ELECTRIC POWER RESEARCH INSTITUTE

Grid-IQ Open Flicker Evaluation Module

Version 1.0

3002010324

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EPRI Project Manager

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THE ELECTRIC POWER RESEARCH INSTITUTE (EPRI) PREPARED THIS REPORT.

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SOFTWARE DESCRIPTION

Grid-IQ Open Flicker Evaluation Module (OS-FEM) Version 1.0 was developed to foster improvement and growth through academia use. The OS-FEM easy flicker evaluation of the loads with fluctuations in power demand.

Description

The application provides a user-friendly interface that can be used to perform high-level flicker assessment of an existing or a proposed fluctuating load. The basic functionality of the tool include:

- Ability to determine the appropriate emission limits of proposed loads that are fluctuating in nature. The emission limits are determined so that recommended or chosen planning levels are not exceeded at Point of Common Coupling.
- Ability to estimate the flicker contribution of individual fluctuating loads and overall flicker can be computed that takes into account background flicker.
- Ability to evaluate compliance of the loads against the determined flicker limits
- Ability to estimate the impact of potential mitigation solutions such as adaptive var compensation equipment.

Benefits and Value

Value and benefits provided by the Grid-IQ OS-FEM software are:

- The module is designed to be used as a screening tool that will perform basic high-level flicker analysis of an existing or new industrial facility. The analyis capability for this tool is expected to be enough in most situations and will provide guidance on the need for performing any additional detailed analysis.
- This user interface is designed to be very user friendly and the approach used does not involve any modeling and simulation efforts. The user inputs that are needed are expected to be readily available to users.
- Access to MATLAB file allows programmer access for customization.

Platform Requirements

Multicore CPU, 2 or more core CPU required for computational speed.
One of the following operating systems is required to run the software:

- Windows 10
- Windows 8

Derivative Version of

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Program
2017 Program 1 Power Quality

Keywords
Flicker, Flicker limits, Flicker standards, Electric Arc Furnace, Repetitive loads, Flicker compliance

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USING THE MODULE

This section describes the various steps that need to be performed for installing the module, loading the module, setting up the study to be performed, running the simulation, and viewing the results.

Installation of EPRI Software at Client Site

EPRI develops software using a number of third party software products and tools that run on various operating systems and server platforms. Reports from the software industry suggest there are known security issues with some products and systems. EPRI recommends that, if you are using EPRI software, you review its use with your Information Technology (IT) department and their overall strategy to ensure that all recommended security updates and patches are installed as needed in your corporation. If you have any concerns, please call the EPRI Customer Assistance Center (CAC) at 1-800-313-3774 (or email askepri@epri.com).

If you experience difficulties accessing the application

If you experience difficulties accessing the application after standard installation on Windows 8 and Windows 10, please consult your IT department personnel to have proper access permissions setup for your use. If the problem cannot be resolved, please call the EPRI Customer Assistance Center (CAC) at 1-800-313-3774 (or email askepri@epri.com).

System requirements

- Multicore CPU, 2 or more core CPU required for computational speed.
- Required Operating Systems (Windows 8, Windows 10, 32-bit machines and 64-bit machines capable of running 32-bit applications).
- MATLAB R2016a (not provided).
- Administrative rights are required to install this application.
- Microsoft Office or Adobe Reader must be installed to support the software HELP button.
- The graphics interface screens are optimized for a 1600 x 900 screen resolution.

Installing the Module

In order to install the module, the user needs to unzip the "OpenFEMRev1.zip file" (the downloaded *.zip file associated with this program installation) and place the contents in a directory created on the main drive of the computer. Assure MATLAB R2016a (or MATLAB R2017a) is installed with up to date user's license.

Launching the Application

From the "Windows" desktop, click on the Windows "Start" icon. Select "All apps" then navigate to and launch the MATLAB program. Through the "Home" tab in MATLAB, click on the "Browse for folder" icon then navigate to the location where the unzipped OpenFEM files have been installed (Figure 1-1) to assure the current folder and associated "Flicker-gui.m" file are available. (Note: if the Flicker_gui.m file is located remote to the other OpenFEM files, the program may not operate correctly as files produced by the Flicker_gui.m file may not end up in the appropriet location.) Double-click on the “Flicker-gui.m” to load the Open-Flicker script.

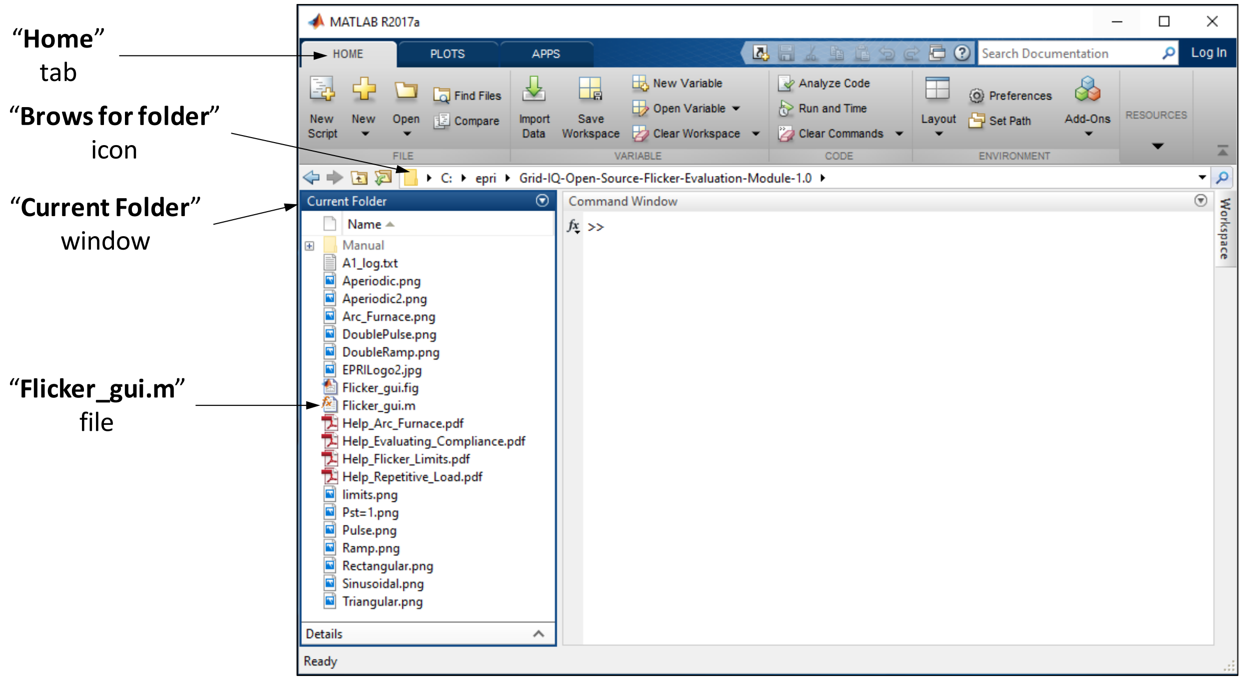

Figure 1-1
MATLAB, HOME navigation screen to “Flicker_gui.m” file

From the MATLAB “Editor” toolbar, click on the “Run” icon (green triangle pointing to the right, see Figure 1-2).

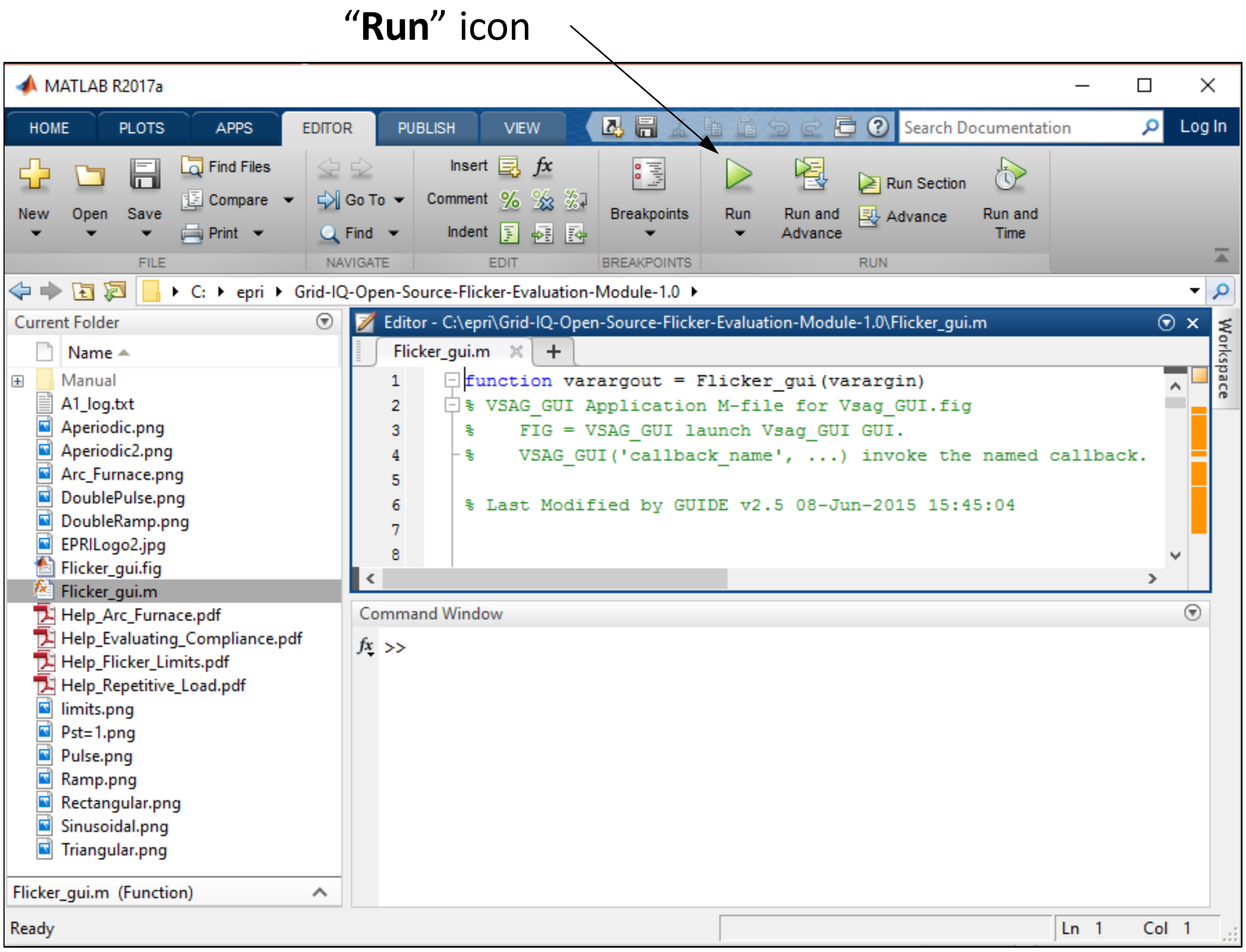

Figure 1-2
MATLAB, EDITOR with Flicker_gui.m file loaded and ready to "Run"

Note: Initial Launching of Application can take approximately 45 seconds.

