Energy Industry
SMP2

APPLICATION NOTE

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Index

Application Note
Energy industry

1. INTRODUCTION

The supply (generation and distribution) of electricity is one of the leading sources of low frequency electromagnetic fields. They are present, to differing degrees, practically everywhere in our surroundings: at work, at home, in schools, in hospitals, and so on, and even outdoors in places near high and medium voltage power grids and other services, such as railways.

Some examples of low frequency EMFs include power plants, transformers, power lines, electric motors, power machinery and equipment, railway power lines, and so on.

The frequency used for these purposes is usually 50 or 60 Hz, depending on the country, and is sometimes lower in the case of railways.

When people are exposed to low frequency fields, electric fields and currents are generated in the human body that may interfere with the body's own electric fields and the currents involved in normal biological functioning.

High voltages produce electric fields and high currents produce magnetic fields. In order to avoid interactions that may affect health, international regulations and standards recommend limiting exposure so that a threshold is never reached at which interactions between the body and an external electric or magnetic field can have detrimental effects on health.

Taking measurements is the easiest, fastest and best way to check field levels and compare the results with legal limits or standards.

This memorandum on application describes measurement procedures for assessing levels of exposure of the human body to electric and magnetic fields. Compliance should checked by comparing the measured values with exposure limits for the general public such as the **ICNIRP** reference values [1], the **IEEE** maximum permitted exposures (MPE) [2], the action levels (ALs) of **European Directive 2013/35/EU** [[3], or other domestic law.

2. MEASUREMENT PROCEDURES AND METHODS

The leading international standards body is the IEC [4] and the standards defining methods for measuring EMFs in connection with low frequency energy production and distribution systems are the following:

- **IEC 62110:2009** "Electromagnetic field levels generated by a.c. power systems – Measurement procedures with regard to public exposure".
- **IEC 61786-1:2013 "**Measurement of DC magnetic, AC magnetic and AC electric fields from 1 Hz to 100 kHz with regard to exposure of human beings – Part 1: Requirements for measuring instruments".
- **IEC 61786-2:2014** "Measurement of DC magnetic fields, AC magnetic and electric fields from 1 Hz to 100 kHz with regard to exposure of human beings – Part 2: Basic standard for measurements".

2.1 IEC 62110:2009

The IEC 62110 standard applies to measurement of the fields generated by AC power systems in areas accessible to the public. It specifies common measurement procedures for evaluation of levels of exposure to electric and magnetic fields, obtaining field values that correspond to a spatial average over the entire human body.

The values obtained are used to determine compliance with exposure limits, such as those defined by ICNIRP, IEEE, European Directive 2013/35/EU or other domestically established limits.

The equipment to be used is defined in the IEC 61786-1 standard.

The standard recommends use of triaxial probes, which allow the resulting total field to be obtained automatically.

Where important harmonic content is suspected, the Weighted Peak Method defined by ICNIRP [5] should be used. This method allows evaluation of complex signals and direct determination of a value for total exposure, taking the full spectrum content into account, as a percentage of the reference limit.

Considerations in the case of the E field

In the case of the E field, taking measurements that represent the undisturbed field means that attention must be paid to the presence of conductive objects. The area must be as free as possible of other power lines, towers, fences, trees, tall grass, etc. since vegetation can have a significant effect depending upon its water content. The measurement site should be as flat as possible.

All movable objects should be removed. Otherwise, the distance between the probe and the object should be three times the height of the object (if it is not fixed) or 1 m (if it is fixed).

To avoid disturbance of the E field, the recommended distance between the operator and the probe is 3 m (1.5 m minimum).

It is important to remember that the E field can be disturbed if the relative humidity is greater than 70%. Make sure to check whether the measurement device can operate correctly under humid conditions.

Considerations in the case of the H field

In the case of the H field, taking measurements that represent the undisturbed field means that non-fixed objects containing magnetic materials or non-magnetic conductors must be at a distance from the measurement point at least three times their largest dimension. The minimum distance between the probe and fixed magnetic objects must be 1 m.

Other nearby sources of magnetic fields other than the power systems must be switched off or removed in order to minimise their influence.

