LegalEVcharge – Practical legal metrology framework for electric vehicle charging stations

NordCharge

Legal metrology framework and guidance for electric vehicle charging stations

Version 1 issued 2021-09-28

Contents

1. History

Version	Description	Modified clauses
1	Initial version	–

2. Executive summary

In recent years, more and more electric vehicles are used. To charge these cars, electric vehicle charging stations (EVCS) are installed all over Europe. In many countries, the legal metrology framework in this domain is missing. Consumers are not being protected as they expect to be, in the same way as, for example, when buying petrol or consuming electrical energy in their homes. Operators of EVCS (charge point operators, CPO) and manufacturers who are expecting a legal metrology framework to be established in the near future lack legal certainty. This might inhibit investments into new EVCS. The lack of charging infrastructure and range anxiety as a direct consequence discourage consumers from switching to electric cars. Electric cars, however, play an important role in the EU's Green Deal.

A number of European countries co-ordinate their work on a legal metrology framework for EVCS in the EURAMET TC-EM project LegalEVcharge and the NordCharge group. NordCharge is the Nordic co-operation on charging stations for electric vehicles, working on metrological regulation.

This document analyses the existing legal metrology framework built on the foundation provided by MID, the European directive on measuring instruments, which is perfectly suitable for active electrical energy meters used in EVCS, regardless of whether AC or DC is used. It identifies key areas where the national implementing legislation may not be harmonised and gives further guidance for conformity assessment bodies, manufacturers of EVCS and charge point operators.

The guiding principle is that of proportionality. State activities must be conducted in the public interest and be proportionate to the ends sought. They must be necessary, suitable and proportional. In consequence, legal metrology requirements must be as light as possible provided they achieve the intended goal. This goal is to maintain all concerned parties' trust in the correctness of the measurement. It has not changed for centuries and will not change for the foreseeable future.

Guidance on practical aspects is intended to help manufacturers, installers, servicing bodies and operators to set up a practical system that respects the legal metrology requirements in a way that is cost effective in the long-term.

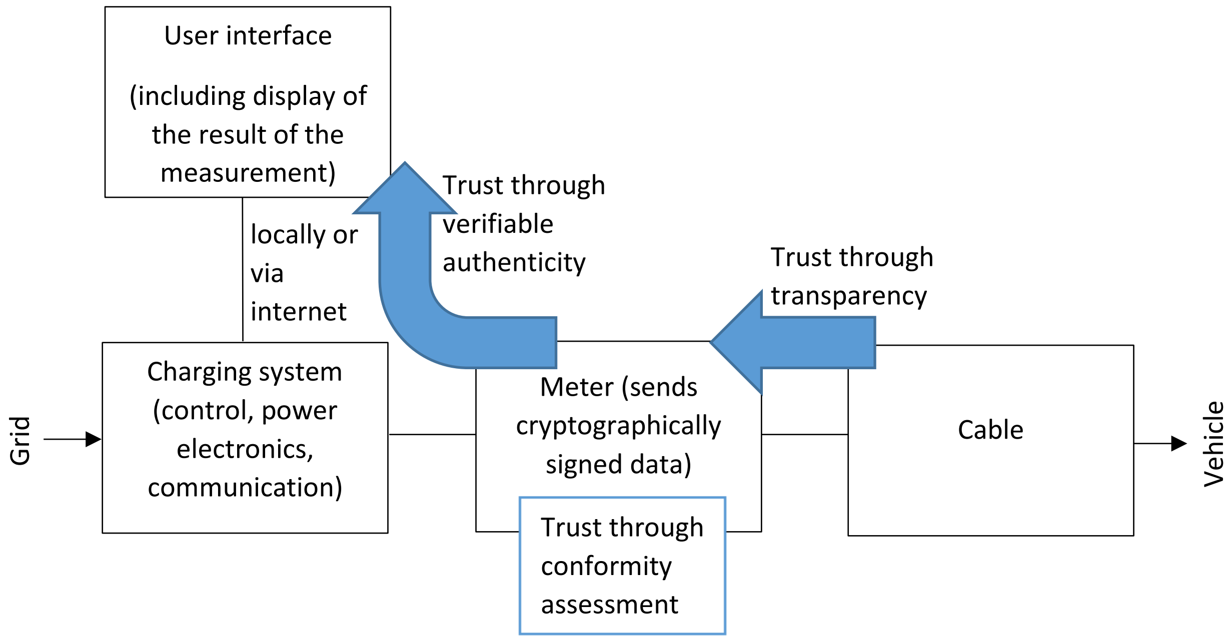

Figure 1: The active electrical energy meter as legal metrology core of EVCS. Trust can be assured even without conformity assessment of the other parts of the system.

3. Introduction

In recent years, more and more electric cars are used. To charge these cars, electric vehicle charging stations (EVCS) are installed all over Europe. In many countries, the legal metrology framework in this domain is missing. Consumers are not being protected as they expect to be, unlike for similar transactions such as when buying petrol or consuming electrical energy at home. Charge point operators (CPO) and manufacturers expecting a legal metrology framework to be established in the near future lack legal certainty and this might inhibit investments into new EVCS. The lack of charging infrastructure and range anxiety as a direct consequence discourage consumers from switching to electric cars. Electric cars, however, play an important role in the EU's Green Deal.

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The guiding principle is that of proportionality. State activities must be conducted in the public interest and be proportionate to the ends sought. They must be necessary, suitable and proportional. In consequence, legal metrology requirements must be as light as possible provided they achieve the intended goal. This goal is to maintain all concerned parties' trust in the correctness of the measurement. Since the goal predates the industrial generation of electricity and did not change with the progress made by electrical engineering since its invention, performance requirements rather than detailed technical specifications can lead to legislation that does not need to be change with every incremental technological step. Since MID was intended to bring stability and avoid frequent updates by specifying performance requirements, the analysis of this document shows that MID is fit for purpose for EVCS without any modification, as expected.

Key point for implementing legislation have been identified. Those are

- the choice of accuracy classes,
- the implementation of the display and the durable proof required by MID,
- cable and instrument transformer corrections,
- the choice of procedures for the maintenance of the metrological stability,
- the definition of the responsibility of the users,
- metrological supervision and
- transitional provisions.

Since the metrology legislation intends to give performance requirements rather than detailed technical specifications, the manufacturers and charge point operators – users – have a lot of freedom to define technical specifications. In a domain such as EVCS, where manufacturers and charge point operators may not necessarily be familiar with legal metrology regulation, the risk of optimising technical specifications without taking into account significant problems that may only appear years later as direct consequence of this optimisation is higher than in mature domains such as electricity supply to households. Guidance on practical aspects is intended to help manufacturers and charge point operators to set up a practical system that respects the legal metrology requirements in a way that is cost effective in the long-term.

4. Abbreviations and references

2014/32/EU	see MID
AC	qualifier; pertaining to alternating electric quantities such as voltage or current, to devices operated with these, or to quantities associated with these devices; derived from “alternating current” (see IEV item 151-15-01)
CENELEC	European Committee for Electrotechnical Standardization
CPO	Charge point operator
DC	qualifier; pertaining to time-independent electric quantities such as voltage or current, to devices operated with direct voltage and current, or to quantities associated with these devices; derived from “direct current” (see IEV item 151-15-02)
EN 50470-1	CENELEC standard “Electricity metering equipment (a.c.). Part 1: General requirements, tests and test conditions - Metering equipment (class indexes A, B and C)”, harmonised with MID and listed by the European Commission
EN 50470-3	CENELEC standard “Electricity metering equipment (a.c.). Part 3: Particular requirements - Static meters for active energy (class indexes A, B and C)”, harmonised with MID and listed by the European Commission
EN 50470-4	CENELEC standard on DC active energy meters, to be prepared (CENELEC TC 13 decision D2021/003)
EURAMET TC-EM	Technical committee “Electricity and Magnetism” of EURAMET, the European association of national metrology institutes
EVCS	electric vehicle charging station
IATE	Interactive Terminology for Europe, the EU’s terminology database (iate.europa.eu)
IEC	International Electrotechnical Commission
IEC 60050	International Electrotechnical Vocabulary
IEC 62053-21	IEC standard “Electricity metering equipment – Particular requirements – Part 21: Static meters for AC active energy (classes 0,5, 1 and 2)
IEC 62053-22	IEC standard “Electricity metering equipment – Particular requirements – Part 22: Static meters for AC active energy (classes 0,1S, 0,2S and 0,5S)
IEV	see IEC 60050
ISO/IEC DIR2	ISO/IEC Directives – Part 2
LegalEVcharge	EURAMET TC-EM project “LegalEVcharge: Practical legal metrology framework for electric vehicle charging stations”
M/541	Commission implementing decision of 15.12.2015 on a standardisation request to the European Committee for Standardisation, to the European Committee for Electrotechnical Standardisation and to the European Telecommunications Standards Institute pursuant to Regulation (EU) No 1025/2012 of the European Parliament and of the Council as regards certain measuring instruments
MID	Directive 2014/32/EU of the European Parliament and of the Council of 26 February 2014 on the harmonisation of the laws of the Member States relating to the making available on the market of measuring instruments
NordCharge	Nordic co-operation on charging stations for electric vehicles, working on metrological regulation-
OJ	Official Journal of the European Union
TEU	Treaty on European Union
WELMEC	European Cooperation in Legal Metrology

5. Legal metrology framework

5.1. Fundamental structure of legal metrology framework in Europe

In Europe, regulation on legal metrology is the responsibility of the Member States. Directive 2014/32/EU of the European Parliament and of the Council of 26 February 2014 on the harmonisation of the laws of the Member States relating to the making available on the market of measuring instruments (MID) harmonises the national implementing regulation for some measuring instruments. In the electrical domain, MID harmonises regulations on active electrical energy meters (Art. 2 MID) for use in household, commercial and light industry applications. Within the scope of MID, Member States may choose whether to prescribe the use of measuring instruments, in which case they must transpose MID, or not (Art. 3 MID). Outside the scope of MID, e.g. for electrical reactive energy meters, power meters or load profile generation, Member States may define the requirements without reference to MID.

