

SOFTWARE IMPLEMENTATION OF POWER QUALITY STANDARDS

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ABSTRACT

In recent years, equipment and network standards have been increasing in both number and complexity. Two standards that will soon be introduced to Australia are the MV and HV standards for assessing distorting and fluctuating loads, AS/NZS 61000.3.6 and AS/NZS 61000.3.7, respectively. Utility engineers, being under increasing time constraints, are turning more and more to software to quickly solve problems. This paper describes the methodology used to implement the above standards in Microsoft Excel in order to assist utility engineers to readily apply these standards in practical situations. The assumptions and simplifications used in this implementation are described.

1. INTRODUCTION

The de-regulation of the power industry has actually brought about an increase in regulation in some areas. One such area is power quality where State regulators are insisting on performance requirements with a greater degree of accountability than ever before. At the same time, the IEC is developing power quality standards with a greater scope and complexity and these are progressively being adopted as national standards by countries like Australia as obliged under the GATT Agreement. In addition, there is a trend towards standards becoming less prescriptive, relying more on general principles. This trend has resulted in modern standards being less clear and not as straightforward to use. Added to this are the facts that standards are generally not used regularly enough for familiarity, utility engineers are under increasing workloads and manual assessment carries the risk of errors. Also, these standards do not make use of calculation procedures that are well publicised or widely known and the symbols that are used are generally peculiar to the standards themselves.

All these considerations make software implementation of standards an attractive proposition. Once the approach of computer-assisted standards assessment is accepted, other benefits not previously considered become possible.

It should be possible to provide automatic documentation of each case. As well as the date and name of the study, all input data can be listed as well as the results of calculations for each step of the standard and an indication of the particular clause causing a proposed installation to pass or fail.

Sensitivity analyses can be performed automatically to identify the effect of changes in each input parameter.

This will allow the calculation of sensitivity indices and the identification of the data which needs to be known accurately. This may give more confidence in the results as some of the parameters in the standards are not well defined and only best-guess values are given.

Software can be easily linked to databases and analysis packages, etc so that when one does a particular study one can easily load in the relevant short-circuit levels and system capabilities plus other information that should be stored in a utility database. Considering a specific example of the flicker standard which deals with the flicker severity indices P_{st} and P_{lt} , it would be possible to link the standard with an analysis package which computes the indices from supplied voltage waveforms.

This paper is intended as a feasibility study of software implementation of two of the more complex power quality standards, IEC 61000.3.6 [1] and IEC 61000.3.7 [2]. Both are intended to give limits on disturbances produced by customer loads in MV/HV power systems, the first limiting harmonics and the second limiting flicker. The two standards have almost completed their normal Standards Australia review process and are due to be formally adopted later this year.

2. PHILOSOPHY BEHIND THE STANDARDS [3]

For AS/NZS 61000.3.6, the quantities used for evaluation are harmonic voltages (as a percentage of nominal voltage) while for AS/NZS 61000.3.7 they are short- and long-term flicker severity indices, P_{st} and P_{lt} respectively. For both standards, a statistical approach is taken for evaluating the effect of time variation.

Reference values, called Compatibility Levels, are stated for co-ordinating the emission and immunity of equipment connected to the supply network to ensure EMC in the whole system. These Compatibility Levels are based on 95% probability levels of entire systems using distributions that represent both time and space variations of disturbances.

Also defined are Planning Levels. These are used by the utility for planning purposes in evaluating the impact of consumer loads on the supply system. Planning Levels are specified by the utility for all voltage levels of the system and will differ from case to case depending on network structure and circumstances. Planning Levels are equal to or lower than Compatibility Levels. Indicative values for Planning Levels are given in the standards.

The relationship between Compatibility Levels and Planning Levels is illustrated in Figure 1 (taken from the standards):

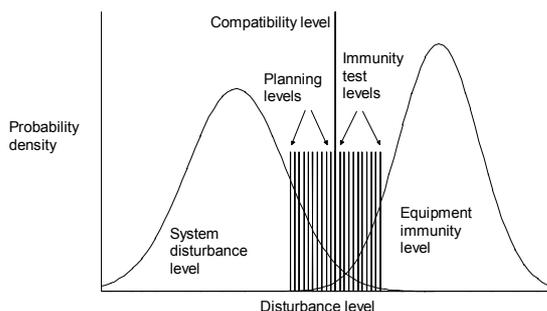


Figure 1: Relationship between Compatibility Level and Planning Levels for whole system.