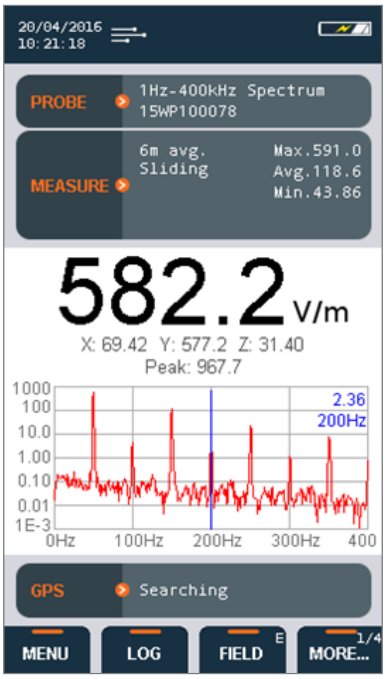

Figure 1. Evaluation of harmonics by spectrum analysis

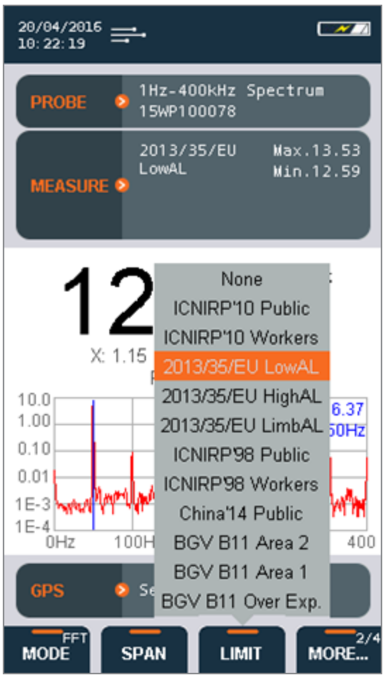

Figure 2. Direct result as % of the chosen limit by means of the weighted peak method

General procedure
Measurements at one, three or five points are used as a rule. For measurement of overhead high voltage lines, the field is considered uniform at ground level and so measurement at one point is sufficient. In the case of public areas with underground cables, interior substations, etc., the field is considered non-uniform and so measurements must be taken at three or five points.

Where the field is considered uniform, it must be measured at a single point 1 m above ground level or the floor of the building. That value is considered the average exposure level.

Where the field is considered non-uniform, the average level of exposure to the E and H fields must be obtained by averaging the results of measurements at three heights: 0.5 m, 1 m and 1.5 m. Near power equipment, the field must be measured at a distance of 0.2 m from its surface or wall, as shown in Figure 3. Where the equipment to be measured stands less than 1.5 m tall, measurements must be taken at three equidistant points such that the highest point is corresponds to the height of the equipment.

This process is very easy using the spatial average function of the SMP2 (Figure 4). The desired number of points can be measured and the device calculates the final average:

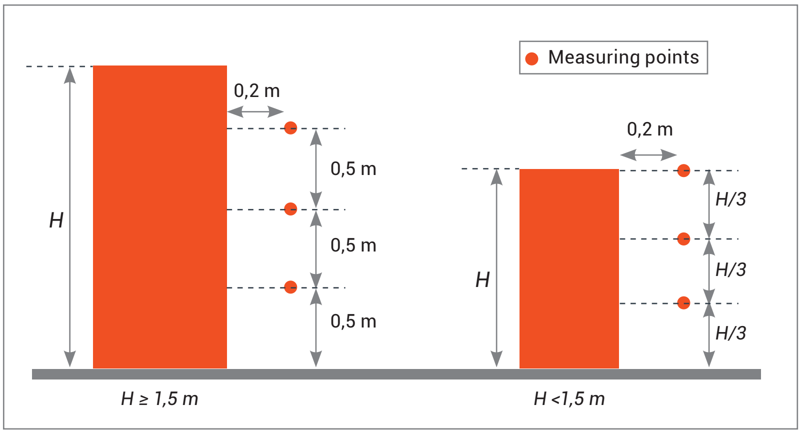

Figure 3. Distances for spatial average

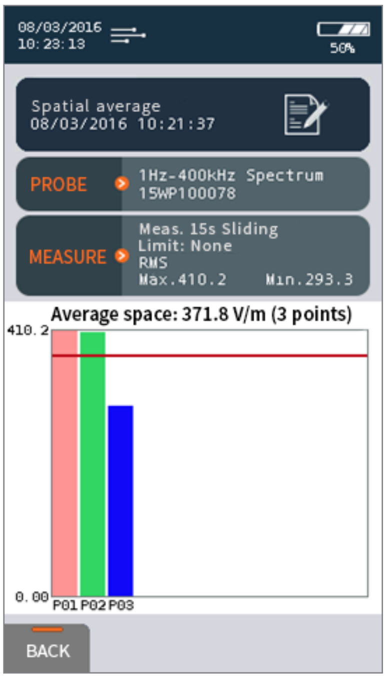

Figure 4. SMP screen for spatial average function

Where there are field sources beneath the ground or floor and someone might be lying on top of that source, the average exposure level must be found by means of the spatial average of five points in the following way: the area should be scanned by moving the measurement device at a height of 0.2 m to find the highest value (P1). That point will then be the centre of an imaginary circle drawn around it at the same height with a radius of 0.5 m. Another scan must then be made around the perimeter of the circle, and the point with the highest value will be considered the second maximum (P2). In relation to that second maximum, 3 more points must them be measured on the circle, i.e. the symmetrical (P3) and two perpendicular (P4 and P5), as shown in Figure 5.