Regulation of the responsibility of the users and the maintenance of the stability, e.g. subsequent verification or statistical survey, is not harmonised by MID.

Regulation regarding information on the unit price, billing requirements, qualification of personnel installing electricity meters etc. is not harmonised by MID and not necessarily considered part of legal metrology.

Often, regulation is limited to the expression of essential performance requirements (see Recital 25 MID) in order not to impede technical progress. For manufacturers and conformity assessment bodies, detailed technical specifications are more convenient to work with than such performance requirements. Those are commonly provided by standards such as harmonised standards that are adopted in accordance with Regulation (EU) No 1025/2012 of the European Parliament and of the Council of 25 October 2012 on European Standardisation for the purpose of expressing detailed technical specifications of those requirements.

5.2. General overview

5.2.1. A proportional legal metrology framework for electric vehicle charging stations

State activities must be conducted in the public interest and be proportionate to the ends sought. They must be

- necessary,
- suitable and
- proportional.

The principle of proportionality is a fundamental requirement of the constitution of many Member States and also of the Treaty on European Union (Art. 5(4) TEU).

5.2.2. Need for metrological regulation

Electric vehicles are increasingly common which means that more and more charging stations for public use are being installed. These fall into the category 'residential, commercial and light industrial use'. Customers are billed for the active electrical energy they receive. Member States wish to prescribe the use of active electrical energy meters for electric vehicle charging stations where they consider it justified for reasons of 'protection of consumers, levying of taxes and duties and fair trading' (Art. 3 MID). Electromobility is an important element of the Green Deal, but it can only be successful if consumers accept it. Hence, it is important that the required infrastructure is available and that the level of protection of consumers is comparable to the benchmark set by that for volumetric meters used in petrol stations.

Therefore, metrological regulation for electric vehicle charging stations are necessary and in the public interest.

However, it is not the role of legal metrology to guarantee the service is provided in a way that satisfies the customer. This is a general principle of legal metrology. For instance, regulations for capacity serving measures such as drinking glasses are harmonised under MID, i.e., in the framework of legal metrology. Other aspects such as the quality of the drink and principles of price declaration are not in the scope of MID, but are often regulated on a different basis. If a waiter is not serving a patron within a reasonable delay, this is no violation of legal metrology regulation, probably not a violation of any regulation at all. Nevertheless, in a functioning market, only a satisfied customer is likely to return and therefore it is in the supplier's interest to satisfy the customer. Thus, there is no need for metrological regulation to ensure customer satisfaction. The reliability of the charging station, the frequency of power cuts, whether the charging station restarts automatically after a power cut or whether the consumer is at risk of finding their car without the battery being recharged as intended is not for legal metrology to regulate. The market mechanisms are more suitable.

5.2.3. Suitability of metrological regulation

The aim of legal metrology is to maintain the high level of trust society puts into measurement that serve as the basis for the price to pay. This trust is based on two essential properties of the measurement:

- The measurement must be carried out using a measuring instrument under legal metrology control. The impartial protection of the state guarantees the instrument does not favour any party.
- The measuring instrument must be used in a transparent way to avoid hidden fraud.

Metrological regulation is only suitable if it includes all relevant properties of the instrument and guarantees the transparency.

5.2.4. Proportionality of metrological regulation

Proportionality requires that state action – which limits freedom – is as limited as possible while responding to the need and remaining effective. Therefore, the metrological regulation must be limited to as small a part of the charging station as possible. For a charging station, the following properties of the meter must be assured by metrological regulation.

1. The measurement must be correct.
2. The billing must be based on the energy transferred across the property boundary. If the cable is part of the charging station, the cable losses are not part of the energy transferred to the consumer. If the cable is the property of the consumer, the cable losses are to be paid for by the consumer.
3. The measurement result that serves as the basis for the price to pay must be available to the consumer.

Point 1 requires the use of a suitable active electrical energy meter. The relevant regulation is harmonised by MID. MID defines technology-independent performance requirements and covers active electrical energy meters for both AC and DC.

→ see section 5.3 (p. 11) for a high level discussion and chapter 5.3 (p. 11) for a technical discussion

Point 2 requires the measurement to be referred to the property boundary. It is not practical to have the meter exactly at the property boundary. If the cable is part of the charging station, the losses between the meter and the property boundary can be significant. In all cases, the losses are always in favour of the supplier if the measurement does not take them into account. MID requires the meter not to systematically favour any party (Annex V (MI-003) point 3 MID). The simple view that only the meter itself must satisfy this requirement violates the suitability requirement of MID ("A measuring instrument shall be suitable for its intended use taking account of the practical working conditions and shall not require unreasonable demands of the user in order to obtain a correct measurement result.", Annex I point 7.2 MID).

→ see section 5.4 (p. 14)

Point 3 requires the measurement result to be communicated to the consumer. The result as made available to the consumer must be

- transparent – the consumer can compare the measurement result indicated by the measuring instrument with the corresponding value on the bill and without having to trust the other party;
- trustworthy – the authenticity of the indicated result is assured;
- non-discriminatory – no party can block the access to the authentic indication of the measurement result by sealing the interface, setting a password or requiring a tool that is not easily available to the other party.

→ see section 5.5 (p. 17)

5.2.5. Conclusion

MID is fit for purpose for active electrical energy meters used in electric vehicle charging station. The performance requirements of MID call for technical implementations that differ from the technical implementations used in other applications. They are necessary and suitable to achieve the aims of legal metrology. There is no need for additional requirements in the case of active electrical energy meters used in EVCS.

Customer satisfaction is outside the scope of legal metrology.

Proportionality requires the metrological regulation to be limited to as small a part of the charging station as possible. This smallest part consists of the meter only, requires the meter to account for the losses between the meter and the property boundary – i.e., the connection between the charging station and the car – and requires the measurement result to be made available to the consumer in a transparent, trustworthy and non-discriminatory way.

A more detailed analysis is available in the following sections.

5.3. Active electrical energy meters

5.3.1. Fundamental question

Are all active electrical energy meters relevant for the protection of consumers, levying of taxes and duties and fair trading, and intended for residential, commercial and light industrial use within the scope of MID or only those for AC active electrical energy?

5.3.2. Situation today

Electric vehicles are increasingly common which means that more and more charging stations for public use are being installed. These fall into the category ‘residential, commercial and light industrial use’. Customers are billed for the active electrical energy they receive. Member States wish to prescribe the use of active electrical energy meters for electric vehicle charging stations where they consider it justified for reasons of ‘protection of consumers, levying of taxes and duties and fair trading’ (Art. 3 MID), regardless of the technology chosen by the industry, i.e. AC or DC.

There is uncertainty amongst the Member States regarding the question whether the scope of Annex V (MI-003) MID (‘active electrical energy meters’) is limited to active electrical energy meters for AC or whether it also includes active electrical energy meters for DC. If the latter are included, Member States can prescribe the use of MID-compliant active electrical energy meters in electric vehicle charging stations providing DC active electrical energy. If they are not included, Member States need to define non-harmonised regulation for the very same reasons foreseen by article 3 MID, i.e. ‘protection of customers, levying of taxes and duties and fair trading’.

Commission’s standardisation mandate M/541 requests the standardisation organisations, “with reference to Annex I (e.g. point 10.4) and Annex V to Directive 2014/32/EU, to draft one or more European standards concerning the legal metrological control of delivery to the public of electricity for use in electrical means of transport covered by Article 4 of Directive 2014/94/EU (i.e. electric road transport, maritime transport and inland navigation),” (Annex II M/541), further specifying that this/these standards shall be “containing technical specifications concerning the legal metrological control of delivery to the public of AC and/or DC electricity, also for on-board metering, for use in electrical means of transport” (Annex I M/541). It is only possible to draft such a standard for DC “with reference to […] Annex V to Directive 2014/32/EU” if such meters are within the scope of Annex V.