The splash screen shown in Figure 1-3 is displayed. Clicking on the "Accept" button serves to launch the Flicker Evaluation Module interface (Figure 1-4). Clicking on the "Reject" button serves to close the module.

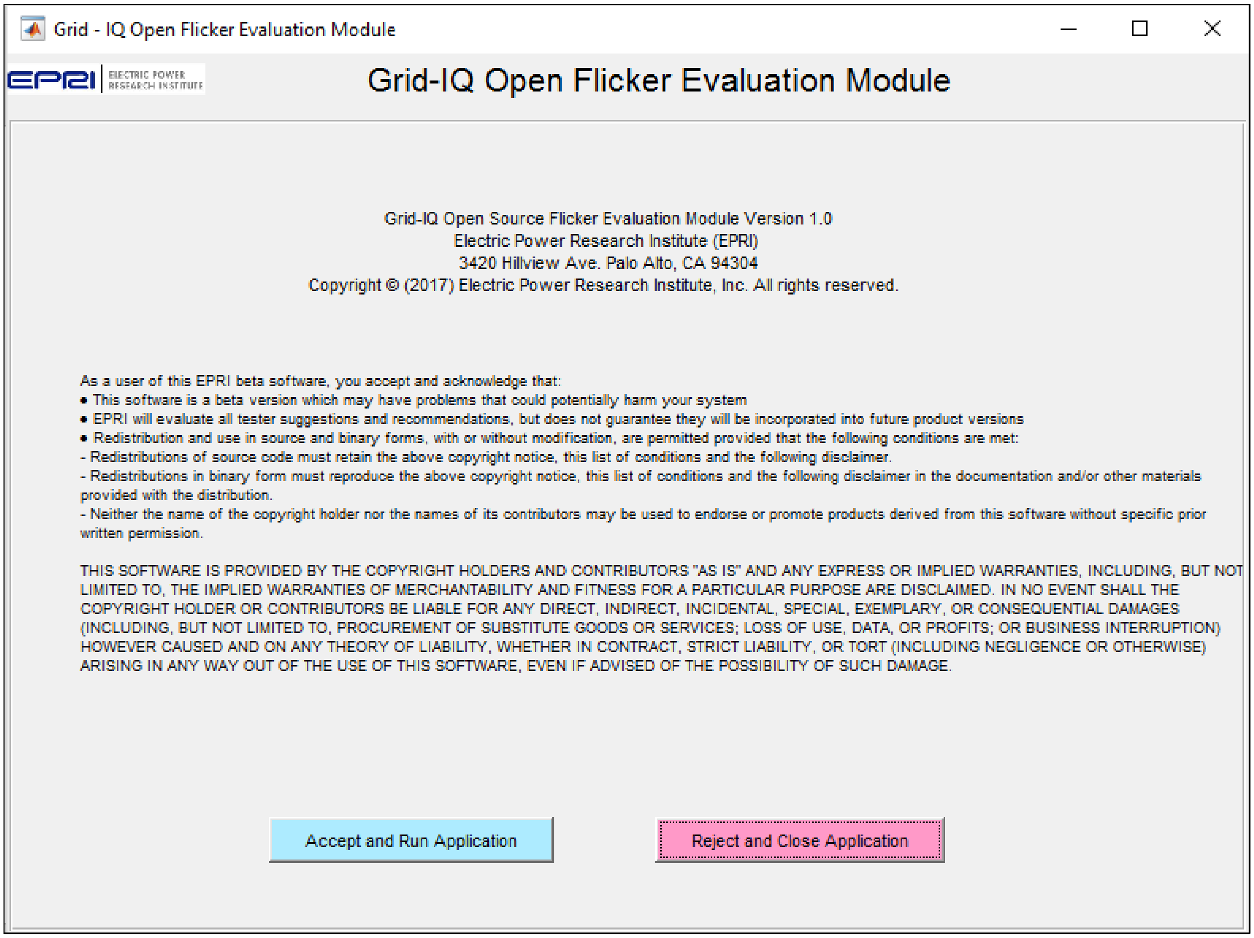

Figure 1-3
Grid-IQ OpenFEM splash screen

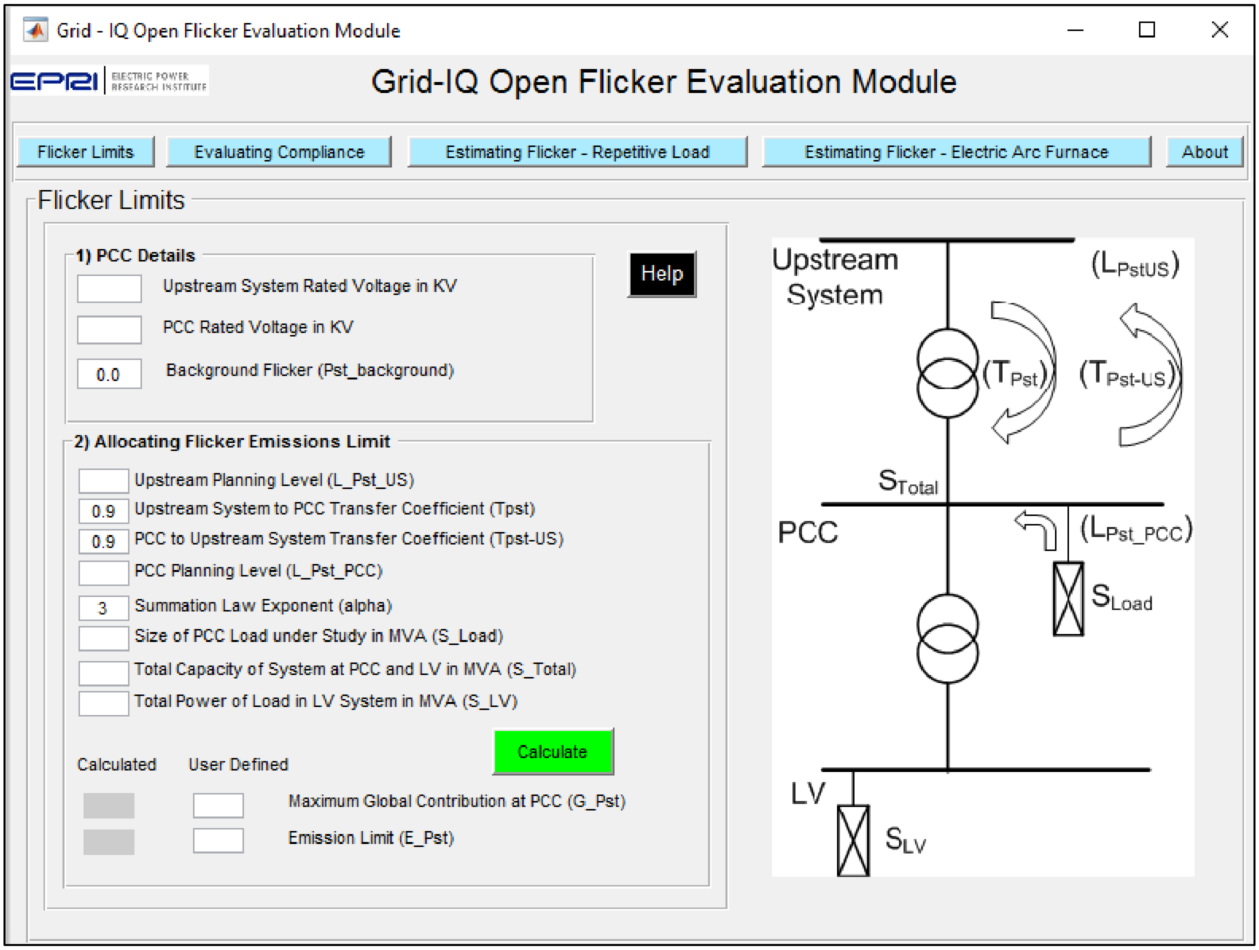

Figure 1-4
Grid-IQ FEM analysis interface – Flicker Limits tab

Background Information

Voltage flicker can be defined as a sudden fluctuation in system voltage, which can result in observable changes in the light output of electric lamps. Because voltage flicker is mostly a problem when it is observed by the human eye, usually voltage flicker is referred to as a problem of perception.