Using the values for those 5 points, the average of the 3 points with the highest values must be calculated. That average is considered the average exposure level, as shown in the example below.

Measuring points:	Measured values (index)	Adopted values
P1	10 µT	X
P2	5 µT	X
P3	1 µT	
P4	2 µT	
P5	3 µT	X

↓

Three-point average exposure level is:

$$\frac{(P1 + P2 + P5)}{3} = 6\ \mu T$$

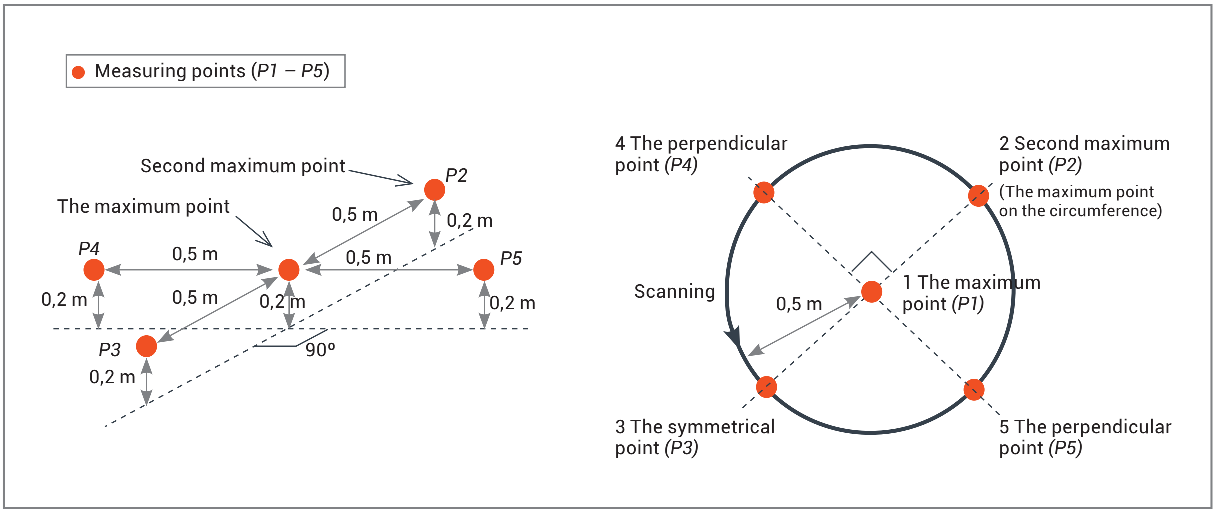

Figura 5. **Points for the spatial average over a field source**

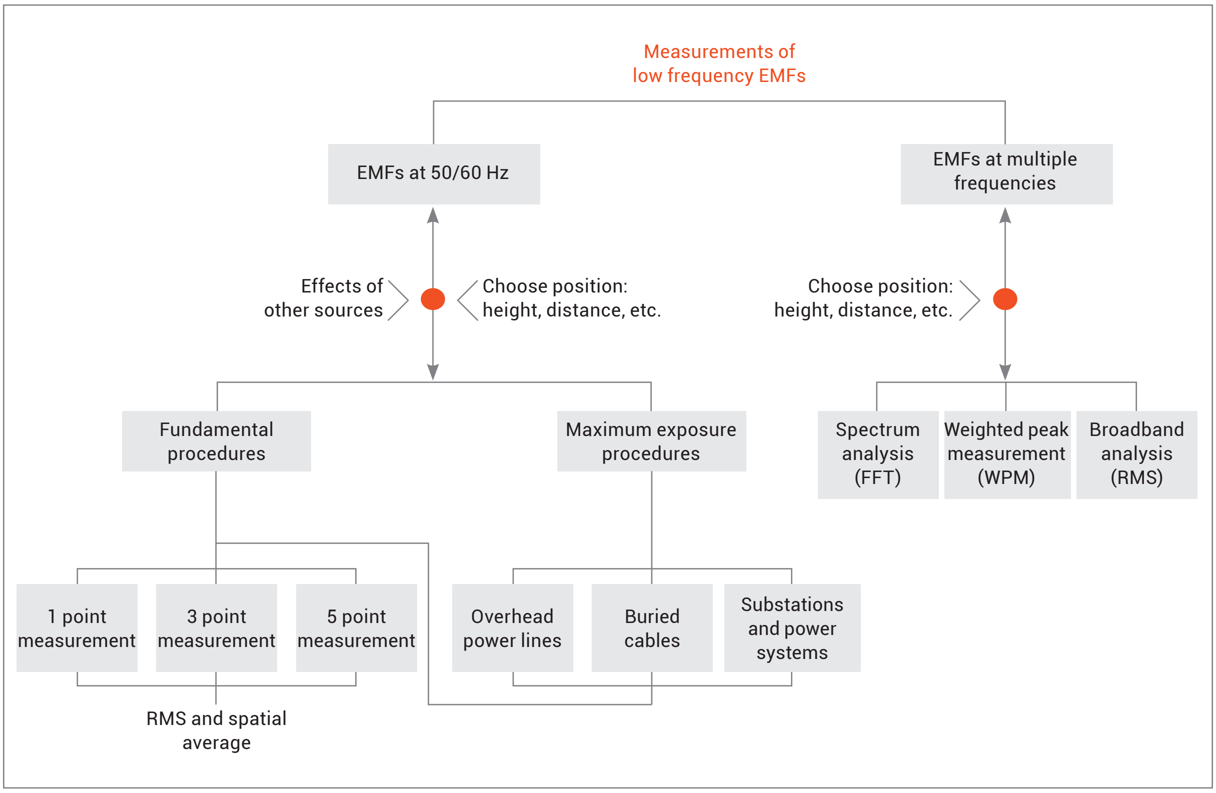

Figure 6. Basic diagram of procedures

Procedures for finding the maximum level of exposure to the E and H fields

Overhead high voltage lines

The highest level of the E and H fields is found at the point where the conductors are closest to the ground. To find the maximum value in that area, measurements must be taken at a height of 1 m along the length of the conductors at appropriate intervals. Once the maximum point is found, measurements must then be taken, also at a height of 1 m, along a line perpendicular to those conductors.

Buried cables

Buried cables do not generate an E field above ground level and therefore it does not need to be measured

The value for the H field generated will be the same along the full length of the conductor except where we are above a break or a change of depth. If there is no break, we can start the measurement at any point. If we know or suspect that there may be variations, we will measure at a height of 1 m along the length of the conductor to find the highest level within that span. From that point, we will find the highest value for the H field by taking measurements at a height of 1 m along a line perpendicular to the cable, at appropriate intervals. Where the maximum is found, a spatial average measurement of 3 points must be applied.

Substations and power systems equipment
Only substations with overhead lines connected can produce E fields and therefore need to be evaluated. Measurements must be taken at a height of 1 m and at a distance of 20 cm around the substation at relevant points and at appropriate intervals to find the maximum.