In 2021, CENELEC TC 13 decided to prepare a new standard in response to this mandate for DC active electrical energy meters, EN 50470-4 (CENELEC TC 13 decision D2021/003).

5.3.3. Historical background

Until recently, electric vehicle charging stations providing active electrical energy using DC were either for companies’ internal use and internal billing, e.g., public transport, postal services or supply for supermarkets, or the use was free of charge, i.e. included in the price of the vehicle. Active electrical energy meters in those charging stations were outside the scope of MID, either because the active electrical energy measurement was not used for billing purposes and thus not relevant for the ‘protection of consumers, levying of taxes and duties and fair trading’ (Art. 3 MID) or because they were not ‘intended for residential, commercial and light industrial use’ (Annex V (MI-003) MID).

Electric vehicle charging stations providing active electrical energy using AC were always intended for use by the general public and the billing was based on the active electrical energy. Therefore, they were relevant for the ‘protection of consumers, levying of taxes and duties and fair trading’ (Art. 3 MID) and thus within the scope of MID from the beginning.

Consequently, the Working Group on Measuring Instruments concluded on 12 June 2014:

‘Slow and medium fast charging systems of e-vehicles requiring AC delivery fall under MI-003, however, no mandate currently considers the metering aspect. Ideally, the maximum permissible errors provided for in Annex MI-003 should also apply to fast charging DC systems, but they are out of the scope of MID.’ (point 7 of MI-14-017)

Considering that

1. the situation did not change between the recast of the MID of 24 February 2014 (2014/32/EU) and the meeting on 12 June 2014 (MI-14-017),
2. the statement 'the maximum permissible errors provided for in Annex MI-003 should also apply to fast charging DC systems, but they are out of the scope of MID' (point 7 of MI-14-017) shows an intention that would have led to a modification of Annex V (MI-003) in the recast of MID (2014/32/EU) had this been deemed necessary to extend the scope of MID to active electrical energy meters both for AC and DC,
3. such a modification has not been made, i.e. it has not been deemed necessary to modify Annex V (MI-003) in the recast of MID (2014/32/EU) to subject active electrical energy meters for DC to the requirements of MID once they are used within the scope of MID,

it is clear that active electrical energy meters used in fast charging DC systems were considered out of scope of MID on and prior to 12 June 2014 because of the way they were used, not because active electrical energy meters for DC were not considered to be active electrical energy meters.

5.3.4. Technical background: Scope (Annex V (MI-003) MID)

'Active energy' is defined as 'electrical energy transformable into some other form of energy' (see IATE, the EU's terminology database, the harmonised standard EN 50470-1 and the International Electrotechnical Vocabulary (IEV, IEC 60050)). The definition includes both DC and AC, since both provide energy transformable into some other form of energy, e.g. mechanical energy in the case of a motor.

Consequently, the term 'active electrical energy meter' includes both DC and AC. 'Active energy meter' and 'watt-hour meter' are synonyms (see IATE, EN 50470-1, IEV). The IATE gives an example for the term in context, 'the procedure requires the use of a bi-directional DC Watt-hour meter' (see OJ L 335, 22.12.2015, p. 1–84). Therefore, 'watt-hour meter', 'active energy meter' and 'active electrical energy meter' include DC. This is also stressed by the title of several standards, which explicitly mention 'AC' to reduce their scope to AC active energy only.

➔ The scope of Annex V (MI-003) MID covers active electrical energy meters for both DC and AC.

5.3.5. Technical background: Requirements (Annex V (MI-003) MID)

For the sake of readability, it is convenient to limit explicit exceptions to a minimum. Some quantities are commonly used in the context of AC, but are often omitted in the context of DC, namely because they take a constant and obvious value. However, they remain defined and therefore, it is valid to use them for both DC and AC without exception.

1. Power factor. The power factor is defined as the ratio of active power to apparent power (IATE, EN 50470-1, IEV). For DC, the active power and the apparent power are identical and the power factor is equal to unity.
2. Frequency. For DC, the frequency is 0 by definition. Only this definition is compatible with the fundamental laws of electrotechnology, e.g. $X_L = 2\,\pi\,f\,L$.

For DC, some requirements are not a limitation for the meter or not applicable.

3. Power factor range. For DC, a manufacturer can specify 'power factor range: unlimited'. Such a meter will comply with the MPEs for all values of the power factor that are physically possible and will be fit for purpose.
4. Disturbance 'DC in the current circuit'. Annex I MID defines the terms 'disturbance' and 'rated operating conditions' to be mutually exclusive and depending on the specifications for the

measurand and the influence quantities. When the specified reference frequency is 50 Hz, 'DC in the current circuit' is a disturbance and the relevant critical change value for disturbances (Table 3) is applicable. When the specified reference frequency is 0 Hz (DC), 'DC in the current circuit' is within the rated operating conditions and the MPEs at rated operating conditions (Table 2) are applicable.

➔ Active electrical energy meters for both DC and AC can meet the requirements of Annex V (MI-003) MID.

5.3.6. Conclusion

'Active electrical energy meters' used for billing purposes, relevant for the 'protection of consumers, levying of taxes and duties and fair trading' (Art. 3 MID) and 'intended for residential, commercial and light industrial use' (Annex V (MI-003) MID) are – and have always been – included in the scope of MID regardless of whether AC or DC is used. Therefore, MID serves the intended purpose as it is, without need for any modification.

5.4. Transformer operated meters

5.4.1. Fundamental question

Does MID allow active electrical energy meters designed for use in combination with external instrument transformers? If so, is this limited to certain instrument transformers and similar external components using some technologies, excluding others? Must the active electrical energy meter display the energy measured by the meter or may it correct for the effect of external components such as the instrument transformer?

5.4.2. Analysis

Annex V (MI-003) applies only to the active electrical energy meters, not to external instrument transformers, but explicitly mentions that meters may be used in combination with such instrument transformers (Annex V (MI-003) MID, note). However, this statement is immediately followed by the definitions. There, "an active electrical energy meter [is defined as] a device which measures the active electrical energy consumed in a circuit". The quantities I and U refer to the inputs of the meter rather than the circuit in which active electrical energy is consumed. Only in the case of direct-connected meters, without transformers, are the two identical (Figure 2).

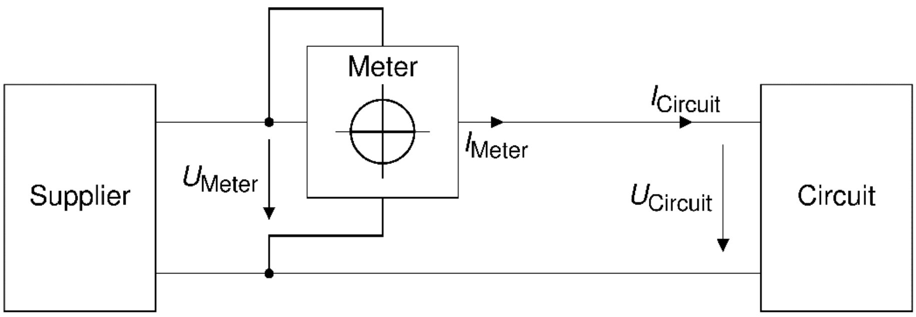

Figure 2: Direct connected meter: The energy measured by the meter is that same as the energy consumed in the circuit since $I_{Meter} = I_{Circuit}$ and $U_{Meter} = U_{Circuit}$.

In the most common case of indirect-connected meters, transformer-operated meters, the energy measured by the meter is not equal to the energy consumed in the circuit (Figure 3) since $I_{Meter} \neq I_{Circuit}$ and $U_{Meter} \neq U_{Circuit}$. In addition, the meter measures the current flowing in one circuit and the voltage across another circuit, so the energy measured by the meter is not consumed anywhere at all; it is a so-called *phantom energy*. Nevertheless, such a measurement is very common and meaningful – the transformers create representations of the voltage U_{Circuit} and the current I_{Circuit}. While the two quantities I_{Meter} and U_{Meter} are not relevant in themselves, they allow for an accurate reconstruction of the voltage U_{Circuit} and the current I_{Circuit} as long as some characteristics of the instrument transformers are known. These characteristics are shown on the nameplate of transformers. Most transformer-operated meters take these characteristics into account and display the energy consumed in the circuit even though they measure the phantom energy applied to its input. While this is very convenient for all concerned parties – the energy that is the basis for the price to pay can be read directly from the meter – there is a risk of fraud if the meter is configured for transformers with specified characteristics, e.g., a given transformation ratio, but used with different transformers having, e.g., a different transformation ratio. Ever since transformer-operated meters exist, this risk has been mitigated by showing the transformer characteristics for which the meter is designed on the nameplate or on the display. A consumer without any knowledge about electricity can compare the information on the nameplate or display of the meter with the corresponding information on the nameplate of the transformer. Only if the two match, the configuration is correct. Therefore, it is not necessary to metrologically secure the connection between the meter and the transformers, which would be very inconvenient; installation seals are sufficient. It is worth noting that this discussion is not limited to inductive analogue transformers. The essential property is that the transformers generate signals – not necessarily analogue or proportional – that allow for an accurate reconstruction of the voltage U_{Circuit} and the current I_{Circuit}.