Flicker monitoring has been standardized in the United States using a meter that is completely described in IEEE Standard 1453. This method has been adopted from IEC Standard 61000-4-15. Flicker level evaluation can be divided into two categories, short-term and long-term. Short-term evaluation of flicker severity, Pst, is based upon an observation period of 10 minutes. This period is based upon assessing disturbances with a short duty-cycle or those that produce continuous fluctuations. The long-term flicker severity, Plt, is calculated from 12 successive Pst values using the equation in (1).

$$P_{lt} = \sqrt[3]{\frac{1}{12}\sum_{j=1}^{12} P_{st}^{3}} \qquad (1)$$

Tab 1 – Flicker Limits

This is the default tab in the interface (see Figure 1-4). It deals with computing the recommended planning flicker levels for the utility system. It also determines appropriate flicker emission limits for a flicker-inducing facility. Various user inputs regarding the system and the load that are needed for the necessary computations are explained in this section.

Point of Common Coupling Details

This section describes the point of common coupling (PCC) parameters that need to be provided:

- Upstream System Rated Voltage in kV: This field represents the system voltage on the HV side of the nearest step-transformer upstream of the PCC. This value is used to determine the recommend flicker planning levels in the upstream system.
- PCC Rated Voltage in kV: This field represents the system voltage on the PCC nearest the step-transformer supplying the PCC. This value is used to determine the recommend flicker planning levels at the PCC.
- Background flicker (Pst_background): These are the flicker levels at the PCC that can be attributed to the operation of all the loads in the system, excluding the facility being investigated. This flicker can be combined with the flicker contribution of the facility itself to arrive at the resultant flicker at the PCC. The default value is 0.0.

Allocating Flicker Emissions Limits

This section describes the various fields that are related to computing the emission limits for the facility.

- Upstream Voltage Planning level (L_Pst_US): This field represents the planning levels corresponding to the system voltage on the HV system upstream of the PCC as described in the previous section. This field gets auto-populated with the levels recommended in IEEE Std 1453 (see the limits tables in Evaluating Compliance Section) based on the specified PCC attributes. This field is editable if another value needs to be used.
- Upstream Step-up System to PCC Transfer Coefficient (Tpst): The transfer coefficient of flicker that represents the proportion of the “Background Flicker” that gets transferred from the upstream HV system to the PCC. The default value is 0.9, which assumes that there is some damping. A value of 1.0 would assume all that flicker is transferred to the PCC system.
- PCC to Upstream System Transfer Coefficient (Tpst-US): The transfer coefficient of flicker represents the proportion of the PCC load flicker that gets transferred from the PCC to the upstream HV system. The default value is 0.9, which assumes that there is some damping. A value of 1.0 would assume that all flicker is transferred to the upstream system.
- PCC Planning level (L_Pst_PCC): This field represents the planning levels corresponding to the system voltage at the PCC. This field also gets auto-populated with the levels recommended in IEEE Std 1453 based on the specified PCC attributes. This field is editable if another value needs to be used.
- Summation Law exponent (alpha): This variable describes how the flicker form the various contributions combine at the PCC. A value of 1.0 assumes that the flicker from the various sources adds uniformly. A value of 2 assumes more diversity in contributing sources. A default value of 3 is provided and is suitable for the majority of cases.

- Size of PCC Load under study in MVA (S_Load): Rated power of the considered fluctuating installation.
- Total capacity of system at PCC and LV in MVA (S_Total): Total supply capacity of the system at the PCC and LV including provision for future load growth.
- Total power of load in downstream LV system in MVA (S_LV): Total power of the load supplied directly at LV in the considered system, including provision for future load growth.
- Maximum global contribution at PCC (G_Pst): Maximum global contribution to the flicker level of all the fluctuating installations that can be connected to the PCC without exceeding the flicker planning levels. The module computes this value and is provided for information purpose. It is assumed here that the LV fluctuating installations have a negligible impact at the medium voltage PCC.
- Emission limit (E_Pst): This is the flicker emission limit for the PCC (medium voltage) load facility. The module computes this value based on the maximum global contribution at the PCC and size of MV/LV load. Limiting MV facility flicker contribution under this limit would ensure that the planning levels are not exceeded at PCC.

Completing the “PCC Details” fields and the “Allocating Flicker Emissions Limit” fields as discussed above and then pressing “Calculate” allows the module to compute the PCC (G_Pst) and “Emission Limit (E_Pst) values. Fields are also provided for the user to provide his/her own G_Pst and/or E_Pst values if preferred. An example completed Flicker Limits screen is provide in Figure 1-5. Depending on user selection, the “Calculated” or “User Defined” limits will be used in subsequent screens for comparison of estimated flicker results.

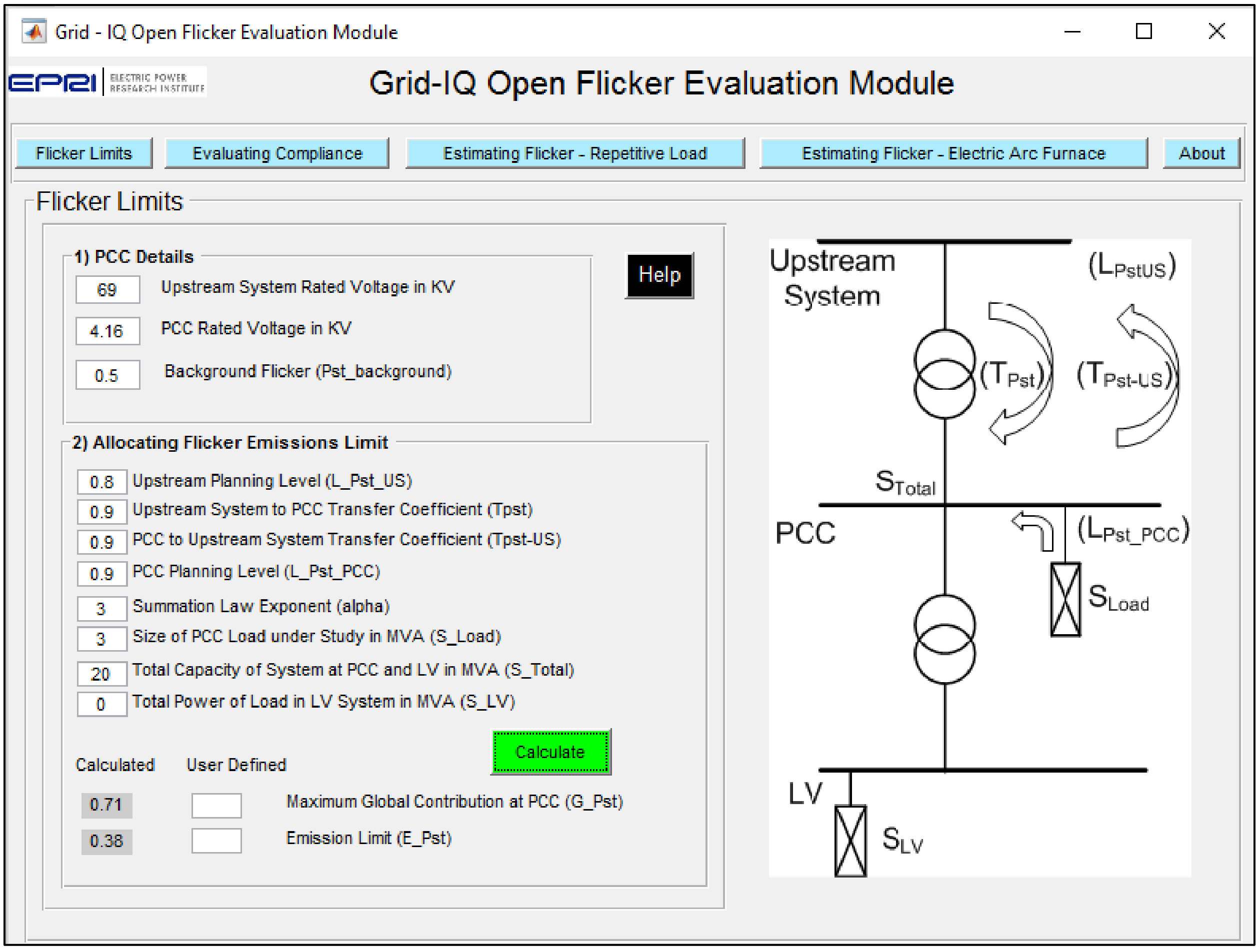

Figure 1-5
Completed Flicker Limits tab

Tab 2 – Evaluating Compliance

This is the second tab in the interface (See Figure 1-6). It deals with determining the flicker compliance for the utility or individual facilities based on the measurement data.