The H field must also be measured at a height of 1 m and a distance of 20 cm, at appropriate intervals. If the equipment to be measured stands less than 1.5 m high, it must be measured at the same height as the equipment rather than at 1 m.

For both the E and H fields, once the maximum has been located, a spatial average of 3 points must be taken.

In the case of substations with overhead lines or buried cables, the maximum fields are found where the conductors are connected to the substation.

In the case of built-in substations where people may be lying on the floor above them, measurements must be taken at five points. Otherwise, measurements will be taken at three points.

2.2 IEC 61786-1

The first part of the IEC 61786 standard is a guide for selection of instruments for measurement of the intensity of quasi-static electric and magnetic fields between 1 Hz and 100 kHz for evaluation of exposure of the human body to such fields.

The sources of fields are defined as the elements and devices operating at grid frequencies and generating fields at those frequencies and their harmonics, as well as all other devices that produce fields between 1 Hz and 110 kHz..

The most important factors defined are:

- **Requirements for field meter specifications**
- **Calibration methods**
- **Requirements for instrumentation uncertainty**

Field meter specifications:
Equipment manufacturers must supply the following information:

- **Measurement uncertainty.**
  This must include all the relevant factors: uncertainty of calibration, frequency response, linearity, isotropy, stability, temperature and humidity response.

- **Dynamic range.**
  The range of magnitude within which the device operates with the specified uncertainty.

- **Passband.**
  Specified between the lower and upper cut-off frequencies, normally defined as the points where the frequency response drops to -3dB.

- **Temperature and humidity range.**
  Must fall at least within the ranges of -10°C to 45°C and 5% to 95%.

- **Power supply.**
  Devices with internal batteries are recommended.

- **Scale legibility.**
  The screen must be digital and large enough to be read easily at arm's length.

- **Probe size and selection**
  1. General scheme.
     The general minimum scheme is a probe with 3 sensors, a detection circuit and a display.