Assessment of loads is made using measured or calculated harmonic voltages/currents or P_{st}/P_{lt} values. The values used are statistical quantities, either 95% or 99% probabilities over defined time intervals, so that time variations of the values can be accounted for.

3. SOFTWARE CONSIDERATIONS

These standards are not as well defined as the previous harmonic and flicker standards AS 2279 [4]. For example, the harmonic standard has under each stage several different tests but does not give any recommendation as to when to use a particular test. This probably arises from their IEC status being not that of a full international standard but a Technical Report Type III, that is a collection of useful facts and calculation techniques. It is likely that the Australian power industry will develop an agreed industry approach to the use of this standard in the future but

for now the programmer has to make a decision as to the likely approach taken and put some flexibility into the software so as not to inhibit other approaches.

The standards are not designed to be used in a paragraph-by-paragraph fashion but are written discursively. Possibly this reflects their origin in passing through many committee meetings with piecemeal corrections and additions. Consequently some aspects in the early pages do not become clear until one has read through the later parts of the standard. It is tempting for the programmer to ignore totally the structure of the standard and concentrate on the underlying algorithm. This has the danger that it may be difficult later to relate parts of the software with the corresponding parts of the standard, making changes to the software very difficult when the standard is modified.

The standard states that utilities are ultimately responsible for the level of harmonic voltages and flicker in their power system allows them some flexibility in their use of the standard. For example the harmonic planning levels given are explicitly stated as being indicative values. The only constraint is that they be less than the Compatibility levels. A utility may wish to choose smaller values where there are uncertainties to give a safety margin. Software must then allow the user to make changes in parameters from the default ones given in the standard.

There is a responsibility to make the program as error free as possible and to adopt a rigorous programming style which minimises errors.

The choice of programming language is also important:

- it should be well supported now and into the future;
- it should incorporate good database and graphics features.

Some candidates that were considered were Microsoft Excel, The MathWorks MATLAB and Microsoft Visual Basic. Excel was chosen because it is excellent for prototype development. All input, output and intermediate calculations can be displayed and it is widely supported. One problem with Excel is that it is not easily amenable to sequential comparisons without resorting to purpose-written macros in Visual Basic, although some of this can be allowed for by good program design.

4. IMPLEMENTATION OF AS/NZS 61000.3.6

We will describe the implementation of the standard for MV systems only to give an example of the approach that we recommend. The standard details evaluation of distorting loads in three stages, shown in

the flow chart of Figure 2 below (taken from the standard):

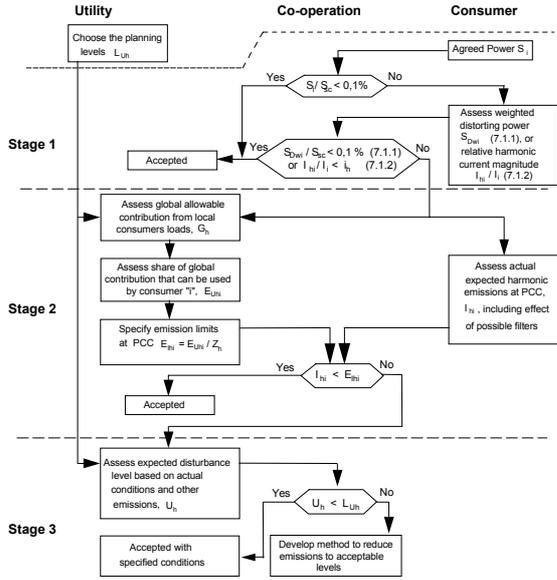


Figure 2: Diagram of Evaluation Procedure for AS/NZS 61000.3.6

Strict application of all calculation methods in the standard would be tedious and is probably unnecessary in most cases. Until significant experience is obtained using the standard in the Australian context, the following simplified assessment approach would seem reasonable, based on some experience we have had in applying the standard to actual cases in the Integral Energy system:

- Only consider the 5th harmonic unless notching or capacitor resonance is important;
- Use the second summation law with $\alpha = 1.4$ for the 5th harmonic;
- First apply Stage 1 / Test 1;
- Then apply Stage 2 / Test 1;
- Finally apply Stage 2 / Test 3 if Stage 2 / Test 1 fails and the assessed installation is separated from the supply point by a significant impedance.

