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FLICKER IN ARC FURNACE APPLICATIONS

Equations are given in this document for estimating flicker in arc furnace applications. These equations have generally been developed based on analysis and experience.

1.0 Flicker Limits in Terms of Pst and Plt

IEEE Standard 1453-2022 – "IEEE Standard for Measurement and Limits of Voltage Fluctuations and Associated Light Flicker on AC Power Systems" is the key standard with regard to flicker. Some of the key points of this document are noted as follows. Other details are available in the standard.

1. P_{lt} is the measure of long-term perception of flicker obtained for a two-hour period. This value is made up of 12 consecutive P_{st} values.

2. P_{st} is the measure of short-term perception of flicker obtained for a ten-minute interval.

3. As given in Section 6 of IEEE Standard 1453-2022, P_{st} and P_{lt} should not exceed the planning levels given in Table 1 more than 5% of the time (95% probability level) with a minimum assessment period of one week.

Table 1 – Planning levels for Pst and Plt in MV, HV, and EHV power systems

	Planning levels	
	MV	**HV-EHV**
Pst	**0.9**	**0.8**
Plt	**0.7**	**0.6**

4. For LV power systems the flicker levels listed in Table 2 are recommended and are also based on 95% probability levels.

Table 2 – Compatibility levels for Pst and Plt in LV power systems

	Compatibility levels
Pst	**1.0**
Plt	**0.8**

5. The 99% probability value may exceed the planning level by a factor (1-1.5), depending on system conditions to be determined by the system operator.

2.0 Calculation of Pst

A formula that is often used to estimate $P_{st95\%}$ in arc furnace applications is given as follows:

$$P_{st95\%} = K_{st} \times (S_{ccf}/S_{ccn}) \qquad \text{EQ (1)}$$

where
- K_{st} = Characteristic emission coefficient for Pst, ranging from 58 to 85 for 120V systems.
- S_{ccf} = Short circuit level at the arc furnace leads
- S_{ccn} = Short circuit level of the network at the PCC
- $\%V_D$ = S_{ccf}/S_{ccn} x 100% (percent voltage drop at the PCC)

See IEEE Standard 1453-2022, Section 7.2.2 for more details.