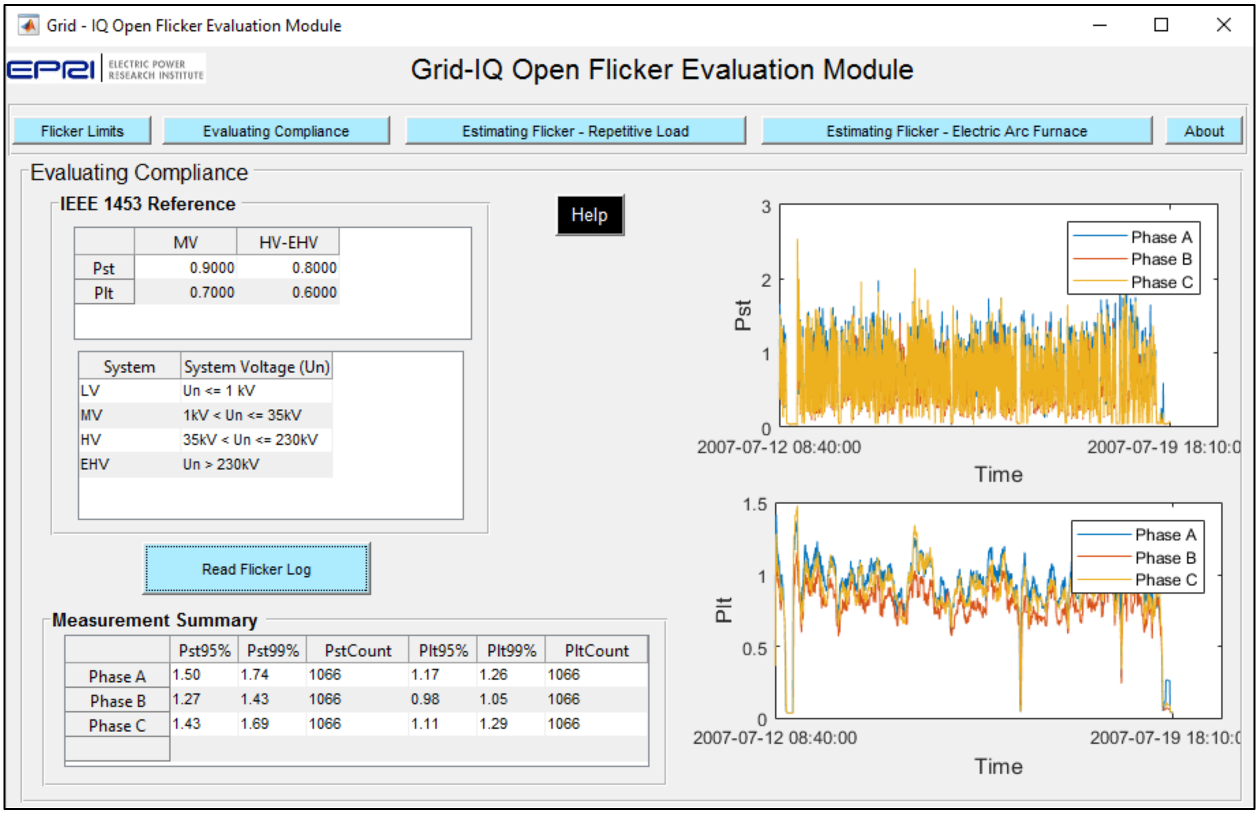

Figure 1-6
Evaluating Compliance tab

A button named "Read Flicker Log" has been provided to read the flicker data for the purpose of evaluating compliance. Clicking on this button will launch a file-selection dialog box (See Figure 1-7). The input file needs to have the format that is shown in Figure 1-8. The program reads from 4th line onwards. The top two lines can contain the header information related to the flicker measurement source and the meter. The third line explains the various parameters in the data from the next line onwards and their sequence that is expected in each line. These parameters can be typically obtained from the flickermeter output log. **It is recommended that a log of at least one week be used for evaluating compliance.**

The module performs the necessary computations, and the summary is provided in tabular form. The individual columns in the summary table are described as follows:

- Pst95%: 95th percentile value of short-term flicker index (Pst) over the evaluation period
- Pst99%: 99th percentile value of short-term flicker index (Pst) over the evaluation period
- Plt95%: 95th percentile value of long-term flicker (Plt) over the evaluation period
- Plt99%: 99th percentile value of long-term flicker (Plt) over the evaluation period

In order to check for compliance, 95th percentile values above can be compared against the planning levels and emission limits as determined in the "Flicker Limits" tab of the interface. The recommended planning levels based on system voltage level are also displayed in tabular form in the interface itself for reference, and the same are reproduced in Table 1-1 and Table 1-2.

In addition, Pst and Plt log is displayed in a plot form.

Table 1-1
System voltage levels (IEEE Std 1453-2015, Table 1, Page 15) [1]

System	System Voltage (U_N)
LV	$U_N \leq 1$ kV
MV	1 kV $< U_N \leq 35$ kV
HV	35 kV $< U_N \leq 230$ kV
EHV	$U_N > 230$ kV

Table 1-2
Planning levels for P_{st} and P_{lt} in MV, HV, and EHV power systems (IEEE Std 1453-2015, Table 2, Page 16)[1]

	Flicker Planning Levels	
	MV	**HV-EHV**
P_{st}	0.9	0.8
P_{lt}	0.7	0.6

[1] IEEE Standard 1453^{TM}-2015, *IEEE Recommended Practice for the Analysis of Fluctuating Installations on Power Systems*, 1992).

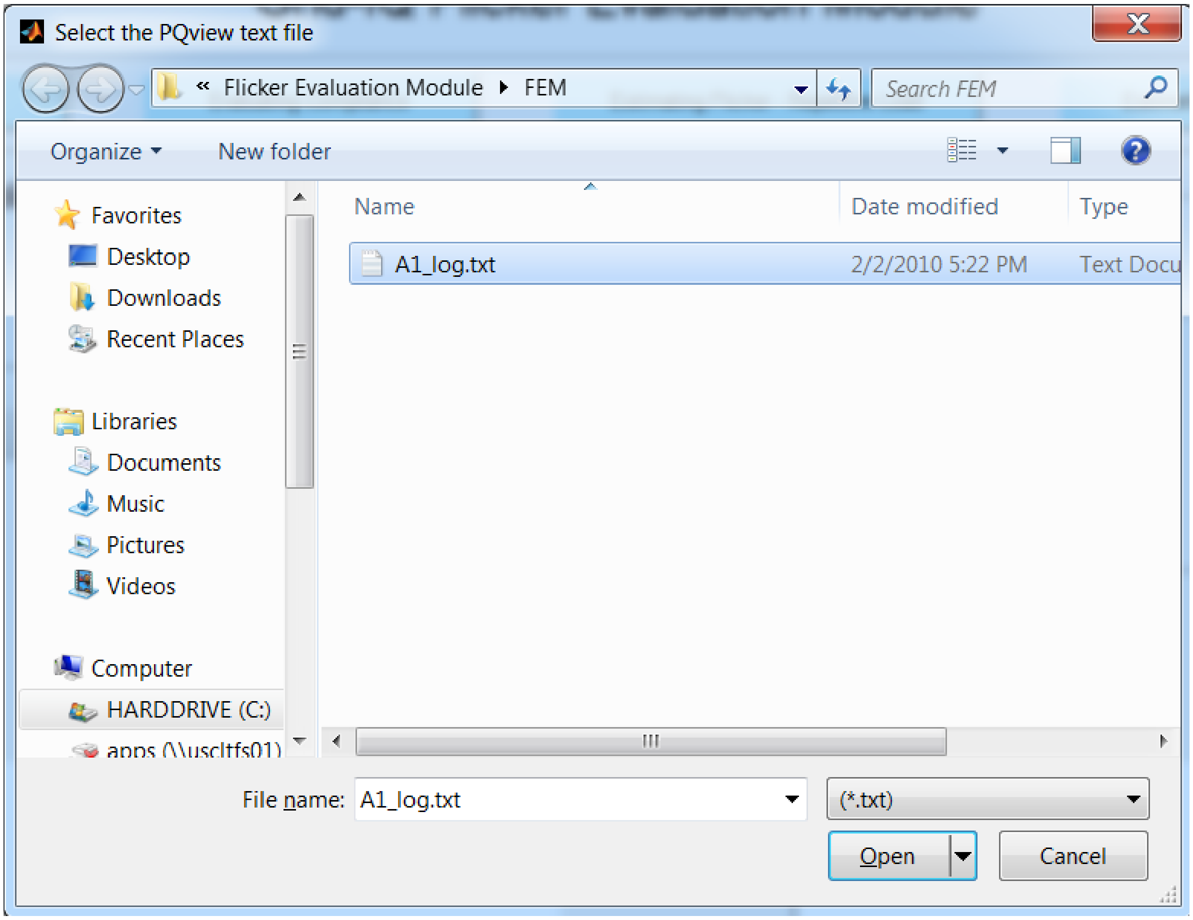

Figure 1-7
Flicker log-selection dialog box

```
[PQView SteadyState]
A1
V Flicker Pst A,V Flicker Pst B,V Flicker Pst C,V Flicker Plt A,V Flicker Plt B,V Flicker Plt C
2007-07-12 08:40:00,0.398,0.3854,0.3631,0.398,0.3854,0.3631
2007-07-12 08:50:00,1.6628,1.3961,1.5197,1.39934358309151,1.15995731309439,1.24336948794752
2007-07-12 09:00:00,0.9593,0.737,0.6943,1.41919073256617,1.20603820214766,1.28477264652263
2007-07-12 09:10:00,1.4573,1.2889,1.3604,1.29634961827527,1.10632593106222,1.17225113860648
2007-07-12 09:20:00,0.518,0.5357,0.4334,1.20584123588303,1.03021101671138,1.09100627353977
2007-07-12 09:30:00,0.3747,0.3699,0.3674,1.16912469960724,0.994169109376688,1.06755808838525
2007-07-12 09:40:00,0.9365,0.754,0.931,1.11318619592181,0.945750014087748,1.01657161346108
2007-07-12 09:50:00,0.4081,0.29542,0.3774,1.14319882066552,0.973660021867953,1.06674656608399
2007-07-12 10:00:00,1.3193,1.1352,1.3309,1.09940406599036,0.936339444802041,1.02585147681527
2007-07-12 10:10:00,0.19253,0.15767,0.17066,1.06152272630448,0.904101021975205,0.990510378159209
```

```
2007-07-19 16:30:00,0.04093,0.04092,0.04098,0.258916612170708,0.0605438919856965,0.0872519213630776
2007-07-19 16:40:00,0.04093,0.04178,0.04122,0.258904780266424,0.0604948506736762,0.0872116426178775
2007-07-19 16:50:00,0.04155,0.04166,0.04161,0.258844080337313,0.0604626062174707,0.0872085956400045
2007-07-19 17:00:00,0.03172,0.028729,0.027715,0.0407236986354826,0.0593340654149846,0.0860967386508518
2007-07-19 17:10:00,0.04093,0.04092,0.04026,0.0396471313192787,0.0388619850078658,0.0390227308782O9
2007-07-19 17:20:00,0.04537,0.0443,0.04431,0.0403481135183752,0.0386544143486085,0.0388634228693173
2007-07-19 17:30:00,0.04776,0.04183,0.0413,0.0401824513269583,0.038741106906478,0.0394626138397876
2007-07-19 17:40:00,0.04012,0.04092,0.04098,0.0401277689637248,0.0387195912912912,0.0393750534905217
2007-07-19 17:50:00,0.041,0.04109,0.04177,0.0402531539985751,0.0386873911136838,0.0394048109476568
2007-07-19 18:00:00,0.041,0.04109,0.04328,0.0460551907877609,0.0395416455286186,0.0396227520133087
2007-07-19 18:10:00,0.07709,0.08064,0.08068,0.0451391122690741,0.0463870974561425,0.0464522435670375
```

Figure 1-8

Flicker log file format

Tab 3 – Estimating Flicker – Repetitive Load

This section describes the various user inputs and parameters that are related to computing the flicker contribution from loads that are repetitive in nature with known duty cycle. The screenshot of the corresponding tab of the interface is shown in Figure 1-9. The limits corresponding to those calculated in the Flicker Limits tab are re-shown here for comparison. When the flicker of the repetitive load exceeds that of the flicker limits, the value is highlighted red. When below limits, the value is highlighted green.