The final step is described very sketchily in the standard and has not been implemented in the example program.

4.1 Stage 1: simplified evaluation requiring short-circuit level (S_{sc}) at PCC

In this stage, small consumers or consumers with only a limited amount of distorting load can be approved without detailed evaluation. Three tests are specified. Test 1 is based on customer agreed power S_i and a pass occurs if $S_i/S_{sc} < 0.1\%$. Test 2 is based on ratings and type of each non-linear load while Test 3 is based on the current spectrum. Either are applied if Test 1

fails. Only Test 1 is implemented in the example program.

4.2 Stage 2: emission limits relative to actual network characteristics

In this stage, the appropriate planning level is apportioned to each individual consumer in accordance with his share of the total capacity of the supply network to which his installation is connected. Detailed information about supply capability, network impedance, installation size and harmonic current spectrum are needed. For each load i & harmonic order h , a current emission limit E_{lhi} is determined.

Three levels of assessment are specified according to network and load diversity conditions:

1. Supply point close to all loads, no LV/MV diversity;
2. Supply point close to all loads, LV/MV diversity considered;
3. Loads spread along a feeder with significant impedance.

Only the first situation is implemented in the example program.

To enable assessment, the method of summation of the disturbances produced by various loads needs to be chosen. The standard presents two summation laws that are commonly used to allow for diversity and phase-shift between harmonic sources. The first is a simple linear law making use of diversity factors. The second law is more general and uses empirically determined exponents. This second law is used in the example program.

The first quantity to be calculated is the allowable global emission to be shared between the consumers. If L_{hMV} is the planning level, accounting for the contribution to the MV level from upstream using the second summation law, gives the following available to MV consumers:

$$G_{hMV+LV} = \sqrt[\alpha]{L_{hMV}^\alpha - (T_{hHM}L_{hHV})^\alpha} \quad (1)$$

The allowance for a particular consumer "i" is given by:

$$E_{Uhi} = G_{hMV+LV} \cdot \sqrt[\alpha]{\frac{S_i}{S_t}} \quad (2)$$

For the case of no capacitor resonance, the standard gives consumer "i" an harmonic current allowance of:

$$E_{lhi} = \frac{E_{Uhi}}{Z_h} \quad (3)$$

4.3 Example Program

The main Excel worksheet is divided up into distinct areas.:

- Input data output results
- Data from the standard with relevant clause number as a label
- Intermediate calculations
- A list of all output messages

Every output has a clause number for easy identification.

The user has access to:

- The input cells
- The data cells if modified values of planning levels, α etc are to be used.

The user interface of the example program is shown in Figure 3.

| | A | B | C | D | E | F | G | H |
|----|---|----------------------|----------------------|------------|---------------------|---------|-------|----------------------|
| 1 | IEC 61000.3.6 | | Intermediate | Data | Used | Default | | Messages |
| 2 | Project Name | Demo | | | | | | |
| 3 | Date | 31-7-2000 | | | | | | |
| 4 | | | | | | | | |
| 5 | Stage 1/Test 1 | | Clause 7.1 | Clause 7.1 | | | | |
| 6 | Input installation rating (MVA) S_i | 3.50 | S_i/S_{sc} | 0.02 | S_1/I_1 limit | 0.001 | 0.001 | |
| 7 | Input fault level at pcc (MVA) S_{sc} | 150.00 | | | | | | Fail - go to Stage 2 |
| 8 | Result | Fail - go to Stage 2 | | | | | | Pass Stage 1 |
| 9 | | | | | | | | |
| 10 | | | Clause J.2.1 | | MV limit | 2.00 | 2.00 | |
| 11 | Stage 2/Test 1 | | G _{HMV+LV} | 3.97 | | | | |
| 12 | Base MVA SB (eg 10) | 10.00 | | | Clause 6.2, Table 5 | | | |
| 13 | Harmonic order (5-10) h | 5.00 | Clause J.2.2 | | alpha | 1.40 | 1.40 | |
| 14 | Input supply capability (MVA) S_t | 10.00 | | | | | | |
| 15 | | | Z _{sc} (pu) | 0.07 | | | | |
| 16 | Clause J.2.2 | | Z _n | 0.33 | Clause J.2.1 | | | |
| 17 | Available voltage emission % | 1.87 | | | T.H.M | 1.00 | 1.00 | |
| 18 | Clause J.2.2 | | | | | | | |
| 19 | Available current emission % (base SB) | 5.62 | | | | | | |
| 20 | Available current emission % (base S _i) | 16.06 | | | | | | |
| 21 | | | | | | | | |
| 22 | | | Colour code | | | | | |
| 23 | | | Required data | | | | | |
| 24 | | | Optional data | | | | | |
| 25 | | | Output | | | | | |