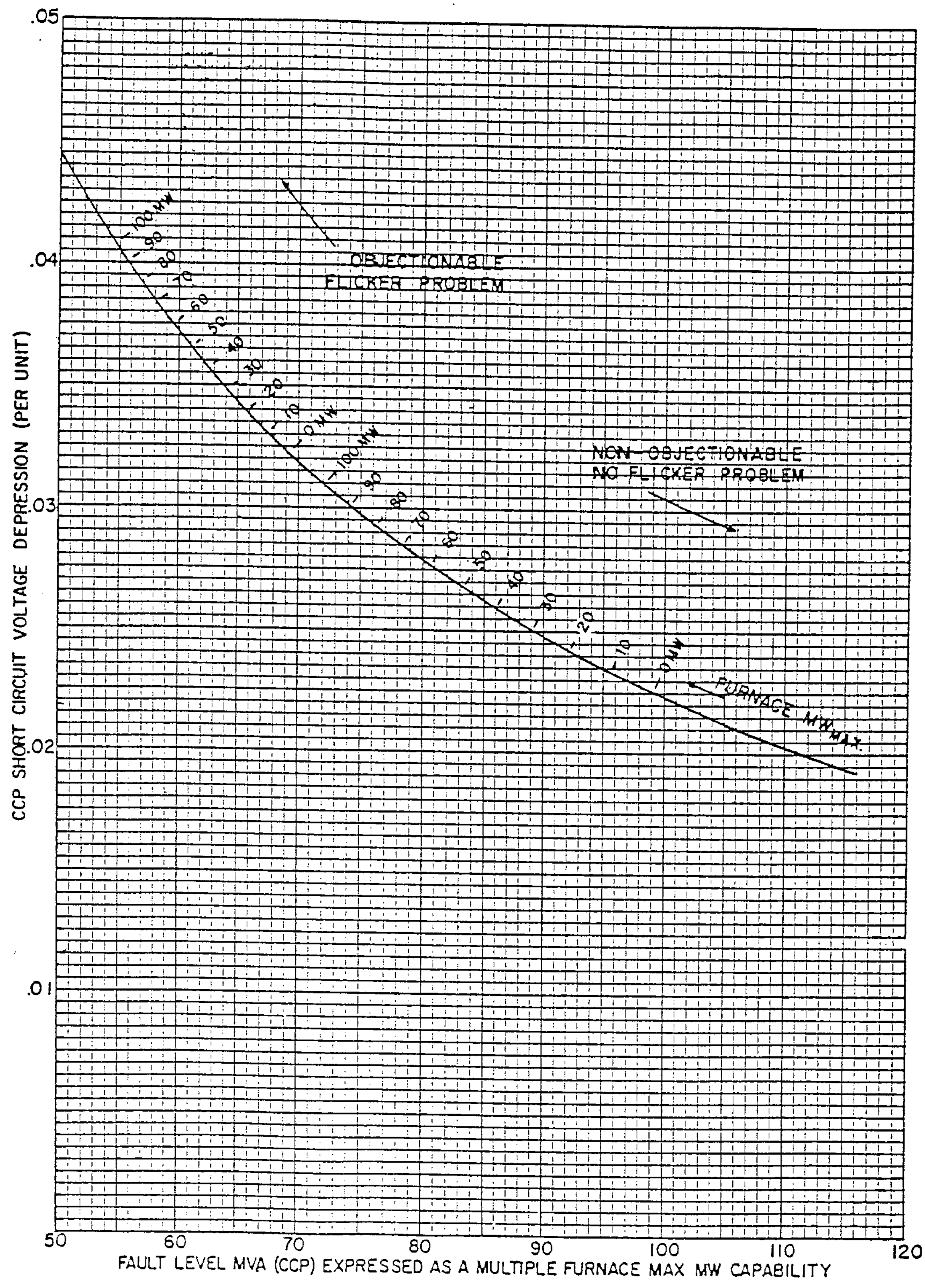
3.0 Example

The following examples and comments are noted:

1. For K_{st} = 60 and $P_{st95\%}$ = 1.0, the maximum percent voltage drop at the PCC would equal 1.67% from EQ (1).

2. For K_{st} = 60 and $P_{st95\%}$ = 0.8 (which is the recommended planning limit in IEEE Standard 1453 for HV-EHV systems), the maximum percent voltage drop at the PCC would equal 1.33%.

3. Historically, the percent voltage drop at the PCC was used in many countries as the criteria for design. The limits were $\geq$ 1.6%.
   a. Great Britain used 1.6% at voltages above 132 kV and 2.0% at lower voltages.
   b. The curve in Figure 1 suggests voltage drop limits in the range of 2.2% to 3.1%, depending upon the MW size of the furnace. This characteristic was based on the observation that larger furnaces are smoother in operation.
   c. Therefore, the limit of $P_{st95\%}$ = 0.8, which corresponds to a voltage drop of approximately 1.3%, is more restrictive compared to the previous percent voltage drop limits noted above.



Fault level/$MW_{MAX.}$ ratios and accompanying short circuit voltage depression.

Figure 1

4.0 Static Var Compensator (SVC)

When flicker is excessive, the typical method of reducing the flicker is to add a static var compensator (SVC) to the system. This is a thyristor-controlled reactor (TCR) in parallel with filter capacitor banks. The SVC can generally reduce the flicker level ($P_{st95\%}$) by a factor of 2. The SVC is a mature and reliable technology that has been used predominantly in arc furnace and transmission applications since the 1970s.

4.1 Voltage Drop and SVCs

The voltage drop due to the operation of the arc furnace is caused predominantly by the var flow to the furnace. The worst condition occurs when the furnace electrodes are shorted. The purpose of the static var compensator (SVC) is to supply capacitive vars to offset the inductive vars drawn by the furnace system and, therefore, to minimize the voltage drop on the system.

1. The maximum useful Mvar size of the SVC would generally be the maximum vars drawn by the furnace system. It is possible that being a little larger than that could be helpful if the MW flow is also contributing significantly to the voltage drop.