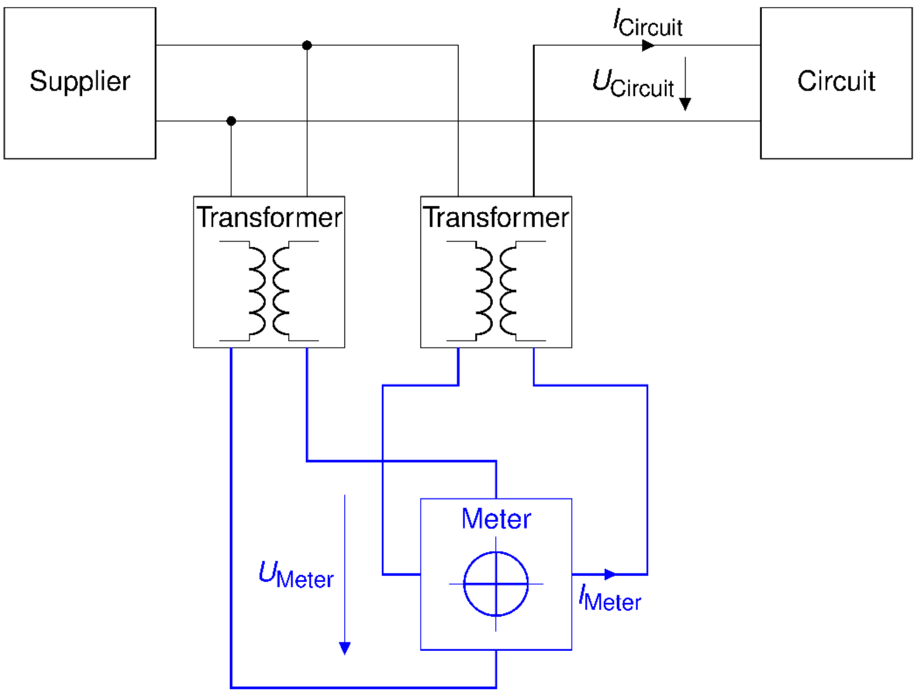

Figure 3: Meter measuring the energy indirectly using instrument transformers: The energy measured by the meter (blue) is different from the energy consumed in the circuit (black) since $I_{\text{Meter}} \neq I_{\text{Circuit}}$ and $U_{\text{Meter}} \neq U_{\text{Circuit}}$, but the meter can display the energy consumed in the circuit based on a simple calculation.

In most of the part *specific requirements* of Annex V (MI-003) MID, I and U are used according to the definition, but the critical change value (point 4.3.1) is referred to the energy in the circuit. For transformer-operated meters displaying the energy consumed in the circuit, the corresponding formula only holds if I and U are referred to the circuit, i.e. the primaries of the instrument transformers and not the quantities measured by the meter. EN 50470-3, the relevant harmonised standard, explicitly mentions such “primary registers”; most transformer-operated meters display the energy consumed in the circuit, i.e., the energy measured by the combination of meter and instrument transformers.

➔ MID explicitly allows active electrical energy meters designed for use in combination with external instrument transformers.

➔ Most transformer-operated meters correct for the effects of the instrument transformers and display the energy consumed in the circuit. The relevant harmonised standard explicitly allows for this.

There is no explicit provision in Annex V requiring or allowing the transformer-operated meters to display the energy consumed in the circuit, correcting for the effect of external components such as the instrument transformer. The energy consumed in the circuit is the basis for the price to pay and most relevant to the consumer; it is appropriate to display this energy rather than the phantom energy measured by the meter itself. Therefore, the harmonisation of EN 50470-3 is consistent with the goals of MID and not a mistake. While the scope of EN 50470-3 is limited to some kinds of instrument transformers, this principle is applies to meters for use with any kind of instrument transformers and other, similar external components.

➔ MID applies to meters designed for use in combination with external components such as instrument transformers without limiting the technology used in these external components. The essential condition is than the energy consumed in the circuit can be determined reliably and that the requirements of protection of consumers and fair trading are satisfied.

➔ When read as a detailed technical specification, the phrasing of MID Annex V (MI-003) is contradictory for indirect-connected meters. This contradiction existed already with state of the art technology of 2004. Therefore, this interpretation cannot reflect the intention of the legislator; it is not appropriate to use this interpretation.

➔ When read as a performance requirement, the phrasing of MID Annex V (MI-003) is perfectly appropriate and free of contradictions for any kind of meter. Since the difference between direct-connected or indirect-connected meters is irrelevant – both kinds of meters measure the active electrical energy consumed in the consumer's circuit in a way that satisfies the requirements of protection of the consumer and fair trading – this statement is valid for both direct-connected or indirect-connected meters.

A practical application using external components generating a representation allowing for an accurate reconstruction of the voltage U_{Circuit} and the current I_{Circuit} are cables with non-negligible losses in electric vehicle charging stations. The energy to be measured is the energy transferred to the consumer, i.e., at the consumer end of the cable, but the energy measured by the electricity meter itself is the energy leaving the charging station, i.e., at the charging station end of the cable (Figure 4).

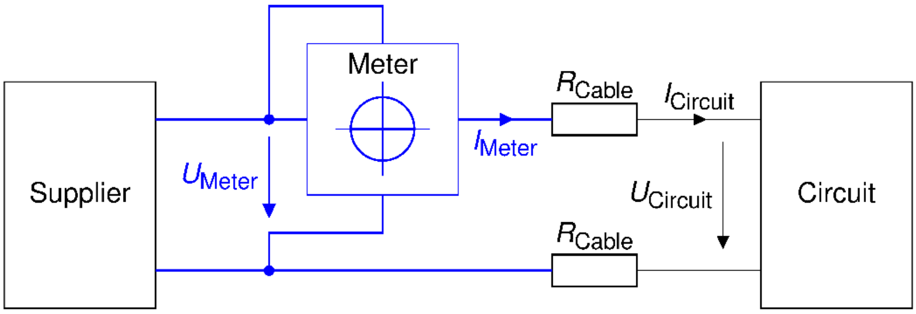

Figure 4: Meter measuring the energy indirectly taking into account cable losses: The energy measured by the meter (blue) is different from the energy consumed in the circuit (black) since $U_{Meter} \neq U_{Circuit}$, but the meter can display the energy consumed in the circuit based on a simple calculation.

The energy measured by the meter is larger than the energy consumed by the circuit due to the cable losses. The cable losses can be easily accounted for with a simple correction. The only difference in the calculation between a correction for instrument transformers and cable losses is that in the case of analogue instrument transformers for voltage, a correction factor multiplied by the voltage U_{Meter} yields $U_{Circuit}$: $U_{Circuit} = k_U \times U_{Meter}$, where k_U is taken from the instrument transformer ratings. In the case of cable losses, $U_{Circuit}$ is calculated subtracting the product of a correction factor and the current I_{Meter} from U_{Meter}: $U_{Circuit} = U_{Meter} – 2\ R_{Cable} \times I_{Circuit}$, where R_{Cable} is taken from the cable ratings.

➔ The calculation required to determine the energy consumed in the circuit when cable losses between the meter and the circuit are not negligible is similar to the calculation required in transformer-operated meters. Therefore, MID can only allow both implementations of indirect measurement or none at all. Since MID explicitly mentions indirect meters designed for use with instrument transformers, it also allows for indirect meters designed for use with lossy cables.

5.4.3. Conclusion

1. MID covers active electrical energy meters, including those for indirect connection.
2. When read as performance requirements aiming for appropriated protection of the consumer and fair trading, Annex V (MI-003) is free from any contradiction. It allows for indirect-connected meters taking any representation of the voltage U_{Meter} and the current I_{Meter} at the input of the consumer's circuit as long as it allows for an accurate reconstruction of the voltage $U_{Circuit}$ and the current $I_{Circuit}$ at the input of the consumer's circuit and hence the energy consumed in the circuit that is the basis for the price to pay.
3. In the interest of protection of the consumer and maintenance of the consumer's trust through transparency, the characteristics of any transforming element used with the active electrical energy meter must be shown on the meter, either on the nameplate or on the display. This is state of the art today and has been state of the art for more than a century.

5.5. Display

5.5.1. Fundamental question

Legal metrology traditionally aims to establish and enforce the rules for measurements that are used in commercial transactions without being party to the transaction. A well-established method is to mark the measuring instruments with a well-recognisable symbol if they respond to the legal requirements. If all concerned parties can convince themselves that this symbol is present on the instrument and read the result of the measurement themselves, they can consider the measurement to be trustworthy.