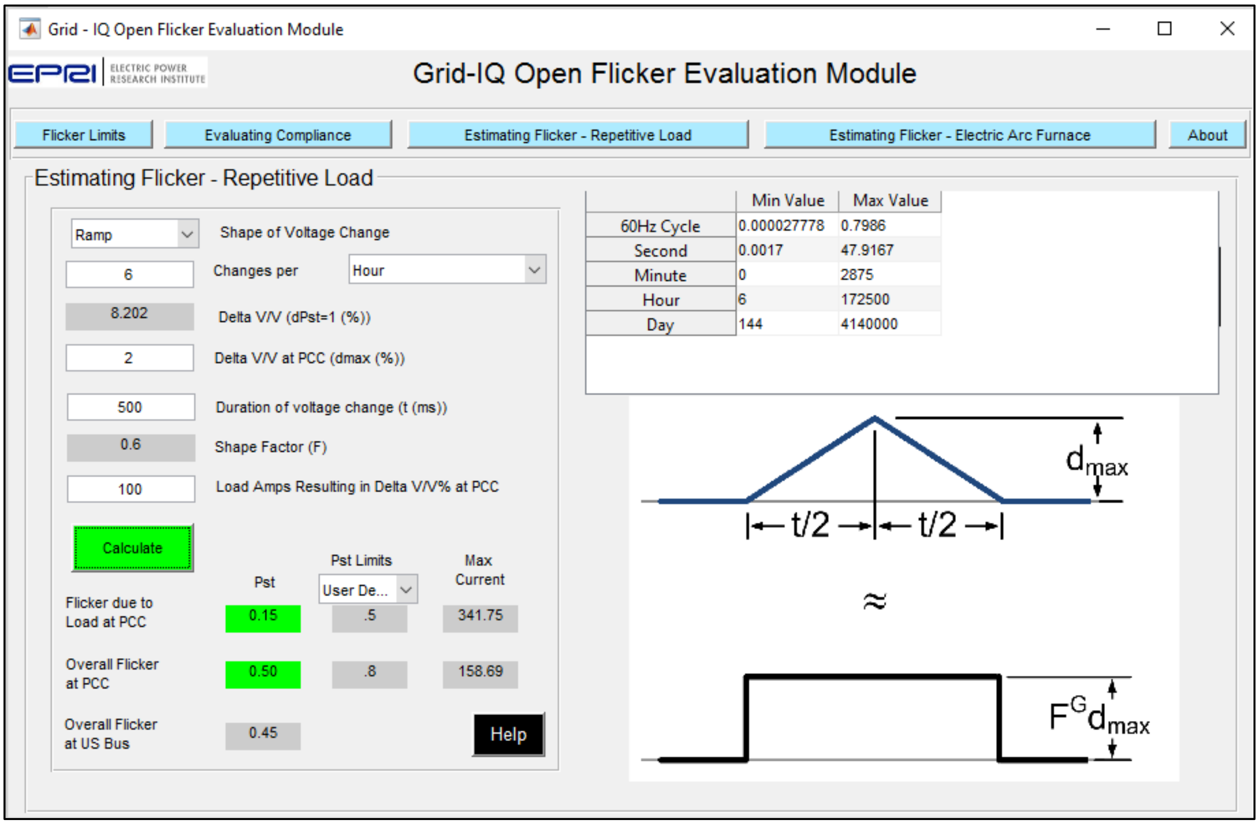

Figure 1-9
Estimating flicker – Repetitive Load tab

Various fields are explained here:

- Shape of voltage changes: The shape of changes in RMS voltage at PCC due to load operation. The shape change options are as follows and illustrated in
- Figure 1-10 through Figure 1-13:
    - o Rectangular
    - o Pulse
    - o Ramp
    - o Double-Pulse

  - Double-Ramp
  - Sinusoidal
  - Triangular
  - Aperiodic
- Number of changes per selected interval. Note: To avoid error message, select an interval before entering number of changes. This selection is disabled for aperiodic shape of voltage change. Otherwise, the selectable interval options are:
  - 60HzCycle
  - Second
  - Minute
  - Hour
  - Day

  * For Pulse or Ramp voltage change shapes changes per interval is the number of pulses or complete ramp cycles per interval.
- Delta V/V (dPst=1(%)) (from Pst=1 curve): Rectangular shape voltage change that would result in Pst of 1 corresponding to the changes per minute specified above. This value can be manually read from the plot in Figure 1-9. However, this module computes this value and populates this field automatically. This selection is disabled for Aperiodic shape of voltage change.
- Delta V/V at the PCC (dmax (%)): Actual voltage change as % of Nominal voltage that is expected at the PCC due to the load operation.
- Duration of voltage change (ms): The time it takes for rms voltage to change its level. This field is only available for the following shapes of voltage change:
  - Pulse*
  - Ramp*
  - Double-Pulse
  - Double-Ramp

  * The duration of the complete shape (up and down)
- t_1 (sec): The duration of the initial voltage sag due to an aperiodic load. This selection is only available for an aperiodic shape of voltage change.
- t_2 (sec): The remaining duration of an aperiodic load after time t_1. This selection is only available for an aperiodic shape of voltage change and is not defined for durations longer than 100 seconds. Use the value of 100 for t_2 when t_2 is greater than 100 seconds.
- Shape Factor: A factor that can be used to translate typical modulation waveforms into equivalent square wave modulating waveform in order to make use of “Pst=1” curve. These can be manually read using plots in
- Figure 1-10 through Figure 1-13. However, the module computes this factor based on the other field values and auto-populates this field.

- Load Amps Resulting in Delta V/V% at PCC is the current of the fluctuating load that causes the resulting Delta V/V% at PCC. This value is used to support the calculation of the “Max Current” values. Max Current describes how much larger the fluctuating load could be before flicker violations occur. For example, if the load is a rolling mill, the load current might change from 50 A to 150 A, causing the DeltaV/V of 2%. The value placed in the “Load Amps Resulting in Delta V/V% at PCC” would be 100 (= 150 A – 50 A).
- Flicker due to Load at PCC: This field gets computed once the user clicks on the “Compute” button. It is an estimate of the flicker contribution at the PCC from the load based on the user inputs above. To the right of this value is the associated “Flicker Limits” value established in the “Flicker Limits” section discussed earlier.
- Overall flicker at PCC: This field also gets computed once the user clicks on the “Calculate” button. It is the combination of flicker contribution of the load and any background flicker that has been specified in the “Flicker Limits” section.
- Pst Limits: This selection window allows the user to select Flicker Limits defined in the “Flicker Limits” section discussed earlier. The selection window allows either the “Calculated” limits to be used, or the “User Defined” limits may be selected. Once this selection is defined, the resulting limits are presented in the fields below the selection box to be used to support “Max Current” calculations when the “Calculate” button is activated.
- Max Current describes an estimate of how much larger the fluctuating load could be before exceeding the Flicker Limit value immediately to the left of the term.
- Overall Flicker at the US Bus is an estimation of the overall flicker at the upstream bus resulting from the overall flicker at the PCC as influenced by the PCC to Upstream System Transfer Coefficient (Tpst-US).

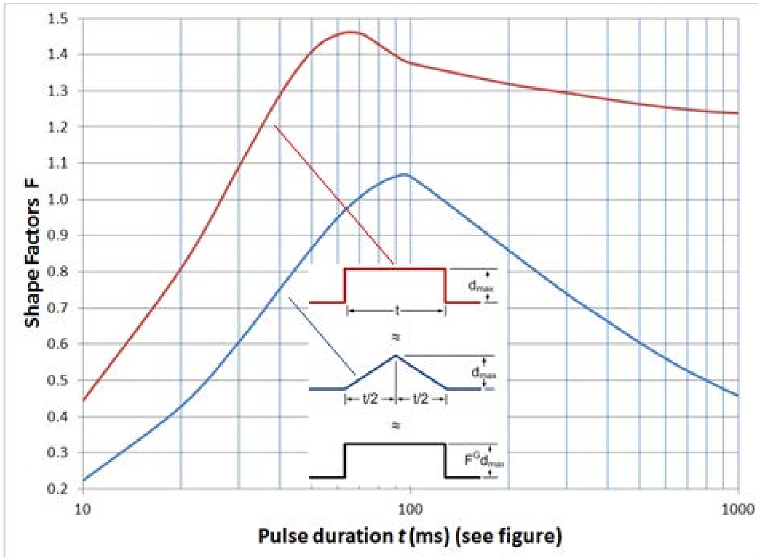

Figure 1-10
Shape factor for pulse and ramp changes (adapted from Figure E.1, IEEE Std 1453.1-2012)[2]