2. The second key issue is that the SVC must respond fast but not too fast.
   a. A voltage drop must occur before the SVC can know to respond. Also, the current in the SCR must go through zero before the SVC can change its response. Therefore, a response time of 0.5 to 2.0 cycles would tend to be the minimum response time. With a delay of 0.5 to 2.0 cycles, a voltage drop will always occur, but the SVC will limit the duration of the voltage drop.
   b. The response time of the SVC cannot be too fast, or else the SVC will be overshooting or responding erroneously to the change in system voltage.

4.2 Typical Arc Furnace Parameters

Typical arc furnace circuit parameters tend to be in the following ranges:

1. The peak furnace MW value is typically in the range of 0.8 to 0.9 times the furnace transformer MVA rating.

2. The peak furnace Mvar value is typically in the range of 1.5 to 1.75 times the furnace transformer MVA rating.

Arc furnace circuits on the order of 100 MVA typically have an X/R ratio of 10 to 15 from the utility source to the shorted electrodes. Approximately 80% to 90% of the circuit resistance (R) is from the furnace transformer primary to the shorted electrodes. In this analysis, references to the “furnace MW” and “MW to the furnace circuit” are referring to the total MW as measured at the primary of the furnace transformer at 34.5 kV. On the order of 6% to 10% of this MW value is associated with the equipment losses from the furnace transformer primary to the shorted electrodes. Approximately 90% to 94% of this MW value is associated with the arc itself.

4.3 Estimating the Mvar Size of the SVC

If the flicker is excessive in a given application, a static var compensator (SVC) is often used. A typically sized SVC reduces the flicker by about 50%. The following formula is often used to estimate the effectiveness of an SVC on the flicker:

$$R_{svc} = 1 + 0.75 \times (S_{svc}/S_f) \qquad \text{EQ (2)}$$

where
R_{svc} = Flicker reduction factor
S_{svc} = SVC Mvar
S_f = Furnace MVA
= ~ 1.2 x Maximum Furnace MW

This formula is believed to be a reasonable approximation up to $S_{svc}/S_f = 2$. At $S_{svc}/S_f = 2$, $R_{svc} = 2.5$. A reduction factor near 2 is typical. A reduction factor greater than 3 is not believed to be possible with conventional SVC design. An optimized classic SVC would generally reduce the flicker by approximately 50% with a Mvar rating on the order of 1.6 to 1.8 x the maximum MW of the furnace.

To achieve $P_{st95\%} = 0.8$, $R_{svc} = P_{st95\% w/o\ svc}/0.8$. From this relationship, the Mvar size of the SVC is estimated as follows from equations (1) and (2):

$$S_{svc} = (((P_{st95\% w/o\ svc}/0.8) - 1)/0.75) \times S_f \qquad \text{EQ (3)}$$

For a given SVC Mvar size, the resultant $P_{st95\% w/SVC}$ can be estimated as follows:

$$P_{st95\% w/\ svc} = (P_{st95\% w/o\ svc})/(1 + 0.75 \times (S_{svc}/S_f)) \qquad \text{EQ (4)}$$

For high X/R systems, the maximum useful size of the SVC is approximately equal to the maximum Mvar drawn by the furnace. In systems with significant resistance values, higher Mvar values may be helpful. Equations (2), (3), and (4) are to generally be used within the bounds of the maximum Mvar that could be drawn by the system.

5.0 Static Synchronous Compensators (STATCOM)

STATCOMs began to be used in the 1980s and 1990s to solve transmission operation problems due to the restrictions on the construction of new transmission lines. It is a shunt device that can supply vars to the power system faster than an SVC. The response time of the STATCOM is on the order of 1 millisecond as compared to 0.5 to 2.0 cycles for an SVC. Since it is on the order of 10 times faster, it also has the potential to control the flicker better. It is believed to be able to reduce the flicker by a factor of 4 to 6 compared to 2 for an SVC. Although it is a technology that has been used from the 1980s to the 1990s, the technology of electronic components is constantly changing approximately every five years.