In the past centuries and even millennia, measuring instruments were isolated instruments, the advance of modern-day technology such as microelectronics and telecommunication infrastructure such as the internet led to the development of distributed systems. It is obvious that the result of a measurement carried out using an instrument without means of remote communication of the result must be shown by the said instrument.

Nowadays, an important question is whether in the case of modern instruments with means of remote communication, the measurement result may be made available using modern-day technology without compromising the aim of legal metrology and violating requirements of MID.

5.5.2. Regulatory context

“Member States may prescribe the use of measuring instruments for measuring tasks, where they consider it justified for reasons of […] protection of consumers, […] and fair trading” (Article 3).

In Annex I point 10, requirements for the indication of the result of the measurement are detailed.

10.1. Indication of the result shall be by means of a display or hard copy.

10.2. The indication of any result shall be clear and unambiguous and accompanied by such marks and inscriptions necessary to inform the user of the significance of the result. Easy reading of the presented result shall be permitted under normal conditions of use. Additional indications may be shown provided they cannot be confused with the metrologically controlled indications.

10.3. In the case of hard copy the print or record shall also be easily legible and non-erasable.

10.4. A measuring instrument for direct sales trading transactions shall be designed to present the measurement result to both parties in the transaction when installed as intended. When critical in case of direct sales, any ticket provided to the consumer by an ancillary device not complying with the appropriate requirements of this Directive shall bear appropriate restrictive information.

10.5. Whether or not a measuring instrument intended for utility measurement purposes can be remotely read it shall in any case be fitted with a metrologically controlled display accessible without tools to the consumer. The reading of this display is the measurement result that serves as the basis for the price to pay.

Given this context, it is clear that the display is required for consumer protection. As a result, the indication of the measurement result is

- transparent – the consumer can compare the measurement result indicated by the measuring instrument with the corresponding value on the bill and without having to trust the other party;
- trustworthy – the authenticity of the indicated result is assured;
- non-discriminatory – no party can block the access to the authentic indication of the measurement result by sealing the interface, setting a password or requiring a tool that is not easily available to the other party.

This requirement can be interpreted as a performance requirement or a detailed technical specification.

There is no explicit definition of the term “display” in MID.

MID “should be limited to the expression of essential requirements that do not impede technical progress, preferably performance requirements” (Recital 25). Harmonised standards are adopted for the purpose of expressing detailed technical specifications (Recital 25).

5.5.3. Strict interpretation as performance requirement

When points 10.1, 10.4 and 10.5 are taken as performance requirements, a technical solution that satisfies the requirements of transparency, trustworthiness and non-discrimination is acceptable. Given the suitability requirement “A measuring instrument shall be suitable for its intended use taking into account of the practical working conditions” (Annex I point 7.2), these three requirements must be met when the meter is in use.

Often, meters are used in closed and locked electrical cabinets where access is restricted to skilled persons for safety reasons. In this case, a meter where the hardware implementation of the display is integrated the meter housing does not satisfy the requirements when in use. The indication of the result shall be shown such that the requirements are met, in this case outside the locked electrical cabinet.

The detailed technical specifications to be derived from this performance requirement, e.g. by manufacturers, conformity assessment bodies and market surveillance authorities, are subject to technological progress and the practical working conditions. Therefore, it is appropriate that MID does not include an explicit and detailed definition of the term “display”.

In conclusion, when taking points 10.1, 10.4 and 10.5 as performance requirements, MID is free of contradictions and satisfies the requirements of consumer protection and fair trading; it is fit for purpose with regards to active electrical energy meters used in EVCS.

5.5.4. Strict interpretation as detailed technical specification

When points 10.1, 10.4 and 10.5 are taken as detailed technical specifications, the hardware implementation of the display must be within the housing of the meter.

Often, meters are used in closed and locked electrical cabinets where access is restricted to skilled persons for safety reasons. In this case, a meter where the hardware implementation of the display is integrated the meter housing does not satisfy the requirements of transparency, trustworthiness and non-discrimination when in use. Therefore, the meter does not contribute to the protection of consumers and fair trading, even if those are the reasons for Member States to require the use of such a meter. It is not “suitable for its intended use taking into account of the practical working conditions” (Annex I point 7.2).

In conclusion, when taking points 10.1, 10.4 and 10.5 as detailed technical specifications, MID is self-contradictory since it is impossible to design a meter that satisfies both the strict interpretation as detailed technical specification and the suitability requirement at the same time in such an installation; protection of consumers and fair trading is not guaranteed.

Moreover, it would be an inconsistency in style to define the performance requirements in the instrument specific annexes with a greater level of detail than a detailed technical specification, which is fundamental to all instruments within the scope of MID. The greatest lack of detail would be the absence of detailed technical definition of the term “display”, which is fundamental to the detailed technical specification.

5.5.5. “Flexible interpretation” as detailed technical specification

At the time of conformity assessment and placing on the market, meters are not mounted in closed and locked electrical cabinets. Therefore, neither the conformity assessment bodies or the market surveillance authorities will notice the meter is not “suitable for its intended use taking into account of the practical working conditions” (Annex I point 7.2).

In conclusion, a meter with a hardware implementation of the display integrated in the housing will not satisfy the requirements in all practical working conditions, but neither the conformity assessment bodies or the market surveillance authorities will notice this. However, especially at electric vehicle charging stations, the lack of a visible display and consumer protection will be very visible and build a strong contrast to traditional petrol stations. Therefore, the “flexible interpretation” is likely to attract a lot of attention of consumers, consumer protection agencies, lawyers and journalists. This interpretation is neither pragmatic nor fit for purpose.

5.5.6. Conclusion

1. With the strict interpretation of points 10.1, 10.4 and 10.5 as a performance requirement, MID is free of contradictions and satisfies the requirements of consumer protection and fair trading; it is fit for purpose.

2. With the strict interpretation of points 10.1, 10.4 and 10.5 as a detailed technical specification, MID is self-contradicting. This interpretation cannot be used in practice. MID is not fit for purpose.

3. With the “flexible interpretation” of points 10.1, 10.4 and 10.5 as detailed technical specification, MID does not satisfy the requirements of consumer protection and fair trading, but this will go unnoticed by conformity assessment bodies and market surveillance authorities. The problem will be obvious especially at electric vehicle charging stations, where consumers will unavoidably notice the strong contrast to traditional petrol stations. It is likely to attract a lot of attention of consumers, consumer protection agencies, lawyers and journalists. This interpretation is neither pragmatic nor fit for purpose.

6. Key points for implementing regulation

6.1. General

This chapter lists some examples of key points that may or may not be subject of non-harmonised regulation as guidance. The list is not exhaustive and does not intend to decide whether these points should be regulated and if so, how and at what level. The examples given here are not intended to be binding in any way.

6.2. Accuracy classes

The accuracy classes defined by MID are A, B and C. Since EVCS are commercial applications, Member States requiring the energy to be measured must allow the use of class B meters. For specific purposes, they may require class C meters (Annex V (MI-003) point 7 MID). The maximum permissible error at reference conditions is 2 % for class A, 1 % for class B and 0,5 % for class C.

For comparison, the accuracy class required by MID for fuel dispensers for petrol is 0,5. The corresponding maximum permissible error is 0,5 % for the measuring system and 0,3 % for the meter.

Some Member States choose to require class B for direct connected meters and class C for transformer operated meters. When instrument transformers are required to be of class 0,5, 0,5S or better, this leads to class B for the overall system composed of meter and, if used, instrument transformers. As a result, the overall accuracy as seen by the consumer does not depend on the choices of the manufacturer or the user.

Other Member States accept class A meters for public EVCS.

6.3. Display

6.3.1. Display resolution

Based on the general suitability requirement (Annex I point 7 MID), many Member States require the display resolution to be sufficient to respect the maximum permissible error for the smallest reasonable commercial transfer of energy. Some Member States define the energy of this smallest reasonable transfer in their legislation or require it to be shown in a clear and unambiguous way before the transaction is started.

Another way of defining the size of the minimum energy transfer, and the corresponding display resolution, is to base it on the energy equivalent to the value of smallest coin in circulation. If the smallest coin is worth 0,01 €, it is generally accepted that prices are rounded to that precision. If 0,01 € is to correspond to the maximum permissible error of, e.g., a class C meter at reference conditions, 0,5 %, the corresponding price of the smallest transfer of energy is 2 €. Assuming a unit price of 0,40 €/kWh, 0,01 € correspond to an energy of 0,025 kWh. Some Member States do not require the energy of this smallest transfer for which the maximum permissible error is respected to be shown if the equivalent monetary value is less that the value of the smallest coin in circulation.

6.3.2. Authenticity

State of the art solutions to guarantee the authenticity of data can be proven (see section 5.5, p. 17) to exist. Common solutions are

1. a hardware implementation of the display within the metrologically sealed housing of the meter or with a metrologically sealed connection to the meter;
2. a meter that cryptographically signs the data it sends to a remote device implementing the display.

