selectivity, etc.).

As far as the second case is concerned (i.e. voltage quality, on which AEEG has now begun to focus), S_{sc} is considered an important parameter for power quality (as far as transmission networks are concerned, the Italian regulator has already planned to publish the minimum conventional levels of S_{sc} for the busses of the Italian transmission network with Resolution n. 250/04 [2]).

Without entering into more specific matters, the present paper will outline the reasons why attention has been focused on S_{sc} with reference to power quality. In particular, it is appropriate (and technically feasible, as described below) to correlate the variations in operating conditions due to the "ordinary" load variability to the capacity of the network of facing such variability without an excessive reduction of the voltage value in the connection point. With good approximation, the rapid voltage variations related to the above-mentioned phenomena can reach different values according to the network S_{sc} levels.

DEFINITIONS AND POSSIBLE USES OF SHORT CIRCUIT POWER

The short circuit power S_{sc} of a network point P is usually obtained by multiplying the threephase short circuit current I_{sc} by the nominal voltage between phase and phase of the system (U_n) and by factor √3:

$$S_{sc} = \sqrt{3} \cdot U_n \cdot I_{sc} \quad (1)$$

According to the above definition, the short circuit power S_{sc} at a PCC can be used to obtain the network impedance from the point itself (Z_{sc}):

$$Z_{sc} = U_n^2 / S_{sc} \quad (2)$$

Generally speaking, it is possible to define different values of short circuit current (and of short circuit power) according to the different aims. The present paper, which makes reference to the document [3] published by CEI 136 working group (a project group established by the AEEG Resolution n. 136/04, referring to guidelines for the connection to the HV and MV networks) defines the following values:

1. Maximum threephase short circuit power (aimed at devices sizing). It is the value of the short circuit current as planned by system operators and adopted in order to choose the short-circuit withstand level of the equipment.
2. Maximum operating threephase short circuit power in

the PCC. It must be calculated under normal operating conditions for the network and at maximum generation; it is used for protection coordination.

3. Minimum operating threephase short circuit power in the PCC. It is the minimum value of the threephase short circuit current in the PCC under normal operating conditions. It must be calculated at minimum generation (HV network) and with no dispersed generation (MV network).
4. Minimum conventional threephase short circuit power in the PCC. It is the minimum value of the threephase short circuit power under the most critical N-1 conditions of the HV network (backfeed for MV network) and with minimum generation (i.e. without dispersed generation on the MV network).

The last two S_{sc} values are useful for coordinating protections (network/customer) and for evaluating power quality levels.

CORRELATION BETWEEN SHORT CIRCUIT POWER AND RAPID VOLTAGE CHANGES

In order to analyze the rapid voltage changes (RVC) to which HV and MV customers are subject, it is possible to make reference to Figure 1, which represents the network impedance upstream of the delivery point (Z_{sc}).

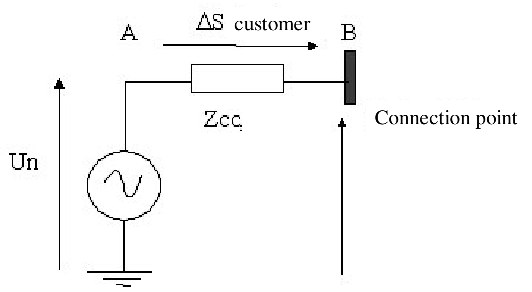


Figure 1 – Schematic diagram aimed at evaluating S_{sc} on HV and MV networks

According to this scheme, it is possible to notice that any variation in the current required by customers causes a RVC on the PCC, that affects any customer connected to the same network. As far as MV networks are concerned, Z_{sc} is the sum of the impedances of HV network, of the HV/MV transformer and of the MV lines.

The total voltage variation in delivery point B is made up by two terms (see equation 3): the first term ($\Delta u_{steady\text{-}state}$) is referred to the steady-state voltage drop; the second term (Δu) is caused by the RVC following the fast variations of customers real (ΔP) and reactive (ΔQ) power. The total variation can be estimated by means of the simplified formula below:

$$\Delta u_{total} = \frac{R_{sc}\cdot(P_{customer}+\Delta P_{customer}) + X_{sc}\cdot(Q_{customer}+\Delta Q_{customer})}{U_B^{\,2}} =$$
$$= \frac{R_{cc}\cdot P_{customer}+X_{cc}\cdot Q_{customer}}{U_B^{\,2}} + \frac{R_{cc}\cdot \Delta P_{customer}+X_{cc}\cdot \Delta Q_{customer}}{U_B^{\,2}} = \tag{3}$$
$$= \Delta u_{stady-state} + \Delta u$$

where R_{sc} and X_{sc} are the resistive and reactive parts of the short-circuit complex impedance Z_{sc}.