  2. Magnetic field meters.
     The dimensions of the probe must be given and it must have an area of 0.01 m2 or less, with 3 concentric sensors, or, if they are not larger than 0.05 cm, they must be as close together as possible. The position and orientation of the sensors must be clearly specified on the device or in the manual.

  3. Electric field meters.
     The dimensions of the sensors must be given and they must be:
     - For free-body meters: maximum volume of 0.2 m.
     - For ground-reference meters: probe dimensions and length of the coaxial connector cable.

  4. Electric field meter base.
     Must be made from non-conducting material. On a tripod, the horizontal arm must be 1 m long. When held by a person, it must be 2 m long.

- **Electromagnetic compatibility**
  1. Immunity
     - E and H fields to grid frequencies.
     - Radiant electromagnetic fields according to IEC 61000-4-3 and IEC 61000-4-6.
     - Transients according to IEC 61000-4-4.
     - Electrostatic discharges according to IEC 61000-4-2.

  2. Emissions
     - Harmonic emissions: according to IEC 61000-3-2 Class A.

  3. Conducted emissions: between 150 kHz and 30 MHz according to CISPR11.

  4. Radiant emissions: between 30 MHz and 1000 MHz according to CISPR11.

- **Peak factor**
  The device must correctly measure the real RMS value of the field, including where the peak factor of the magnetic field is 3.

- **Durability**
  The device and its components must be sturdy enough to withstand knocks and vibrations in transport. The device should be equipped with a carrying case. It must comply with IEC 60721-3: storage class 1M2, transport class 2M3 and operation class 7M3.

- **Weight**
  The weight of the device should be suitable for ease of use under special conditions, such as in certain industrial surroundings.

- **Choice of instrument**
  The device should be chosen depending on the measurement procedures and particularly on the data to be included in the measurement report.

The SMP2+WP400 combination meets all the requirements set out above and it also includes the most up-to-date specific functions, such as real-time digital processing spectrum analysis and the Weighted Peak Method specified by ICNIRP.

Calibration

Calibrations must be made regularly. According to IEC 61786, the initial interval should be 12 months, which may vary depending on the performance observed in the response of the instrument. Based upon observed performance, Wavecontrol recommends recalibration every two years.

NOTE: *The user of the device is responsible for following the indications of IEC 61786 or Wavecontrol's recommendation.*

The standard describes calibration methods for the E field and the H field. The uncertainty of the calibration must be determined.

Wavecontrol offers its clients the use of **LabCal Wavecontrol**, its ISO 17025 accredited calibration laboratory for calibration of E and H field probes. All E and H field probes manufactured by Wavecontrol are delivered with their accredited individual calibration certificates..

Verification

Verification is a simple procedure to check that the device is in good working order, to be performed before using the device.

It includes:

- Visual inspection of the device.
- Checking the battery charge.
- Ensuring validity of the calibration date.
- Possession of all the necessary accessories.