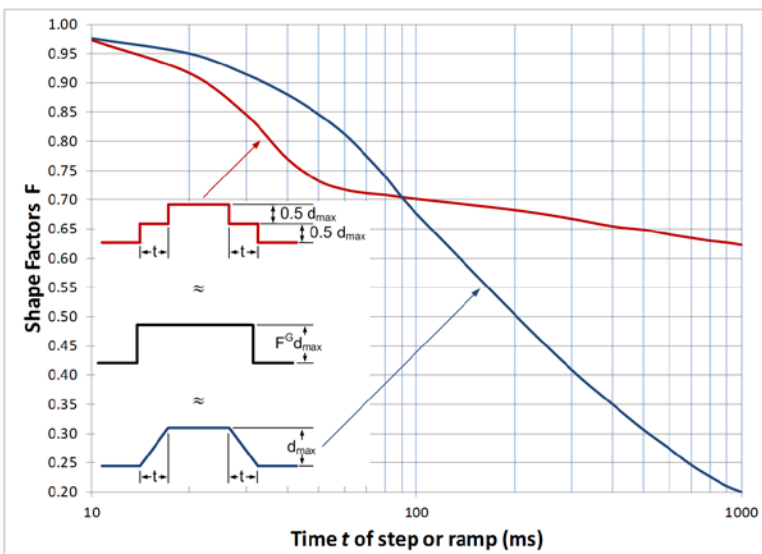

Figure 1-11
Shape factor for double step and double ramp changes (adapted from Figure E.2, IEEE Std 1453.1-2012)[3]

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[2] IEEE Standard 1453.1TM-2015, *IEEE Guide – Adoption of IEC/TR 61000-3-7:2008, Electromagnetic compatibility (EMC) – Limits – Assessment of emission limits for the connection of fluctuating installations to MV, HV, and EHV power systems.*
[3] IEEE Standard 1453.1TM-2015, *IEEE Guide – Adoption of IEC/TR 61000-3-7:2008, Electromagnetic compatibility (EMC) – Limits – Assessment of emission limits for the connection of fluctuating installations to MV, HV, and EHV power systems.*

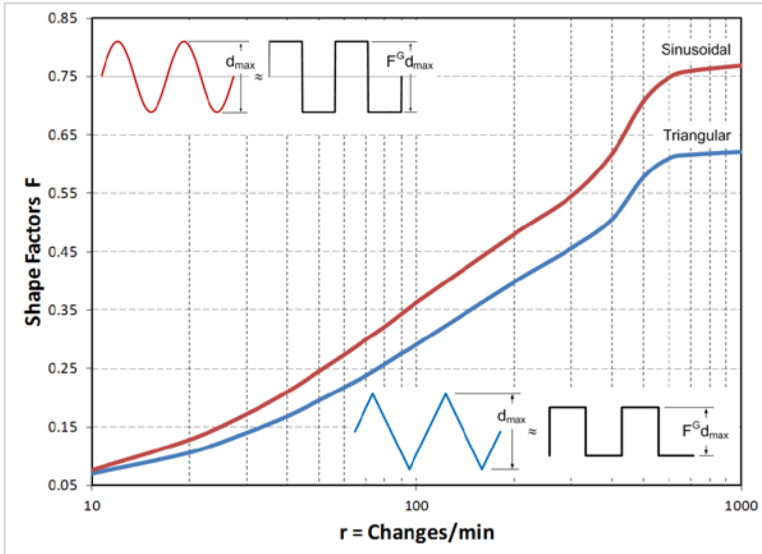

Figure 1-12
Shape factor for sinusoidal and triangular pulses (adapted from Figure E.3, IEEE Std 1453.1-2012)[3]

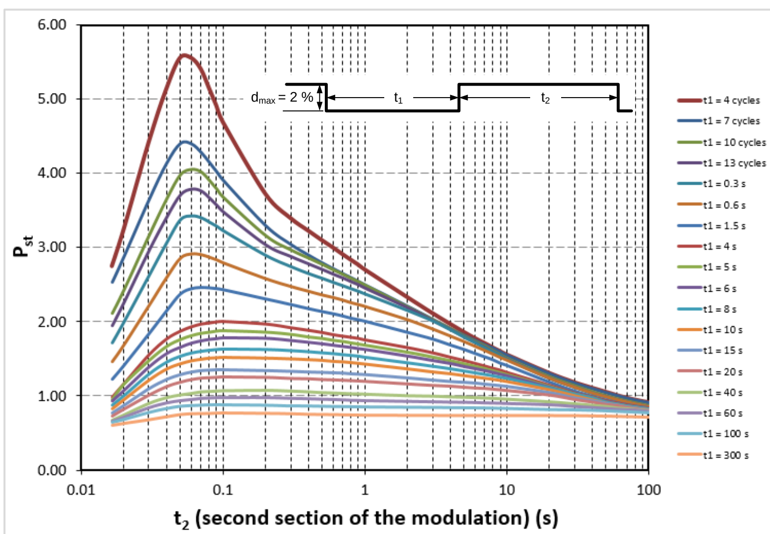

Figure 1-13
Shape factor curves for aperiodic changes (adapted from Figure E.4, IEEE Std 1453.1-2012)[4]

Tab 4 – Estimating Flicker – Electric Arc furnace

This section describes the various data fields related to computing the flicker contribution from an electric arc furnace installation. The screenshot of this tab in the user interface is shown in Figure 1-14. It also shows the single-line drawing of the typical AC electric arc furnace facility

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[4] IEEE Standard 1453.1™-2015, *IEEE Guide – Adoption of IEC/TR 61000-3-7:2008, Electromagnetic compatibility (EMC) – Limits – Assessment of emission limits for the connection of fluctuating installations to MV, HV, and EHV power systems.*

that identifies the key components. The limits corresponding to those calculated in the Flicker Limits tab are re-shown here for comparison. When the flicker of the Electric Arc Furnace load exceeds that of the flicker limits, the value is highlighted red. The value is highlighted green when the limits are not exceeded.

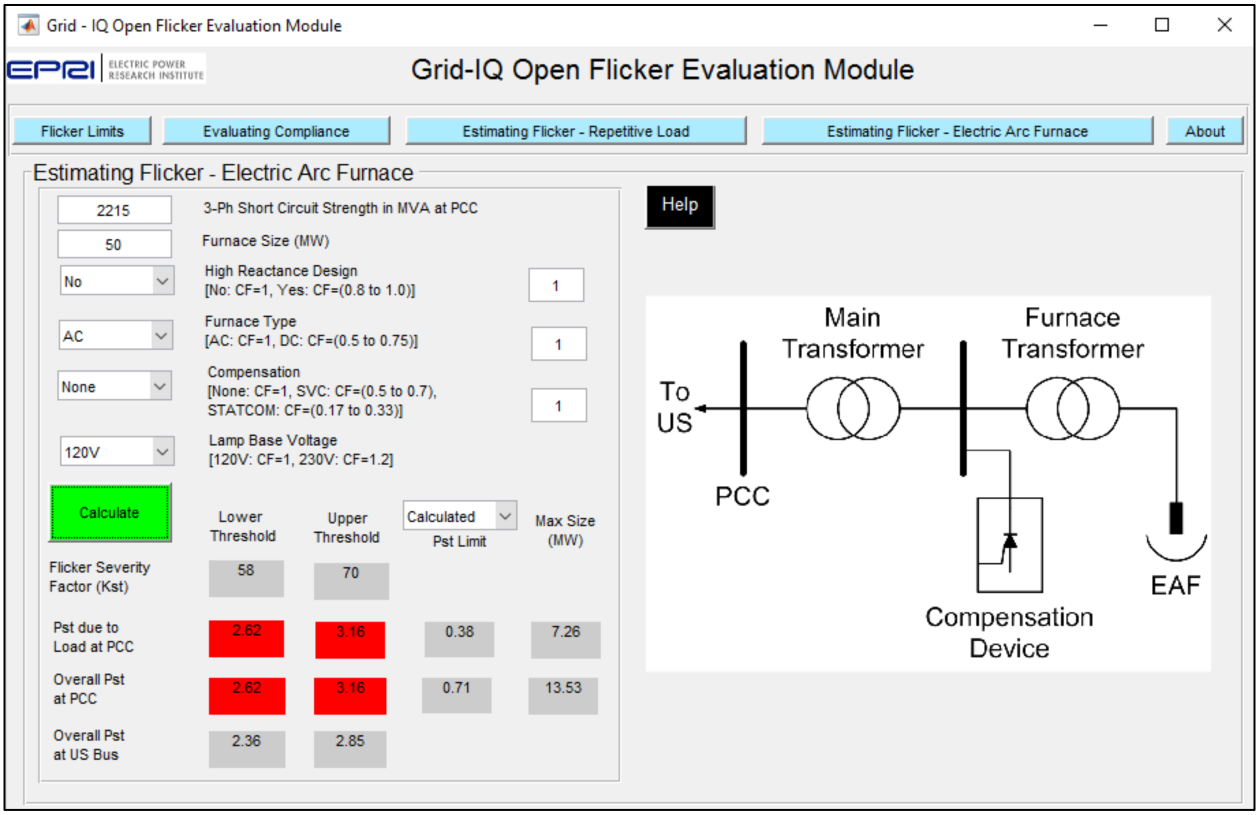

Figure 1-14
Estimating Flicker – Electric Arc Furnace tab

Various fields are explained here:

- 3-Ph Short circuit Strength in MVA at PCC: The three-phase short-circuit strength at PCC in MVA represents the stiffness of the system and is used to compute the estimated flicker contribution of the load.
- Furnace Size (MW): Size of the electric arc furnace in MW.
- High Reactance Design: Yes/No. Some electric arc furnace installations make use of additional reactance to stabilize and optimize the furnace process. Depending on the tap selection, flicker reduction of up to 20% (correction factor (CF) = 0.8) is attainable. A 20% reduction in flicker is assumed for high-reactance design. The box to the right of the “High Reactance Design” provides the associated default value of 0.8 based on the selection to the left of “High Reactance Design.” The user may modify the default value between 0.8 and 1.0 when the selection in the right box is “Yes.”