By focusing on the rapid variation Δu, being the short circuit power S_{sc} in a given bus inversely proportional to the short circuit impedance Z_{sc} in the same bus, one can obtain:

$$\Delta u = \frac{R_{sc}\cdot \Delta P_{customer}+X_{sc}\cdot \Delta Q_{customer}}{U_B^{\,2}} =$$
$$= \frac{\frac{R_{sc}}{Z_{sc}}\cdot \Delta P_{customer}+\frac{X_{sc}}{Z_{sc}}\cdot \Delta Q_{customer}}{U_B^{\,2}/Z_{sc}}$$
$$= \frac{\frac{R_{sc}}{Z_{sc}}\cdot \Delta P_{customer}+\frac{X_{sc}}{Z_{sc}}\cdot \Delta Q_{customer}}{S_{sc}} =$$
$$= \frac{\frac{\Delta P_{customer}}{\sqrt{1+\tau^2}}+\frac{\Delta Q_{customer}}{\sqrt{\frac{1}{\tau^2}+1}}}{S_k^{"}} = \frac{\alpha(\tau)\cdot \Delta P_{customer}+\beta(\tau)\cdot \Delta Q_{customer}}{S_{sc}} =$$
$$= \frac{\Delta S_{customer}\left(\alpha(\tau)\cdot\cos\varphi_{starting}+\beta(\tau)\cdot\sin\varphi_{starting}\right)}{S_{sc}} =$$
$$= \frac{\Delta S_{customer}}{S_{sc}}\gamma(\tau,\varphi_{starting}) \tag{4}$$

where $\cos\varphi_{starting}$ is the power factor of the instantaneous power change $\Delta S_{customer}$ and τ is the ratio (X_{sc}/R_{sc}).

As shown in Figure 2, in case of high τ values, in equation (4) it is possible to neglect the contribution due to ΔP and to make reference to following simpler equation (5).

$$\Delta u_{total} \approx \Delta S_{customer}/S_{sc} \tag{5}$$

Such approximation is only valid in case of HV networks, whereas in case of MV networks it is valid only at a short distance from the HV/MV substation (high values of X_{sc}/R_{sc}, see Figure 2).

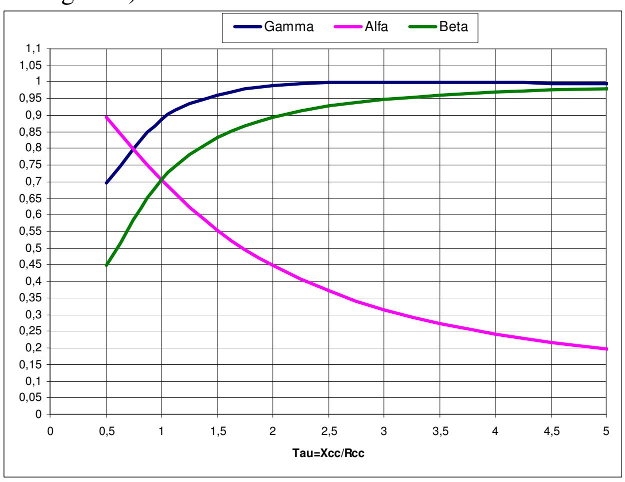


Figure 2 – Coefficients of eq. (4), $\cos\varphi_{starting} = 0{,}3$

An over estimation of the RVC variation is introduced and it increases with the distance from the HV/MV substation. That error can reach up to 30% in the points characterized by the lowest ratio X_{sc}/R_{sc}

CHARACTERIZATION OF CUSTOMERS THROUGH PARAMETER K_T

In general, the instantaneous power variation $\Delta S_{customer}$ required by customers during ordinary service depends on the type of customer and can also be related to the customer rated power S_{rated} through the following formula:

$$\Delta S_{customer} = K_t \cdot S_{rated} \qquad (6)$$

The value of the parameter K_t can vary according to the type of customer (HV customers, MV customers, HV/MV and MV/LV substations), but it is reasonable to suppose that it decreases according to S_{rated} in order to take into consideration the load simultaneous operation. Table I reports the values of K_t assumed for HV networks.