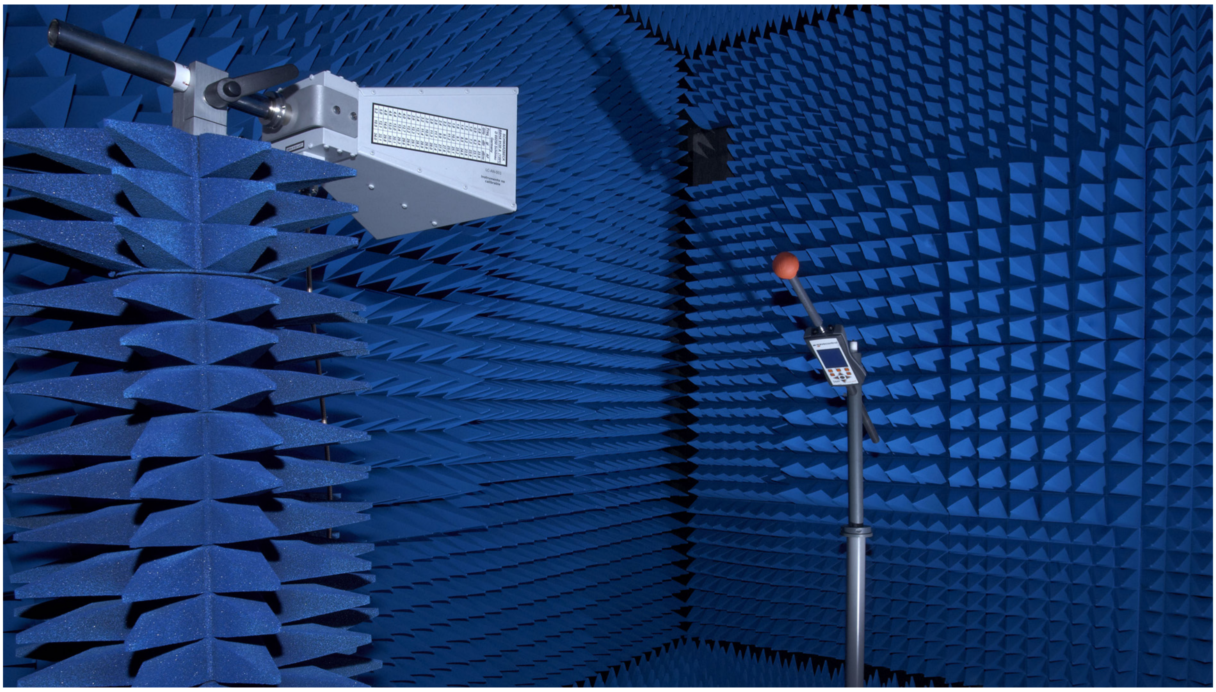

Figure 7: **Anechoic chamber at LabCal Wavecontrol**

2.3 IEC 61786-2

The second part of the IEC 61786 standard establishes the requirements and procedures for measurement of EMFs within a frequency range of 1 Hz to 100 kHz. Specific measurement procedures may vary depending on the characteristics of the EMFs in different surroundings and the objectives of the measurements. This standard presents 3 measurement methods:

- **broadband evaluation (RMS)**
- **frequency domain evaluation (FFT)**
- **time domain evaluation (%)**

The frequency domain evaluation can also provide further information on the sources of exposure and their individual contributions. On the other hand, the time domain evaluation is simpler for the operator and gives immediate overall results on compliance or non-compliance.

Some examples of the field sources that can be measured with the standard include:

- Devices operating at grid frequencies (50/60 Hz) and generating fields at those frequencies and their harmonics (power lines, electric devices, etc.)

- Devices generating fields other than at grid frequencies, such as railways (DC at 20 kHz), commercial aviation (400 Hz), induction heating (up to 100 kHz), electric vehicles, etc.

- Devices generating static magnetic fields: MRI, DC power lines, DC welding, electrolysis, etc. The transformers used normally generate AC components that also need to be measured.

This standard defines different possible measurement scenarios and the methods to be used:

- Characterisation of field levels for compliance with safety standards,

- Characterisation of spatial or time variations,

- Characterisation of the frequency content of the E or H field,

- Evaluation of human exposure.

It also defines the possible measurement methods for sources with multiple frequencies, which is most often the case. Good spectrum analysis is very important between 1 Hz and 100 kHz because (i) the E and H fields normally contain grid frequency harmonics and other unrelated frequencies, and (ii) maximum exposure limits vary significantly within that frequency range.

The standard concludes that the best and most accurate method is the **weighted peak method**. The good news for SMP2 users is that that method is already implemented and the instrument does all the work. It is, in fact, the simplest and most direct method for checking compliance with regulations, since the SMP2 performs the full analysis via digital processing, weighting each frequency component with its maximum value and delivering a total result directly as a percentage of the limit (Figure 8).

To allow measurement subject to all the conditions described above, it is ideal to use an instrument such as the SMP2 + WP400 combination:

- Isotropic response
- E and H fields
- Logging and time averages
- Logging and spatial averages

- Direct comparison with limits for compliance with regulations
- Weighted peak method
- Frequency analysis of E and H fields

Measurement procedures

The first step is to define the measurement method and the protocol to be followed, taking into account all the possible sources of magnetic and electric fields, the surroundings and the possible locations of people who might be exposed.

Other important parameters to define and take into account include the type of instrument, its calibration, frequency passband and measurement range.

It is important to consider whether or not spectrum analysis and the weighted peak method will be needed.

The standard defines the following measurement procedures:

AC magnetic field

Measurements of the resulting H field must be taken using triaxial instruments, although uniaxial devices may be used in some circumstances.

The device must have a passband appropriate to the frequency content of the field to be measured. In the case of measurement of grid frequency (50/60 Hz), the harmonics up to at least 800 Hz must be measured. A smaller passband may only be used where it can be shown that the harmonics are negligible. In the case of some transport systems, the frequencies may be lower, while in the case of induction heaters, video terminals, commercial aircraft, boats and the harmonics produced by motor speed shifters, higher frequencies, up to 100 kHz, may be generated.