Figure 3: User interface for example program for AS/NZS 61000.3.6

Following the project name "Demo" and date, the user inputs the plant agreed power $S_i = 3.5\text{MVA}$ and the supply fault level at the pcc, $S_t = 150\text{MVA}$. The quantity S_i/S_{sc} is calculated at 0.02 which is more than the recommended value of 0.001 and the installation fails Test 1. The user is then notified that further evaluation takes place under Stage 2. This requires additional information of the supply capability $S_t = 10\text{MVA}$. The user may change the default values of the base MVA (10MVA) and the harmonic assessed (5th). From the upstream limit of 2% and the Planning level of 5%, the allowance for all MV customers is $G_{5MV+LV} = 3.9\%$. This customer is allocated a voltage allowance of $E_{U_{S_i}} = 1.87\%$. From the fault level, a short-circuit impedance of $Z_{sc} = 0.07\text{ pu}$ is found. Assuming no resonance, the 5th harmonic impedance is 5 times this or 0.33pu . Hence the allocated current allowance is $E_{I_{S_i}} = 5.62\%$ on the 10MVA base. The program also calculates a value of 16.1% on the base of the installation (3.5MVA).

5. IMPLEMENTATION OF AS/NZS 61000.3.7

The standard was implemented for MV systems only. The standard details evaluation of fluctuating loads in three stages to limit the flicker effect from light sources. The evaluation process is shown in the flow chart of Figure 4 below (taken from the standard). If flicker assessment is satisfactory, a further evaluation is performed to ensure that voltage magnitude changes are within accepted tolerances.

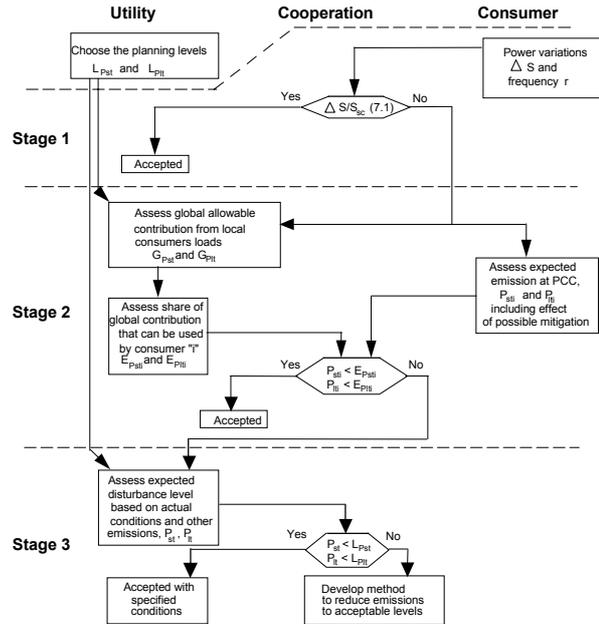


Figure 4: Diagram of Evaluation Procedure for AS/NZS 61000.3.7

5.1 Stage 1: simplified evaluation of disturbance emission

For small loads, detailed calculations are not required. The load is accepted without further analysis if the load power variation ΔS relative to the short-circuit capacity of the system S_{sc} at the PCC is within the limits given in Table 4 of the standard (this table is located on the Tables worksheet of the spreadsheet). The limit depends on the number r of voltage changes per minute.