Table I – K_t values for connections to the HV network
(HV customers and HV-MV substations)

S_{rated} (kVA)	$K_{t,HV/MV\ substations}$	$K_{t,HV\ customers}$
16	0,30	0,50
25	0,25	0,40
40	0,20	0,30
63	0,15	0,25

A possible interpolation (dotted line in Figure 2) between the values given to parameter K_t in the above tables and a continuous function of S_{rated} is the following:

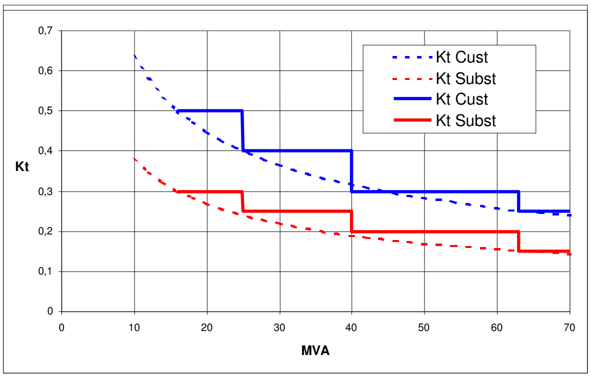
HV and MV customers **:**

$$K_{t,customer} = 2 \big/ \sqrt{S_{rated}} \qquad (7)$$

HV/MV and MV/LV substation **:**

$$K_{t,substation} = 1{,}3 \big/ \sqrt{S_{rated}} \qquad (8)$$

It is important to notice that in this formula, which is valid for both HV and MV networks, S_{rated} is expressed in MVA.



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gure 3 – Discrete values and interpolating function
for K_t on HV networks

Such values, which can only be referred to "non-disturbing" customers, have not been deduced neither from field observations nor from a measurement campaign, but only from preliminary estimations. In that regard it is important to underline that the ongoing monitoring campaign on voltage quality undertaken by RdS [4] will provide useful information by means of appropriate correlations studies between the rapid voltage variations recorded and the S_{sc} calculated.

The values assumed at the present moment seem to be reasonable, as K_t preliminary estimations are based on criteria that:

- allow a 10% voltage drop on HV/MV transformers (HV customers and HV/MV substations) and MV/LV (MV customers and MV/LV substations);
- take into account typical load transients (motor starting, etc).

Table II reports the values of K_t assumed for MV networks.

Table II – K_t values for connections to the MV network
(MV customers and MV-LV substations)

S_{rated} (kVA)	$K_{t,MV/LV\ substations}$	$K_{t,MV\ customers}$
100	2,00	4,00
250	1,60	2,80
400	1,50	2,50
630	1,43	2,30
1000	-	1,80
2500	-	1,30
5000	-	0,80

Figure 4 shows the values of K_t for MV networks, along with the relevant interpolating function.

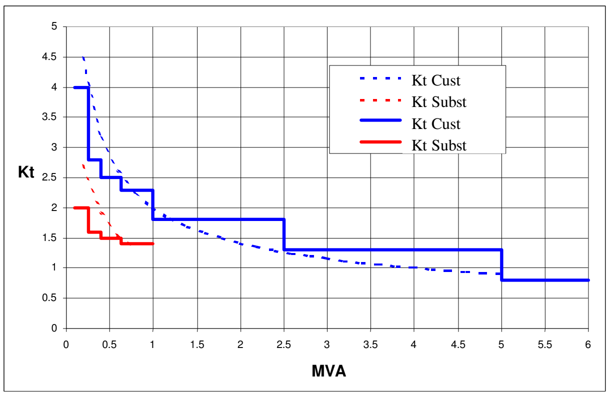

Figure 4 – Discrete values and interpolating function
for K_t on MV networks

In case of energization of HV/MV or MV/LV transformers (inrush current), the parameter K_t would certainly be higher, as it can even reach 4-6 or 6-11 respectively. However, it has to be noticed that the energization is not usually carried out during ordinary service; for this reason, it is not taken into consideration in the present methodology.