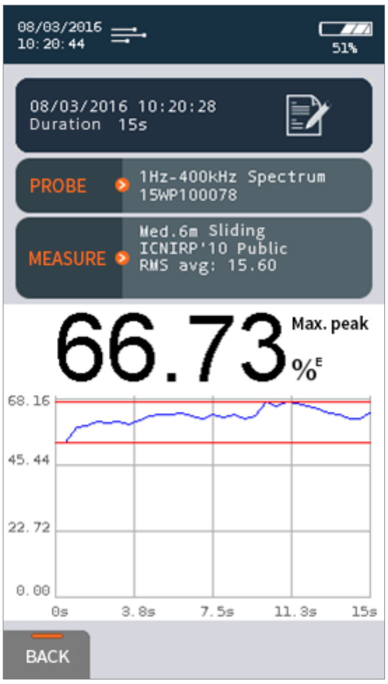

Figure 8: SMP2 screen in weighted peak mode

When measuring very low frequencies, it is important to take into account that movement of the probe within static or quasi-static fields can produce erroneous readings, and so the probe should not be moved during the reading.

The IEC 61786-2 standard cites the IEC 62110 standard as the reference for the protocol for measurement of high voltage lines.

Finally, it is important to remember that the magnetic field is proportional to the current and that the current may vary over time, and the suitable moment must be chosen to take the measurements, under conditions of maximum consumption, or to extrapolate the results accordingly.

In the case of high voltage lines, load currents can vary widely and with them the results for the field, and this factor must be taken into account. The load will vary depending on the time of day and the temperature (seasonality), which will cause changes in consumption and therefore in the amount of current carried by the line. In addition, the levels of the magnetic field may also vary with changes in the sag of the conductors due to heating caused by passage of massive currents or environmental conditions.

There are also other factors to be taken into account when taking measurements of mass transport systems and other areas where variable speed motors might be present. For example, in the case of trains, the magnetic field may depend on the speed of the train.

In the case of electric equipment, currents are constant or vary regularly in relatively short cycles, making measurement easier.

AC electric field

In the case of the electric field, the IEC 61786-2 standard specifies that the resulting electric field must be measured undisturbed. This means that measurements must be taken using a triaxial device (with isotropic response) and in the absence of the operator or other elements that might disturb the field.

Unlike measurements of the magnetic field, the device operator or other people nearby can cause significant disturbances in the field that can give rise to unacceptable errors and therefore measurements should be taken using a non-conductive tripod, so that the operator can move away while the measurements are taken.

The E field is also easily disturbed by different types of objects, including those that are in themselves poor conductors (trees, fences, plants, buildings, etc.). Any movable objects should therefore be removed if possible. Otherwise, the distance between the probe and the object should be at least equal to 3 times the height of the object (in the case of movable objects) and at least 1 m (in the case of fixed objects). The fixed objects present at the measurement location must be listed and described (including their dimensions and placement).

The device must have a passband suitable to the frequency content of the field to be measured. Where what is being measured are E fields produced by electric power systems such as high voltage lines, transformers, etc., the main frequency will be 50/60 Hz. However, the possible presence of harmonics must be taken into account. Where the E fields from other sources (trains, aircraft, boats, etc.) are measured, the fundamental frequency may be very different, and so the correct passband must be chosen.

Since the passband of the SMP2+WP400 combination is very broad (1 Hz to 400 kHz), all the possibilities are covered and this factor is not a matter of concern.

Except in the vicinity of high voltage sources, the electric field does not have to be measured, since the measured values would normally be a few dozen V/m at the most.

Unlike the H field, the E field produced by high voltage lines does not vary significantly with the load, since the voltage remains nearly constant. It may vary with changes in the sag of the conductors caused by heating due to massive current loads.

Measurement uncertainty

The measurement uncertainty must be calculated, associating a standard deviation to each parameter that might influence the measurement, such as uncertainty of calibration, frequency response, linearity, temperature, and so on. More detailed information may be found in the ISO/IEC Guide 98-3 and in the IEC 61786-1:2013 standard.

Measurement reports

The IEC 61786-2 standard gives some examples of the information that must be included in reports, which may vary depending on the objectives of the measurement:

- Objectives of the measurements
- Measurement procedure
- Instrument and probe manufacturer and model
- Passband of the device
- Date of latest calibration
- Date and time of measurements
- Identification of the individuals responsible for the measurements
- Weather conditions
- Description of the measured source and working conditions
- Spectrum analysis resolution
- Statement of the measured amount (resulting field, RMS value, peak weighting ...) using IS (international system) units
- Location (GPS) and diagram of the place of measurement including distances
- Total measurement uncertainty
- Conclusions

3. KEY FACTORS CONCERNING INSTRUMENTATION

The key factors of the instruments dedicated to probing and measuring electric and magnetic fields in connection with human exposure and their regulated limits may be summed up in the following points:

Isotropy and RMS detection:

The different international standards specify the use of triaxial devices with isotropic response. The WP50 and WP400 probes show an isotropic response and they also allow measurement of both the E field and the H field (with the same probe).