- Furnace Type: AC/DC. It is typically assumed that DC arc furnaces will only have about 50% to 75% of the flicker levels associated with a similarly sized AC furnace. A 50% reduction in flicker is assumed for DC design. The box to the right of the “Furnace Type” provides the associated default value of 0.5 based on the selection to the left of “DC.” The user may modify the default value between 0.5 and 0.75 when the selection in the right box is “DC.”
- Compensation: Adaptive var compensation serves to compensate for the reactive power variations resulting in significant reduction in the flicker contribution. SVC (static var compensator) with thyristor-controlled reactors can typically provide up-to 50% reduction of flicker levels with optimized controls. Newer compensators known as STATCOM (Static Compensator) can be used for even better reduction of flicker levels. These systems can be designed for very fast control of the voltage fluctuations to achieve just about whatever level of flicker reduction is needed, dependent only on the sizing and controls for the STATCOM. A flicker reduction factor between 3 and 6 can be assumed for a STATCOM. A 50% reduction in flicker is assumed for SVC and 83% for STATCOM. The box to the right of “Compensation” provides the default value based on the type of compensation selected. When SVC compensation is selected, the correction factor (CF) value in the box to the right may be changed from 0.5 to 0.7. Similarly, when STATCOM compensation is selected, the correction factor (CF) value in the box to the right may be changed from 0.2 to 0.33.
- Lamp Base Voltage: Pst values were first defined for 230-V lamps. When the IEC standard was adopted for 120-V lamps, it became necessary to adjust the results. Consequently, the Lamp Base Voltage must be defined for the analysis. The correction factor for the Lamp Base Voltage may not be changed as these are standard values.
- Flicker severity factor (Kst): A measure of the arc furnace flicker-causing characteristics independent of the effect of the short-circuit strength. Typical values range between 58 and 70. Lower values represent optimal furnaces.
- Flicker at PCC due to Load (Pst95%): In response to clicking the “Calculate” button, this tool computes and populates the range (lower and upper limit) of expected flicker contribution of the arc furnace installation (95^{th} percentile value of Pst) based on the user selections above.
- Overall flicker at PCC (Pst95%): These are the overall flicker levels that can be expected at the PCC based on the combined impact of the arc furnace operation and any specified background flicker.
- Overall flicker at US Bus (Pst95%): These are an estimation of the overall flicker levels that can be expected at the upstream bus resulting from the overall flicker at the PCC as influenced by the PCC to Upstream System Transfer Coefficient (Tpst-US) provided in the Flicker Limits section.
- Pst Limits: This selection window allows the user to select Flicker Limits defined in the “Flicker Limits” section discussed earlier. The selection window allows either the “Calculated” limits to be used or the “User Defined” limits may be selected. Once this selection is defined, the resulting limits are presented in the fields below the selection box to be used to support “Max Current” calculations when the “Calculate” button is activated.
- Max Current describes an estimate of how much larger the fluctuating load could be before exceeding the Flicker Limit value immediately to the left of the term.

Tab 5 – About

This tab contains the following notice text elements:

- Copyright
- Disclaimer
- Ordering Information

The screenshot of this tab is shown in Figure 1-15.

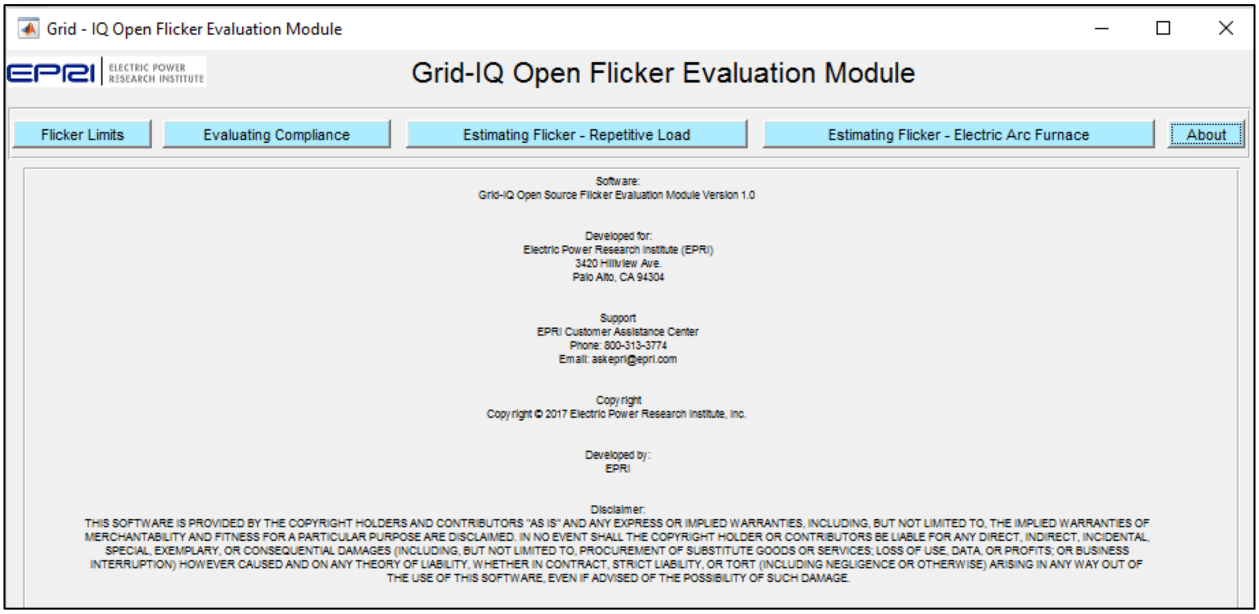

Figure 1-15
About tab

TEST CASES

This chapter presents the two case studies that illustrate the usage of this tool

Test Case 1 – Estimating Flicker due to Rolling Mill

This case deals with estimating flicker due to the operation of a rolling mill whose load profile is known. A rolling mill example is presented here from IEC Standard 61000-3-7. The expected voltage profile at the PCC due to the operation of the mill is shown in Figure 2- .

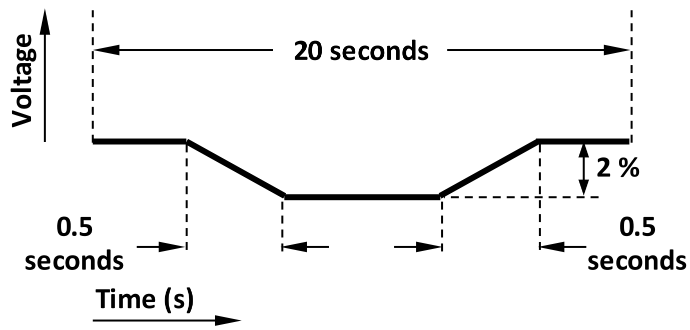

Figure 2-1
Expected voltage profile at PCC due to rolling mill

Flicker Limits Tab – Input Fields and Computed Values

The various input fields and computed values for this case are provided in this section.

PCC Details

- Upstream System Rated Voltage in kV: 69
- PCC Rated Voltage in kV: 4.16
- Background flicker (Pst background): 0.5

Allocating Flicker Emission Limit

- Upstream Voltage Planning level (L_Pst_US): 0.8 (recommended)
- Upstream System to PCC Transfer Coefficient (Tpst). 0.9 (assumed)
- PCC to Upstream System Transfer Coefficient (Tpst_US). 0.9 (assumed)
- PCC Planning level (L_Pst_PCC): 0.9 (recommended)
- Summation Law exponent (alpha): 3 (assumed)
- Load agreed power in MVA (S_Load): 3
- Total capacity of system at PCC in MVA (S_Total): 20
- Total power of installations in downstream LV system in MVA (S_LV): 0

Clicking on the “Calculate” button yields the following results:

- Maximum global contribution at PCC (G_Pst): 0.71
- Emission limit (Pst): 0.38

Based on system details and loading information at the PCC, the module has computed for the rolling mill load an emission limit of 0.38 for Pst. This load falls in the category of "Repetitive Loads," so the next section presents the various fields and computed values under "Estimating Flicker – Repetitive Load" Tab.

Estimating Flicker – Repetitive Load 1 – Input Fields and Computed Values

- Shape of voltage changes: Double-Ramp
  (be careful that Double-Ramp is selected and not Double-Pulse; they both look the same if the FEM window is sized too small.)
- Number of changes per minute: 6 (see 2 changes in 20 sec duration in Figure 2-)
- Delta V/V (%) at PCC: 2 (see Figure 2-)
- Duration of voltage change (ms): 500 (see Figure 2-)
- Load Amps Resulting in Delta V/V% at PCC: 100

Clicking on the "Calculate" button yields the following results:

- Delta V/V (%) (from Pst=1 curve): 1.797 (computed by module)
- Shape Factor: 0.3 (computed by module)
- Flicker due to Load at PCC:
  - Value: 0.33
  - Limit: 0.38
  - Max current: 113.81
- Overall flicker at PCC:
  - Value: 0.55
  - Limit: 0.71
  - Max current: 130.18
- Overall flicker at US Bus: 0.49

It may be noted that flicker estimated due to load at the PCC is below the emission limit determined in the previous section, so no mitigation step is required. Also, overall flicker value is much lower than the recommended planning level meaning, there is some margin to add additional flicker-causing loads at the PCC. The Max Current level indicates the amount of load current that would be allowed without exceeding the indicated flicker limits.