Option 1 has been used ever since electricity meters were made subject to legal metrology regulation. Option 2 became practically and economically implementable in microelectronic systems such as electricity meters in the recent decades. Here, the result of the measurement is cryptographically signed by the meter. This data can be send on any channel without need for the channel to be metrologically controlled, e.g., the internet. Nowadays, asymmetric cryptography is commonly used even by consumers. Here, the meter signs the data with a private key. The consumer is supplied with the meter's public key, which allows for the verification of the authenticity of the data.

In some Member States, public databases with the public keys of the meters are used [1]. Another solution is to show the public key in a human-readable and in a machine-readable form on the meter and the EVCS. To verify the authenticity, the consumer may use publicly available software, which can also be implemented as web service.

The principle of provable authenticity is fundamental to legal metrology, but the acceptability of different solutions may differ across Europe.

6.3.3. Non-discrimination: Acceptable devices

Another fundamental principle of legal metrology is that the possibility for both parties to a transaction to access the data must be possible not only in theory, but also in practice and without unreasonable demands especially on the side of the consumer who cannot chose the measuring instrument (Annex I point 10; see section 5.5, p. 17).

In some countries, the hardware implementation of the display may be placed behind a transparent window in the EVCS even if this window is not ergonomically accessible. Other countries accept such solutions only if the window is accessible to the disabled and elderly.

In other countries, the EVCS are fitted with a general user interface that is not under legal metrology control. This user interface may show the measurement result with the cryptographic signature, e.g., in machine-readable form. Another solution is to show the measurement result on this user interface for information only if it is provided with the cryptographic signature in another way.

Another implementation can consist in showing the measurement result on a mobile device. Especially in Member States where a very large part of the society uses such devices or when the specific consumer uses such a device to control the charging process, this is considered acceptable. While some Member States require an open software solution, others accept proprietary smart phone apps.

Some Member States require the measurement results to be shown in real time during the charging process while others accept that they are shown at the end of the charging process.

6.3.4. Calculation of the energy of the transaction

Many EVCS manufacturers use traditional active electrical energy meters that only have a non-resettable register for the total energy. In this case, the price is based on the difference of the values of this register at the beginning and at the end of the charging process.

Many Member States consider the register for the total energy to be metrologically relevant, but accept that the difference is calculated outside of the metrologically controlled system since the calculation of the difference is a simple operation the consumer can be expected to check themselves if desired. For household active electrical energy meters, this is by far the most common approach. In the domain of direct sales such as EVCS, some Member States require the difference to be calculated under metrological control and consider the difference the measurement result.

The latter approach has been found problematic in some cases where the difference is calculated based on total register values with finite-resolution floating-point numbers. During conformity assessment, the values of the total register is generally very small and the resolution of the floating-point numbers is largely sufficient. In practical use, the value of the total register, which cannot be reset to zero (Annex V (MI-003) point 5.2 MID), increases with time. At some point, the resolution of the floating-point numbers become insufficient to guarantee the required accuracy of the difference. Such a problem is unlikely to be detected during conformity assessment. However, if the values at the beginning and at the end are considered measurement results, they have to be made available to the user and to the consumer. A problem in the difference calculation algorithm is likely to be persistent and will therefore be identified quickly even if only a small fraction of the consumers check it.

6.4. Durable proof

The requirements for the durable proof (Annex I point 11 MID) are similar to those for the display. Some Member States accept differences, namely concerning the authenticity.

For comparison, in petrol stations, the display is implemented using a physical display integrated into the measuring system. The authenticity of the measurement result shown by this implementation is guaranteed through conformity assessment and sealing. In many Member States, the durable proof, however, is a receipt printed on commonly available, blank thermo-paper. Anyone who has access to a commercially available thermo-printer with the right font can print a similar receipt either on new paper or on the original paper after erasing the original content and claim this to be the genuine, durable proof.

A level of authenticity protection similar to that of such a receipt can easily be achieved using simple text messages, which are as easy to manipulate, even though this requires different skills [2, 3].

In addition, the durable proof must be durable and include not only the measurement result, but also information required to identify the transaction. It must be made available on request. The latter point is considered by many Member States to imply that the durable proof becomes the possession of the consumer – as for the case of the paper receipt at traditional petrol stations. This excludes proprietary solutions such as proprietary apps, since access is only possible while the app is available and the consumer has access to the relevant account – which might not be the case once a contract is terminated. Once paper mail and e-mail, for instance, are in the possession of the consumer and the public key is publicly available, the consumer does not depend on the co-operation of the supplier.

6.5. Cables

The energy to be measured is the energy transferred to the consumer, i.e., at the consumer end of the cable, but the energy measured by the electricity meter itself is often the energy leaving the charging station, i.e., at the charging station end of the cable. In this case, the cable losses become a relevant parameter in the same way as, e.g., the transformation ratio in the case of a transformer-operated meter (see section 5.4, p. 14) or the conversion of volumes at ambient temperature to the equivalent volume at 15 °C in petrol stations. Therefore, many Member States define requirements for the cable in a similar way. A simple solution may consist of encouraging the cable and meter manufacturers make the characteristics of the cable easily comparable with the characteristics used to correct the meter reading, e.g. by standardisation (see section 9.1.4, p. 38). In this case, some Member States consider it a sufficient if those characteristics are rendered visible to the consumer based on the general suitability requirement (Annex I point 7 MID). Metrological supervision (see section 6.9, p. 25) checks if this is correctly implemented in practice.

A technical implementation avoiding the need for correction is a four-wire measurement at the property boundary. In this case, the properties of the cable are not relevant parameters. Some

Member States may require this solution based on the general suitability requirement (Annex I point 7 MID).

6.6. Instrument transformers

Since the accuracy of instrument transformers have a significant impact on the accuracy of the energy measurement, many Member States subject instrument transformers to metrology law. Usually, these requirements are aligned with all or with some standards of the IEC 61869 series.

Other Member States consider those situations where instrument transformers are used to be outside the scope of household, commercial and light industry applications and exclude them from their metrology law.

In any case, MID does not harmonise requirements for instrument transformers.

6.7. Maintenance of the stability

After installation, measuring instruments are subject to ageing as well as wear and tear. Therefore, most Member States consider it essential that procedures are carried out to maintain the stability of the instruments. The most common procedures are

- subsequent verification: each individual measuring instrument is checked for compliance with the metrological requirements at regular intervals;
- statistical surveying: batched of similar measuring instruments are defined; at regular intervals, a sample is taken from each batch; if the sample complies with the requirements, the whole batch is assumed to comply with the requirements.

The exact names of these procedures vary in different Member States.

6.8. Responsibility of the charge point operators

6.8.1. General

An instrument that satisfies the requirements at the time it is made available on the market can be used in a way that is not intended by the manufacturer and leads to incorrect measurement results or, e.g., an inaccessible hardware implementation of the display. Such a meter does not satisfy the legal metrology requirements in its practical working conditions without any possibility for the manufacturer, conformity assessment bodies or market surveillance authorities to detect this and to take appropriate measures. Therefore, many Member States give responsibility to the charge point operators to make sure that, e.g., the manufacturer's instructions are followed by the users and that instruments that are designed for the practical working conditions are used.

6.8.2. Rated operating conditions

Many Member States require the rated operating conditions to match the practical working conditions. This usually includes specified reference voltage – which may differ significantly from 230 V and may have to include a range such as 150 V to 1000 V – and the current range – which is even explicitly mentioned in MID (Annex V (MI-003) point 7(c) MID). Furthermore, polyphase meters may or may not be designed for use in single-phase applications. For these meters operating with a single phase load, the maximum permissible errors are increased (Annex V MI003 point 3 MID). For EVCS that can provide energy to both in polyphase and single phase mode, many Member States require meters designed for both modes to be used.

6.8.3. Test after installation

In Member States giving responsibility to the charge point operators to make sure that, e.g., the manufacturer's instructions are followed by the operators and that instruments that are designed for the practical working conditions are used, it is general practice for operators to verify that the meter and the whole measuring system is cabled and configured correctly after installation. It is good practice to document such checks in case of litigation.

6.9. Metrological Supervision

Since it is important that the instrument satisfies the requirements when in use, metrological supervision checks instruments as installed. For instance, a real car may be charged at an EVCS while the energy transferred to the car is measured with a reference instrument. The difference between the reference measurement and the measurement of the instruments included in the EVCS must be within the maximum permissible errors in use. In many Member States, these are larger than the maximum permissible errors at the time of making available on the market by a factor of 1,5 or 2 to account for phenomena related to acceptable and unavoidable drift between subsequent verifications. For example, a meter may show an error that is slightly less than the maximum permissible error at the time of last subsequent verification. Therefore, it may be accepted for use for another verification period, e.g., five years. With time, all meters drift. If this meter drifts as it did before the verification, its error will slightly exceed the maximum permissible error before the next subsequent verification. If this was deemed acceptable at the time of the last subsequent verification, many Member States deem it acceptable if an additional check is performed.