5.2 Stage 2: emission limits proportional to the agreed power of the consumer

Stage 2 enables the sharing of the total allowed flicker emission between the users connected to a common supply system. To determine this the flicker emission (P_{st_i} and P_{lt_i}) from each consumer must be combined. A cubic summation law has been used for some time and has been found to give conservative results:

$$P_{st} = \sqrt[3]{\sum P_{st_i}^3} \quad (4)$$

$$P_{lt} = \sqrt[3]{\sum P_{lt_i}^3} \quad (5)$$

This law is used in the example program.

5.2.1 Allowable global emission contribution of MV loads

Firstly it is necessary to determine the global contribution from all the fluctuating loads which are fed by the MV system. The actual flicker level in a MV system results from the combination of the flicker level coming from the upstream HV system and of the flicker level resulting from all fluctuating loads connected to the MV system. This actual flicker level should not exceed the planning level of the MV system.

Application of the summation law gives:

$$G_{P_{st}MV} = \sqrt[3]{L_{P_{st}MV}^3 - B_{P_{st}MV}^3 - T_{P_{st}HM}^3 \cdot L_{P_{st}HV}^3} \quad (6)$$

and:

$$G_{P_{lti}MV} = \sqrt[3]{L_{P_{lti}MV}^3 - B_{P_{lti}MV}^3 - T_{P_{lti}HM}^3 \cdot L_{P_{lti}HV}^3} \quad (7)$$

5.2.2 Individual emission limits for consumers

For each user in a given supply system, only a part of the globally acceptable emission may be allowed, due to the presence of other users. This share can be determined according to the ratio between the consumer's agreed power S_i ($S_i = P_i / \cos\phi_i$) and the total power of the loads directly supplied at MV, at saturation of the system, S_{MV} . In addition, if the background flicker level is significant, the already-connected power S_B responsible must be taken into account. This is assumed 0 in the spreadsheet.

Furthermore, all MV fluctuating loads may not be in simultaneous use, so that a coincidence factor $F_{MV} \neq 1$ may be introduced. F_{MV} is taken to be 1 in the spreadsheet.

Considering the above, the individual emission limits are:

$$E_{P_{sti}} = G_{P_{st}MV} \cdot \sqrt[3]{\frac{S_i}{(S_{MV} - S_B)} \cdot \frac{1}{F_{MV}}} \quad (8)$$

$$E_{P_{lti}} = G_{P_{lti}MV} \cdot \sqrt[3]{\frac{S_i}{(S_{MV} - S_B)} \cdot \frac{1}{F_{MV}}} \quad (9)$$

The use of these formulae can lead to too strict limitations on consumers having comparatively low agreed power. Hence minimum allowable individual emission levels have been specified in the standard in Table 6. These have been incorporated into the example program calculations.

5.2.3 Assessment against measured/calculated P_{sti} and P_{lti}

The emission limits $E_{P_{sti}}$ and $E_{P_{lti}}$ are compared with the measured/calculated P_{sti} and P_{lti} values to check compliance under Stage 2.

5.3 Stage 3: acceptance of higher emission levels on an exceptional basis

Failure at Stage 2 necessitates a detailed network study taking into account:

- Expected flicker contribution from the load
- Existing background flicker
- Future network changes and load growth
- Future corrective methods

This stage is not implemented in the spreadsheet.

5.4 Emission limits for rapid voltage changes

The utilities have to maintain the voltage magnitude within narrow limits and individual consumers should not produce voltage variations outside these limits even if they are tolerable from the flicker point of view.

For single-phase and symmetrical three-phase loads, a simple assessment of relative voltage change can be performed as follows:

$$\Delta U_{dyn} \approx \Delta I_p \cdot R_L + \Delta I_q \cdot X_L \quad (10)$$

This voltage change is assessed using Table 8 of the standard which relates repetition frequency of voltage changes to the maximum allowable dynamic voltage change (as a percentage of the nominal system voltage). This table is located on the Tables worksheet of the example program.