CORRELATION AMONG VOLTAGE CHANGES, S_{sc}, AND CUSTOMER RATED POWER THROUGH PARAMETER K_T

With reference to the above paragraphs, the voltage variation required by a customer can be calculated (with precision on HV network and with good approximation on MV network) according to the following equation:

$$\Delta u = \frac{\Delta S_{customer}}{S_{sc}} \gamma(\tau, \varphi_{starting}) = \qquad (9)$$

$$= K_t \cdot \frac{S_{customer}}{S_{sc}} \gamma(\tau, \varphi_{starting}) \approx K_t \cdot \frac{S_{customer}}{S_{sc}}$$

As a consequence, after establishing the maximum rapid voltage variation to be expected on the PCC (Δu_{lim}) MV networks and the parameter K_t related to the power variation that the customer requires, it is possible to calculate the value of S_{sc} necessary for each network bus:

$$S_{sc} \approx K_t \cdot \frac{S_{customer}}{\Delta u} \qquad (10)$$

For instance, if relations (8) e (9) are adopted for K_t and if a maximum rapid voltage change of 5% is to be expected in the PCC, this results in:

HV and MV customers:

$$S_{sc,cust,5} = 40\sqrt{S_{rated}} \qquad (11)$$

HV/MV and MV/LV substations:

$$S_{sc,subst,5} = 26\sqrt{S_{rated}} \qquad (12)$$

APPLICATION OF THE METHODOLOGY

The application of the above-described methodology to the analysis of the S_{sc} on the busses of the Italian Transmission Network[1] (RTN – "Rete di trasmissione nazionale") gave some interesting results.

In particular, none of the busses to which HV/MV substations are connected shows a minimum operating S_{sc} or a conventional minimum S_{sc} (N-1) lower than the prescribed values.

As regards customers, the results are as follows (see also Figure 4):

- none of the busses to which HV customers are connected shows a minimum operating S_{sc} below the threshold value for rapid variations of 3%;
- there is an extremely limited number of busses with a minimum conventional S_{sc} below the threshold value for rapid variations of 3%; nevertheless, it is far above the threshold value for rapid variation of 5%;
- none of the busses to which HV customers are connected shows a minimum conventional S_{sc} below the threshold value for rapid variations of 5%.

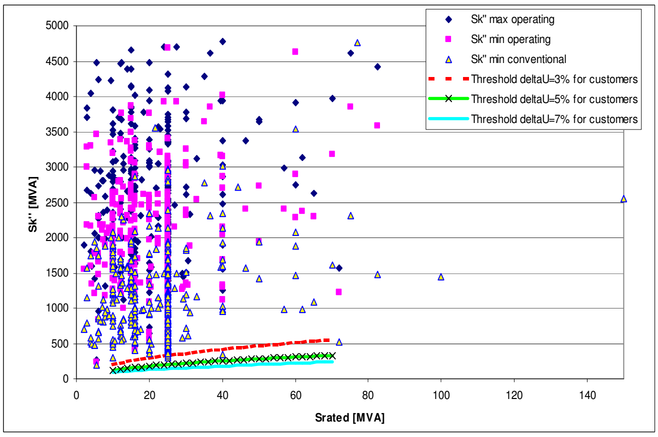

Figure 4 – Application of the methodology proposed to the analysis of S_{sc} on the RTN: busses with HV customers

CONCLUSION – ONGOING RESEARCH

The paper proposes a methodology to correlate rapid voltage changes to the load variation and to the short circuit power in the point of common coupling.

The method has been based on theoretical considerations and studies: as a consequence, further investigations are needed about the assumptions adopted.

In particular, field studies and analysis are needed to assess if the behaviour of customers (in terms of fast load variations) is correctly modelled by the parameters K_t.

Once such parameters will be confirmed with on-field evidence, it will be possible to make use of the proposed approach by a regulatory point of view.

Some first results indicate that the short circuit power levels available on the Italian HV networks (132-150 kV) are typically higher than the minimum levels calculated with the procedure proposed.

As for MV networks, the data collected from the monitoring campaign on the voltage quality will allow for a better tuning of the parameters used in the methodology proposed.

REFERENCES

[1] Towards Voltage Quality Regulation in Europe: An ERGEG Public Consultation Paper, E06-EQS-09-03 06-DEC-2006 available on www.ceer-eu.org

[2] Italian Regulator Resolution n. 250/04, available on www.autorita.energia.it

[3] Consultation document 34/06, about technical rules for the connection to HV and MV distribution networks, available on www.autorita.energia.it

[4] F. Villa, A. Porrino, R. Chiumeo, S. Malgarotti, "The power quality monitoring of the MV network promoted by the Italian regulator. Objectives, organisation issues, 2006 statistics", Proc. of CIRED 2007- Wien

1 The S_{sc} values on RTN are communicated by TERNA (Italian TSO) according to Italian Regulator Deliberation n. 250/04.