A general problem surveillance authorities face is that the device under test could intentionally show one behaviour in actual use and another behaviour when under test if it detects being tested ("Verification mode loophole"). Metrological supervision by charging a real car at an EVCS while the energy transferred to the car is measured with a reference instrument will detect such problems. If the problem is systematic, a moderate number of checks will detect it. Metrological supervision is not harmonised by MID.

6.10. Transitional provisions

By default, regulation becomes effective immediately or on a single, fixed date. When newly regulating systems that existed prior to the regulation coming into force, this may have undesired consequences. One example possible solution is sketched in Table 1, where some systems are exempt from parts of the regulation for a given duration. In consequence, the aims of legal metrology will only be partially achieved during the transition period. However, the situation will never be worse than before entry into force of the regulation and will get better with time. The underlying assumption is that the advantage, such as maintaining trust of all concerned parties in the Member States' respect of the principle of proportionality, outweighs the effects of the delays, especially given that the situation without any regulation was deemed acceptable before.

Table 1: Transitional provisions

Years after entry into force of regulation	Measure/Exemption	Remarks
0	Entry into force in principle	• Conformity assessment becomes possible • Market gets certainty about the regulation to be expected

Years after entry into force of regulation	Measure/Exemption	Remarks
3	Electricity meters and instrument transformers not previously regulated must satisfy the requirements	• Manufacturers have sufficient time to adapt their products • Conformity assessment bodies have sufficient time to assess products if manufacturers submit requests in time • Sellers of EVCS may sell their pre-existing stock • Users (owners) of EVCS may install their pre-existing stock and EVCS they receive based on pre-existing contracts.
3	For meters and transformers manufactured earlier than two years after entry into force, the delays for the procedures for the maintenance of the stability start.	• Meters and transformers manufactured before they must satisfy the requirements are deemed manufactured on the first day of year 3. • No problem of overdue verifications when meters and transformers must satisfy requirements. Before the requirements are in force, no verification is possible, so no problem should be created the day the requirements enter into force.
3	Meters may continue to be used where they are installed on day 1 of year 3 even if their accuracy class does not satisfy the requirements until the end of year 17.	• No need to change installed meters just for the accuracy class requirement • But: Meters may not be installed elsewhere – when work is done to install another meter in a given installation, this meter must satisfy the requirements • The lifetime of these meters and transformers is finite, possibly limited by the lifetime of the EVCS. To allow this exemption to be withdrawn at some point, the duration is limited to a value larger than the expected lifetime

Years after entry into force of regulation	Measure/Exemption	Remarks
3	For meters and transformers without declared accuracy class, the maximum permissible errors are twice the maximum permissible errors of class A (active energy), class 3 (reactive energy), class 0,5S (current transformers) and class 0,5 (voltage transformers) until the end of year 17.	• When the requirements enter into force, meters and transformers installed previously might not have an accuracy class declared. In this case, the maximum permissible error is defined as twice the value of the accuracy class with the largest maximum permissible errors. • This does not change the requirement "The meter shall not exploit the [maximum permissible errors] or systematically favour any party," (Annex V (MI-003) point 3 MID) or any similar requirement for transformers. Therefore, fair trading is not compromised. • The lifetime of these meters and transformers is finite, possibly limited by the lifetime of the EVCS. To allow this exemption to be withdrawn at some point, the duration is limited to a value larger than the expected lifetime
3	Meters and transformers installed before day 1 of year 3 need not satisfy Annex I points 8.2, 8.3, 8.4, 10 and 11 MID until the end of year 17.	• Such meters and transformers may not be designed to satisfy these requirements • These requirements do not per se affect the quality of the measurement • The lifetime of these meters and transformers is finite, possibly limited by the lifetime of the EVCS. To allow this exemption to be withdrawn at some point, the duration is limited to a value larger than the expected lifetime
8	For meters installed before day 1 of year 3, cable losses be up to one-third of the maximum permissible errors of class A until day 1 of year 8. Afterwards, "The meter shall not exploit the [maximum permissible errors] or systematically favour any party," applies.	• Such meters may not allow for correction of the cable losses. • Since there were no requirements before day 1 of year 3, it should be acceptable if this requirement is introduced later for legacy cases.
18	None of these exemptions applies any more.	• All documents explaining these exemptions can be withdrawn from documents from daily use.

6.11. Examples of matters outside the scope of legal metrology

6.11.1. Non-metrological requirements for EVCS

Non-metrological requirements for EVCS are generally considered important by manufacturers, owners and consumers. For instance, the IEC 61851 series of standards covers EVCS [4].

6.11.2. Efficiency of the EVCS

The measurand in the context of legal metrology is the energy transferred across the property boundary, i.e., that is transferred from the supplier to the consumer. This energy is the subject of the contract and the bill.

Many owners of EVCS are also interested in the efficiency of the EVCS. Ideally, they would like to have information about it when comparing EVCS models with respect to their efficiency before deciding to buy one model rather than another.

6.11.3. Efficiency of the car

The measurand in the context of legal metrology is the energy transferred across the property boundary, i.e., that is transferred from the supplier to the consumer. This energy is the subject of the contract and the bill.

Many consumers would also like to know how far they can travel with the vehicle given the state of charge of the battery. Consumers are used to the fact that the driving behaviour influences the range and that conversion of the volume of petrol in the tank to the range is often approximative only. A new effect it that some energy transferred to the car is lost before it is stored in the battery, a phenomenon that did not exist for petrol. Apparently, the losses can be significant [5].

The efficiency of the car does not affect the correct measurement of the energy provided.

6.11.4. Declaration of the unit price

Many consumers are used to comparing unit prices before deciding for a product or a supplier, e.g., a petrol station or one brand of milk rather than another. In the case of petrol stations or EVCS, this is the only way for comparing prices since the total price to be paid depends on the quantity to be purchased, which cannot be known before the refuelling or charging process is terminated.

In the case of EVCS, many consumers are unhappy about confusing price declarations [6]. In many Member States, regulation and guidance exists [7, 8, 9].

6.11.5. Information on consumer's rights

The information to be given to the consumers about their rights may differ between the Member States. It is out of scope of this document and often considered outside the scope of legal metrology.

6.11.6. Attribution of the transaction to the consumer's payment account

Often, consumers are billed monthly for all transactions of the month. Therefore, it may be important that the transaction is attributed correctly to the consumer's payment account, as it is important to attribute credit card payments to the correct credit card account.

6.11.7. Service quality and customer satisfaction

High levels of service quality and customer satisfaction may give an advantage on the market to some suppliers. Consumers expecting to return to a fully charged car are, for instance, unlikely to be satisfied when finding their car's battery half-empty due to an interruption of the charging process and might choose a different supplier next time.Common database showing availability, price and public keys

It is convenient for consumers to be able to see remotely in a common and user-friendly database whether a charging station is currently in use or available, relevant characteristics such as the maximum power, the price and public keys required to verify the authenticity of legally relevant data [1, 10, 11].

In some Member States, such databases exist and the charge point operators are required to use them.

6.11.8. Safety

Safety, including electrical safety, is an important consideration. In most Member States, relevant regulation exists. This subject may also be discussed in standardisation committees [12].

7. Scope of MID – Technical details

7.1. Introduction

This chapter analyses the Directive 2014/32/EU of the European Parliament and of the Council of 26 February 2014 on the harmonisation of the laws of the Member States relating to the making available on the market of measuring instruments ('MID') with the aim of establishing whether the Directive applies to all active electrical energy meters or only to active electrical energy meters for alternating current (AC).

7.2. Definition of the scope

7.2.1. Definition of active electrical energy in MID

The scope of MID is defined with reference to Annex V (MI-003) MID: '[The] Directive applies to the measuring instruments defined in the instrument-specific Annexes III to XII (hereinafter "instrument-specific Annexes") concerning […], active electrical energy meters (MI-003), […].' (Article 2 MID).

According to the given Definition of Annex V of the MID, *'an active electrical energy meter is a device which measures the active electrical energy consumed in a circuit*', the key term is 'active electrical energy'. Since there is no corresponding definition in the Directive, the following sources of definitions are consulted:

S1: IATE (Interactive Terminology for Europe). On its website (iate.europa.eu/home), it explains: 'IATE (Interactive Terminology for Europe) is the EU's terminology database. It has been used in the EU institutions and agencies since summer 2004 for the collection, dissemination and management of EU-specific terminology. The project was launched in 1999 with the aim of providing a web-based infrastructure for all EU terminology resources, enhancing the availability and standardisation of the information'. Since it predates the Directive, it seems fair to assume that it was known and used when deciding whether or not a definition for a term used in the Directive needed to be included in the Directive itself.