The user interface of the example program is shown in Figure 5 below showing each stage of the assessment process.

After entering the project name and date, the user inputs the number r of voltage changes per minute, the power variation ΔS due to the load and the fault level S_{SC} at the PCC. This gives the ratio $\Delta S/S_{SC}$ as 0.38% which is greater than the 0.2% limit and hence failure of Stage 1 is indicated. Stage 2 requires entry of planning levels, transfer coefficients and background levels to determine the allowable global contribution of all loads. Default values are used here and background is assumed 0 to give $G_{P_{st}MV}=0.78$ and $G_{P_{lti}MV}=0.61$. The agreed power S_i of the consumer is then entered together with the capacity of the MV system S_{MV} . Coincidence factor F_{MV} is assumed equal to 1 which will give conservative results. The individual emission limits which result from this are

$E_{P_{sti}}=0.54$ and $E_{P_{lti}}=0.43$. These are assessed against the measured/calculated 99% P_{sti} and P_{lti} values of 0.29 to give a pass for Stage 2. The emission limits for rapid voltage changes is then assessed knowing the power factor of the load and the R & X of the source impedance. Inputting the appropriate values gives a maximum dynamic voltage change of 0.23% which is less than the limiting value of 1.25% for the present case and hence the installation passes.

| | A | B | C | D | E | F | G | H | I | J |
|----|---|--------|--------------------------|------|-------------------------------|---|---|---|---|---|
| 1 | ASSESSMENT OF FLUCTUATING LOADS IN MEDIUM VOLTAGE (MV) SYSTEMS USING AS/NZS 61000.3.7 | | | | | | | | | |
| 2 | Project Name: Demo | | | | | | | | | |
| 3 | Date: 31-1-2000 | | | | | | | | | |
| 4 | | | | | | | | | | |
| 5 | | | | | | | | | | |
| 6 | | | | | | | | | | |
| 7 | | | | | | | | | | |
| 8 | STAGE 1: simplified evaluation of disturbance emission (Clause 7.1) | | | | | | | | | |
| 9 | f_{min} | 0 | $\Delta S_{P_{sti}}$ [%] | 0.54 | Stage 1 result: | FAILED: DO NOT STAGE 2 | Determine at PCC | | | |
| 10 | $\Delta S_{P_{sti}}$ (MVA) | 1 | | | | | | | | |
| 11 | S_{in} (MVA) | 288 | $\Delta S_{P_{lti}}$ [%] | 0.2 | | | | | | |
| 12 | | | for given: | | | | | | | |
| 13 | | | | | | | | | | |
| 14 | STAGE 2: emission limits proportional to the agreed power of the consumer (Clause 7.2) | | | | | | | | | |
| 15 | Allowable global contribution of MV loads (Clause 7.2.1) | | | | | | | | | |
| 16 | L_{stmn} | 0.8 | L_{stmn} | 0.8 | | | Default values initially given (Clause 3, Table 2 plus notes) | | | |
| 17 | T_{stmn} | 0.8 | | | | | | | | |
| 18 | E_{stmn} | 0 | | | | | | | | |
| 19 | | | | | | | | | | |
| 20 | | | | | | | | | | |
| 21 | L_{stmn} | 0.7 | Given: | 0.8 | | | | | | |
| 22 | L_{stmn} | 0.8 | | | | | | | | |
| 23 | T_{stmn} | 0.8 | | | | | | | | |
| 24 | E_{stmn} | 0 | | | | | | | | |
| 25 | | | | | | | | | | |
| 26 | Individual emission limits for consumer (Clause 7.2.2) | | | | | | | | | |
| 27 | S_{in} (MVA) | 45 | E_{stmn} | 0.8 | | | | | | |
| 28 | S_{in} (MVA) | 45 | | | | | | | | |
| 29 | S_{in} (MVA) | 0 | E_{stmn} | 0.8 | | | | | | |
| 30 | F_{stmn} | 1 | | | | | | | | |
| 31 | | | | | | | | | | |
| 32 | Assessment against measured/calculated P_{sti}, P_{lti} (Clause 3) | | | | | | | | | |
| 33 | P_{sti} | 0.29 | | | Stage 2 result: | PASSED: CHECK RAPID VOLTAGE CHANGE LIMITS | The 99% values of P_{sti} & P_{lti} should be used | | | |
| 34 | P_{lti} | 0.29 | | | | | | | | |
| 35 | | | | | | | | | | |
| 36 | EMISSION LIMITS FOR RAPID VOLTAGE CHANGES (Clause 9) | | | | | | | | | |
| 37 | ΔU_{dyn} [%] | 1.25 | ΔU_{dyn} [%] | 0.23 | Rapid voltage change results: | PASSED | | | | |
| 38 | ΔI_p [%] | 0.035 | | | | | | | | |
| 39 | ΔI_q [%] | 0.035 | ΔI_{lim} [%] | 125 | | | | | | |
| 40 | R_L [%] | 0.0028 | for given: | | | | | | | |
| 41 | X_L [%] | 0.0045 | | | | | | | | |