The devices can give peak and RMS results..

Spectrum analysis:

This is required in situations with multiple harmonics or frequencies, since regulatory limits at low frequencies vary greatly depending on the frequency. This is not the case with high frequencies, since the limits do not vary greatly, and in this case broadband probes can be used and comparison made with the lower limit of the working band.

The SMP2 allows spectrum analysis by means of FFT in real time, using modern digital processing techniques, allowing suitable probing of the spectrum.

It also includes other specific functions such as tracking a given frequency over time to record its progression and behaviour.

Weighted Peak Method:

The Weighted Peak Method is an evaluation method defined by ICNIRP that allows very easy real-time evaluation of compliance with limits. Some standards, e.g. IEC 61786-2, refer to this method as Time Domain Assessment.

The SMP2 takes into account the full frequency band (1 Hz - 400 kHz) and presents the result as a percentage (%) of the limit. It performs automatic weighting of each value in respect of the limit for each frequency, depending on the chosen standard.

In short, the device automatically produces a result that represents the degree of compliance taking into account all the spectrum components. All that the user needs to do is select the desired regulatory limit.

4. CONCLUSIONS

This memorandum on application is an introduction to the methods for evaluating human exposure to low frequency EMFs generated by power energy systems, in the generation, distribution and use of energy.
It is important to bear in mind that the E and H fields must be measured, that measurement should preferably be made using an isotropic field probe, and that a non-conductive tripod must be used to keep the operator from influencing the measurement.
We have stressed the importance of having frequency information to allow evaluation of the harmonics of the signal and the major advantage of using a device that offers results by means of the weighted peak method, to provide a direct value for comparison as a percentage of the regulatory limit.
Finally, we demonstrated the suitability of the SMP2 + WP400 combination, as it offers all the elements mentioned above and is therefore the ideal device for carrying out this sort of tests and evaluations.
The SMP2 + WP400 combination allows the three types of measurements required for the different applications:

- **Broadband measurements**
- **Frequency domain analysis (FFT)**
- **Time domain analysis (weighted measurement) using the weighted peak method.**

All with the range of 1 Hz to 400 kHz and comparison with varied list of limits (ICNIRP98, ICNIRP2010, IEEE, Directive 2013/35/EU, etc.) at the user's choice.

5. APPENDIX

Appendix I: Further details on the SMP2

The main characteristics of the SMP2 + WP400 combination are:

- FFT-based real-time spectrum analysis
- Weighted peak method for real-time comparison with limits
- Broadband measurement
- Available limits according to ICNIRP, EU, IEEE, FCC, etc.
- Designed to allow addition/modification of limits
- RMS and peak values
- Same probe for electric and magnetic fields
- Different types of units available for both H and E fields
- Automatic probe detection
- Different spans for spectrum analysis
- Different high-pass filters, 1 Hz, 10 Hz, 25 Hz and 100 Hz
- Max-hold function
- Time measurement of a specific frequency (selectable between 1 Hz and 400 kHz)
- Display of X, Y and Z components and the resulting field value
- Min, Max, Max-hold and averages
- Screen showing configuration, results and graphics
- Remote firmware updates
- Built-in latest generation GPS
- Fibre optics and USB connection for downloading data and remote control
- Large storage capacity
- Screenshot function for presentation of high-quality reports
- Field level alarm with adjustable threshold
- Rechargeable internal Li-ion battery with over 14 hours autonomy for broadband measurements and around 5 hours for selective measurements
- Lightweight and easy to use

Appendix II: Leading worldwide regulation organisations

National authorities and international organisations are the main bodies responsible for establishing standards and providing scientific advice and guidance on the health and environmental effects of exposure to non-ionising radiation (NIR).

The following are some examples:

- International Commission on Non-Ionising Radiation Protection (ICNIRP)
- World Health Organisation (WHO)
- International Electrotechnical Commission (IEC)
- European Committee for Electrotechnical Standardization (CENELEC)
- European Union (EU)
- Federal Communications Commission (FCC)
- Occupational Safety and Health Administration (OSHA)

Appendix III: References

- **[1] ICNIRP:** *International Commission on Non-Ionizing Radiation Protection*
- **[2] IEEE:** *Institute of Electrical and Electronics Engineers*
- **[3] Directive 2013/35/EU of the European Parliament** and of the Council of 26 June 2013 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields) (20th individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC) and repealing Directive 2004/40/EC.
- **[5] IEC:** *International Electrotechnical Commission*
- **[4] ICNIRP** *"Guidance on determining compliance of exposure to pulsed and complex non-sinusoidal waveforms below 100 kHz with ICNIRP guidelines".*

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