Estimating Flicker – Repetitive Load 2 – Input Fields and Computed Values

All variables are similar to repetitive load 1 except for:

- Shape of voltage changes: Rectangular

Clicking on the "Calculate" button yields the following results:

- Shape Factor: 1 (computed by module)

- Flicker due to Load at the PCC:
  - Value: 1.11
  - Limit: 0.38
  - Max current: 34.14
- Overall flicker at the PCC:
  - Value: 1.15
  - Limit: 0.71
  - Max current: 61.97
- Overall flicker at US Bus: 1.03

The flicker estimated due to load at the PCC is above the emission limit, so mitigation steps would be required. Also, overall flicker value is above the recommended planning level, meaning that there would be no margin to add additional flicker causing loads at the PCC. The Max Current levels indicate the amount of load current that would be allowed without exceeding the indicated flicker limits. In this case, without other mitigation, significant current reduction would be required to meet flicker limits.

Estimating Flicker – Repetitive Load 3 – Input Fields and Computed Values

Random loads (such as motor starts) that may not recur within a specific 10-minute window may be considered aperiodic in nature. The resulting aperiodic voltage changes may be evaluated on a Pst basis. For example, assume that a large motor that was started cross-line takes 10 seconds to start while drawing up to 836 A and then runs in excess of 100 seconds. The voltage drop during starting is 2%. Assuming the same PCC details and allocated flicker emissions limits setting used in the above two examples, we need to determine whether the load exceeds the Flicker due to the load at the PCC and the Overall Flicker at the PCC. To do this, assume all variables are similar to repetitive load 1 except for:

- Shape of voltage changes: Aperiodic
- Delta V/V (%) at PCC: 2
- t1 (sec): 10
- t2 (sec): 100
- Load Amps Resulting in Delta V/V% at PCC: 836

Clicking on the “Calculate” button yields the following results:

- Flicker due to Load at PCC:
  - Value: 0.81
  - Limit: 0.38
  - Max current: 389.79
- Overall flicker at PCC:
  - Value: 0.87
  - Limit: 0.71

- Max current: 679.57
- Overall flicker at US Bus: 0.79

The flicker estimated due to load at the PCC is above the emission limit, so mitigation steps would be required. However, overall flicker value is below the 0.9 recommended planning level, meaning it may be possible to accept this load, assuming that no additional flicker-causing loads at the PCC or upstream are added. The Max Current levels indicate the amount of load current that would be allowed without exceeding the indicated flicker limits.

Now, let's try to mitigate the flicker level. Assume we provide a part-voltage starter that only applies ½ voltage during the starting sequence. Assume this reduces the starting current to 418 A but requires twice as long (20 sec.) to start. The voltage drop during starting is 1%. How will these new parameters effect the flicker at the PCC? To determine this, assume all variables are similar to repetitive load 1 except for:

- Shape of voltage changes: Aperiodic
- Delta V/V (%) at PCC: 1
- t1 (sec): 20
- t2 (sec): 100
- Load Amps Resulting in Delta V/V% at PCC: 418

Clicking on the "Calculate" button yields the following results:

- Flicker due to Load at PCC:
  - Value: 0.41 (red background)
  - Limit: 0.38
  - Max current: 392.20
- Overall flicker at the PCC:
  - Value: 0.58 (green background)
  - Limit: 0.71
  - Max current: 514.95
- Overall flicker at US Bus: 0.52

While the flicker estimated due to load at the PCC is still slightly above the emission limit due to load at the PCC, the overall flicker at the PCC has now dropped below the 0.71 limit. This solution seems to be a feasible mitigation approach.

Test Case 2 – Estimating Flicker due to AC Electric Arc Furnace

Flicker Limits Tab – Input Fields and Computed Values

The various input fields and computed values for this case are provided in this section.

PCC Details

- Upstream System Rated Voltage in kV: 345
- PCC Rated Voltage in kV: 138

- Background flicker (Pst_background): 0.2

Allocating Flicker Emission Limit

- Upstream Voltage Planning level (L_Pst_US): 1.0
- Upstream System to PCC Transfer Coefficient (Tpst). 0.8
- PCC to Upstream System Transfer Coefficient (Tpst_US). 0.9
- PCC Planning level (L_Pst_PCC): 1.0
- Summation Law exponent (alpha): 3 (assumed)
- Size of PCC Load under Study MVA (S_Load): 200
- Total capacity of system at PCC in MVA (S_Total): 200
- Total power of installations in downstream LV system in MVA (S_LV): 0
- Calculated Pst Limits:
  - Maximum global contribution at PCC (G_Pst): 0.79
  - Emission limit (E_Pst): 0.79
- User Defined Pst Limits:
  - Maximum global contribution at PCC (G_Pst): 0.7
  - Emission limit (E_Pst): 0.5

Based on system details and loading information at the PCC, the module has computed for the electric arc furnace emission limits of 0.79 for both G_Pst and E_Pst. The next section presents the various fields and computed values under “Estimating Flicker – Electric Arc Furnace” tab.

Estimating Flicker – Electric Arc Furnace Tab – Input Fields and Computed Values

Case 1 – Base Case (AC Arc Furnace Without Compensation)

- 3-Ph Short circuit Strength in MVA at PCC: 2215
- Furnace Size (MW): 50
- High reactance design: No
  - Results in CF = 1 value in box on right
  - Attempting to change default value causes “Value out of range” error message.
- Furnace Type: AC
  - Results in CF = 1 value in box on right
  - Attempting to change default value causes “Value out of range” error message.
- Compensation: None
  - Results in CF = 1 value in box on right
  - Attempting to change default value causes “Value out of range” error message.
- Lamp Base Voltage: 120 V

- Flicker severity factor (Kst) – 58 (lower limit) and 70 (upper limit)
- Flicker at PCC due to Load (Pst95%)
    - 2.62 (lower limit) and 3.16 (upper limit)
    - Max Size (MW): 15.08
- Overall flicker at PCC (Pst95%)
    - 2.62 (lower limit) and 3.16 (upper limit)
    - Max Size (MW): 15.08
- Overall flicker at US Bus (Pst95%)
    - 2.36 (lower limit) and 2.84 (upper limit)
- Pst Limits Based on: Calculated
    - Pst due to Load at PCC limit: 0.79
    - Overall Pst at PCC limit: 0.79
- Changing Furnace size to 15 MW
    - Achieves Lower Threshold values showing up in green background
- Changing Furnace size to 12 MW
    - Achieves Upper Threshold values showing up in green background
- Changing to “User Defined” Pst Limits
    - With 12 MW Furnace Size
        - Exceeds 3 of 4 Thresholds
    - With 10 MW Furnace Size
        - Exceeds 2 of 4 thresholds
    - With 9 MW Furnace Size
        - Meets all 3 of 4 thresholds
    - With 7 MW Furnace Size
        - Meets all 4 thresholds
- Change Furnace size back to 50 MW and back to “Calculated” Pst Limit
    - Both Lower and Upper Threshold values should be exceeded with red background.

Case 2 – DC Arc Furnace Without Compensation

- 3-Ph Short circuit Strength in MVA at PCC: 2215
- Furnace Size (MW): 50
- High reactance design: No
- Furnace Type: DC
    - Results in default CF = 0.5 value in box on right
    - Default value may be changed from 0.5 to 0.75 without error message.

- Compensation: None
- Lamp Base Voltage: 120 V
- Pst Limits Based on: Calculated
  - Pst due to Load at PCC limit: 0.79
  - Overall Pst at PCC limit: 0.79
- Flicker severity factor (Kst) – 58 (lower limit) and 70 (upper limit)
- Flicker at PCC due to Load (Pst95%)
  - 1.31 (lower limit) and 1.58 (upper limit)
  - Max Size (MW): 30.17
- Overall flicker at PCC (Pst95%)
  - 1.31 (lower limit) and 1.58 (upper limit)
  - Max Size (MW): 30.13
- Overall flicker at US Bus (Pst95%)
  - 1.18 (lower limit) and 1.42 (upper limit)
- Changing Furnace size to 30 MW
  - Achieves Lower Threshold values showing up in green background
  - Changing Furnace size to 24 MW
  - Achieves Upper Threshold values showing up in green background
- Change Furnace size back to 50 MW

Note: Impact of changing Furnace Types from Case 1 to Case 2 allows a larger Furnace Size with DC Type Furnace.

Case 3 - AC arc furnace with SVC

- 3-Ph Short circuit Strength in MVA at PCC: 2215
- Furnace Size (MW): 50
- High reactance design: No
- Furnace Type: AC
- Compensation: SVC
  - Results in default CF = 0.5 value in box on right
  - Default value may be changed from 0.5 to 0.75 without error message.
- Lamp Base Voltage: 120 V
- Flicker severity factor (Kst) – 58 (lower limit) and 70 (upper limit)
- Flicker at PCC due to Load (Pst95%)
  - 1.31 (lower limit) and 1.58 (upper limit)
  - Max Size (MW): 30.17

- Overall flicker at PCC (Pst95%)
  - 1.31 (lower limit) and 1.58 (upper limit)
  - Max Size (MW): 30.13
- Overall flicker at US Bus (Pst95%)
  - 1.18 (lower limit) and 1.42 (upper limit)

Case 4 – AC Arc Furnace with STATCOM

- 3-Ph Short circuit Strength in MVA at PCC: 2215
- Furnace Size (MW): 50
- High reactance design: No
- Furnace Type: AC
- Compensation: STATCOM
  - Results in default CF = 0.17 value in box on right
  - Default value may be changed from 0.17 to 0.33 without error message.
- Lamp Base Voltage: 120 V
- Flicker severity factor (Kst) – 58 (lower limit) and 70 (upper limit)
- Flicker at the PCC due to Load (Pst95%)
  - 0.45 (lower limit) and 0.54 (upper limit)
  - Max Size (MW): 88.73
- Overall flicker at PCC (Pst95%)
  - 0.46 (lower limit) and 0.55 (upper limit)
  - Max Size (MW): 86.2
- Overall flicker at US Bus (Pst95%)
  - 0.41 (lower limit) and 0.49 (upper limit)

Note: Impact of changing Compensation from Case 3 to Case 4 allows a larger Furnace Size with STATCOM compensation.

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