Figure 5: User interface for example program for AS/NZS 61000.3.7

6. DISCUSSION

The case has been made for the implementation of power quality standards in software. A methodology has been given for an implementation in an Excel spreadsheet. A lot of effort has gone into determining how the standard needs to be interpreted for specific cases because of the lack of clear direction in the standard. There is ample scope for developing these ideas further with the enhancements previously mentioned such as sensitivity studies, etc.

While Excel is good for prototyping, the full commercial package should be written in Visual C++ or Visual Basic for porting to both Windows and Unix systems. This will be the next step forward once the standards are clarified.

7. REFERENCES

- [1] IEC 61000-3-6 Electromagnetic Compatibility (EMC) Part 3: Limits – Section 6: Assessment of Emission Limits for Distorting Loads in MV and HV Power Systems.
- [2] IEC 61000-3-7 Electromagnetic Compatibility (EMC) Part 3: Limits – Section 7: Assessment of

Emission Limits for Fluctuating Loads in MV and HV Power Systems.

- [3] Gosbell, V.J. et al, “A review of the new Australian harmonics standard AS/NZS 61000.3.6”, Proceedings of AUPEC/EECON’99, September 1999, Darwin, pp.134-139.
- [4] AS 2279-1991 “Disturbances in mains supply networks: Part 2 Limitation of harmonics caused by industrial equipment” and “Part 4 Limitation of voltage fluctuations caused by industrial equipment”.

8. DEFINITIONS

- G_{hMV+LV} the acceptable global contribution of the local MV and LV loads to the h^{th} harmonic voltage in the MV system (expressed in percent of the fundamental voltage);
- L_{hMV} the planning level of the h th harmonic in the MV system (from Table 2 of the standard);
- L_{hHV} the planning level of the h th harmonic in the upstream HV system (from Table 2 of the standard);
- T_{hHM} the transfer coefficient from the upstream HV system to the MV system at harmonic order h (given a value of 1 in the spreadsheet);
- α the summation law exponent (Table 5 of the standard);
- $E_{U_{hi}}$ is the acceptable harmonic voltage emission level for consumer (i) directly supplied at MV (%);
- S_i ($= P_i / \cos\phi_i$) agreed power of consumer i;
- S_t is the total available power in the MV network;
- α is the summation law exponent.
- $E_{I_{hi}}$ is the acceptable harmonic current emission level of consumer i at harmonic order h ;
- Z_h is the frequency-dependent impedance of the network at the point of common coupling.
- G_{PstMV} the maximum global contribution of the local loads to the flicker level in the MV system (expressed in terms of P_{st});
- L_{PstMV} the planning level of the flicker level in the MV system (from Table 2 of the standard);
- L_{PstHV} the planning level of the flicker level in the upstream HV system (from Table 2 of the standard);
- T_{PstHM} the transfer coefficient from the upstream HV system to the MV system (assumed equal to 0.8 in the spreadsheet);
- B_{PstMV} the background flicker level (assumed 0 in the spreadsheet)
- ΔU_{dyn} dynamic voltage change due to load
- ΔI_p in-phase component of dynamic current change due to load
- ΔI_q quadrature component of dynamic current change due to load
- R_L resistive component of network impedance at PCC
- X_L reactive component of network impedance at PCC