S2: Harmonised standards such as the EN 50470 series. Since a harmonised standard, adopted on the basis of the Directive and the references to which have been published in the Official Journal of the European Union, forms part of EU law (see, to that effect, judgment of 27 October 2016, C-613/14, *James Elliott Construction Limited v Irish Asphalt Limited*, paragraph 31), a harmonised standard is a valid source of definitions for the interpretation of terms used in the Directive.

S3: IEC 60050, the International Electrotechnical Vocabulary (IEV, Electropedia).

While none of the terminology sources S1 to S3 define 'active electrical energy', all include the same definition for the term 'active energy' which explicitly refers to 'electrical energy': 'the electrical energy transformable into some other form of energy' (IATE item 1376352; EN 50470-1:2006 subclause 3.1.8; IEC 60050 item 601-01-19). This definition does not differentiate between AC and DC. If DC could not be used to transfer active energy thus defined, no practical device using DC, such as battery-operated devices or electrical DC machines, could be realised; DC would be of no use and the question of measuring its energy would be irrelevant. This is not the case.

Moreover, all three terminology sources S1 to S3 definite for the term 'active energy meter' with the synonym 'watt-hour meter' (IATE item 1373017; EN 50470-1 terminological entry 3.1.3; IEC 60050 item 313-06-01): 'instrument intended to measure active energy by integrating active power with respect to time'. In addition, IATE provides an example of the use of this term: 'The procedure requires the use of a bi-directional DC Watt-hour meter' (Regulation No 13-H of the Economic Commission for Europe of the United Nations (UN/ECE) — Uniform provisions concerning the approval of passenger cars with regard to braking [2015/2364], CELEX:42015X1222(01)/EN). This example would be a contradiction in terms should the term 'active energy' exclude DC.

The IEC seems to take the same approach. The title of the standards IEC 62053-21:2020 and IEC 62053-22:2020 is 'Electricity metering equipment - Particular requirements - Part […]: Static meters for AC active energy (classes […])' – where AC would be redundant if active energy did not include the contrary of AC, DC. The titles of the standards IEC 62053-23:2020 and IEC 62053-24:2020 are 'Electricity metering equipment - Particular requirements - Part 23: Static meters for reactive energy (classes 2 and 3)' and 'Electricity metering equipment - Particular requirements - Part 24: Static meters for fundamental component reactive energy (classes 0,5S, 1S, 1, 2 and 3)', respectively – since there is no reactive energy at DC, the qualifier AC is not needed and thus omitted.

The IATE lists the term 'alternating current static watt-hour meter for active energy' originating from Commission communication in the framework of the implementation of the Council directive 89/336/EEC (2005/C 77/03) listing EN 60687:1992 as harmonised standard. Thus, the Commission considers that the limitation to 'alternating current' is not included in the term 'active energy'; if such a limitation is desired, a term like 'AC active energy' is required.

Consequently, the Commission's standardisation mandate M/541 (Commission implementing decision of 15.12.2015 on a standardisation request to the European Committee for Standardisation, to the European Committee for Electrotechnical Standardisation and to the European Telecommunications Standards Institute pursuant to Regulation (EU) No 1025/2012 of the European Parliament and of the Council as regards certain measuring instruments) requests the standardisation organisations, "with reference to Annex I (e.g. point 10.4) and Annex V to Directive 2014/32/EU, to draft one or more European standards concerning the legal metrological control of delivery to the public of electricity for use in electrical means of transport covered by Article 4 of Directive 2014/94/EU (i.e. electric road transport, maritime transport and inland navigation)," (Annex II M/541), further specifying that this/these standards shall be "containing technical specifications concerning the legal metrological control of delivery to the public of AC and/or DC electricity, also for onboard metering, for use in electrical means of transport" (Annex I M/541). It is only possible to draft such a standard for DC with reference to […] Annex V to Directive 2014/32/EU if such meters are within the scope of Annex V.

CENELEC TC 13 decided to prepare a new standard in response to this mandate for DC active electrical energy meters, EN 50470-4 (CENELEC TC 13 decision D2021/003).

7.2.2. Conclusion

The term 'active energy' includes both AC and DC active energy. Therefore, the term 'active electrical energy', which is not explicitly defined, also includes both AC and DC active energy. Since the term 'active electrical energy' defines the scope of the Directive, both AC and DC active electrical energy meters are within the scope of the Directive. Was DC excluded from MID, the scope would refer to, e.g., 'active electrical energy meters for AC' or 'active electrical energy meters except for DC'; this is not the case. This is supported also by the Commission's standardisation mandate M/541.

7.3. Practical question: Can the requirements of MID be fulfilled by DC active electrical energy meters?

7.3.1. Fundamental question

Should the Directive 2014/32/EU of the European Parliament and of the Council of 26 February 2014 on the harmonisation of the laws of the Member States relating to the making available on the market of measuring instruments ('MID') define requirements for active electrical energy meters that cannot be fulfilled by DC active electrical energy meters, such meters could not be legally made available on the market or put into use (Art. 1 MID) in Member States prescribing the use of such meters (Art. 3(1) MID). The only solution to this self-contradiction would consist in arguing that such a self-contradiction cannot be desired by the legislator, the term 'active electrical energy' in the Directive must, contrary to the use in other EU documents, be taken to exclude DC active energy.

7.3.2. Annex V (MI-003) MID Definitions: Power factor and 'PF'

The definitions of Annex V (MI-003) MID do not distinguish between AC and DC and are equally valid, with one exception. The term 'PF' is defined as: 'Power factor = cosφ = the cosine of the phase difference φ between I and U'. It is clear that 'PF' is intended to be defined as 'power factor', as the abbreviation 'PF' suggests. The definitions for 'Power factor' in all three terminology sources S1 to S3 are of equal meaning, while the exact phrasing differs; S1 is using pure text ('ratio of the absolute value of the active power [IATE:1372761] to the apparent power [IATE:1372759] under periodic conditions', IATE item 1372763), while S2 and S3 use text and a formula ('under periodic conditions, ratio of the absolute value of the active power P to the apparent power S: $\lambda = |P|/S$', EN 50470-1:2006 terminological entry 3.1.9; IEC 60050 item 131-11-46). The statement 'under periodic conditions' merely requires the period of the currents and the voltages to be the same, but not necessarily finite (IEC 60050 item 131-11-27) and does not discriminate between AC and DC. Usually, the frequency is used instead of the period in this context. The frequency is defined in S3 as 'reciprocal of the period' (IEC 60050 item 103-06-02) and in S1 as 'the number of times an electromagnetic signal repeats in a unit of time, usually one second' (IATE item 1592600) and 'the number of occurrences of a repeating event per unit time' (IATE item 1369107). In S2, the definition of the term 'frequency' is circular ('the frequency in the circuit to which the meter is connected', EN 50470-1 terminological entry 3.5.11), i.e. does not serve the purpose of a definition, which is to replace the term in its context (ISO/IEC DIR2:2018 subclause 16.5.6). Basic laws of electrical engineering work only if the frequency of DC is assumed to be zero. For instance, the impedance of an ideal inductor is $Z_L = j\ 2\pi\ f\ L$. For DC, this impedance is zero, which is the result of this formula when the frequency f is set to zero. This property of the formula derives directly from the definition of 'ideal inductor' in S1 ('an ideal 2-terminal circuit element for which the instantaneous voltage is proportional to the time derivative of the current', IATE item 1372663).

In addition, a note in S2 and S3 explains: 'Under sinusoidal conditions, the power factor is the absolute value of the active factor'. The term 'active factor' is not used anywhere else in S2, suggesting that it is irrelevant in the context of active electrical energy meters. In S3, the active factor is defined as 'for a two-terminal element or a two-terminal circuit under sinusoidal conditions, ratio of the active power to the apparent power' with the explanatory note: 'The active factor is equal to the cosine of the displacement angle' (IEC 60050 item 131-11-49). Therefore, the active factor is equal to the power factor under sinusoidal conditions. Under non-sinusoidal conditions, such as DC or AC with disturbances, the power factor is different from the active factor, which is not defined in all cases. The main question is whether the part 'power factor = cosφ' of the definition of the term 'PF' is a requirement, i.e., all active electrical energy meters are required to make the power factor equal to the active factor, or purely explanatory. Since neither the power factor nor the active factor are a property of the active electrical energy meter, but of the circuit connected by the consumer, reading the definition as a requirement would imply that the consumer could push a meter out of the scope of the Directive by connecting a load creating non-sinusoidal conditions. In standards, requirements shall not be put into definitions, because readers do not expect requirements there (see ISO/IEC DIR2:2018 subclause 16.5.6: "A definition shall not take the form of, or contain, a requirement.").

The term 'PF' is used only on two occasions: 'The display of the total energy shall have a sufficient number of digits to ensure that when the meter is operated for 4 000 hours at full load ($I = I_{max}$, $U = U_n$ and PF = 1) the indication does not return to its initial value and shall not be able to be reset during use' (Annex V (MI-003) point 5.2 MID) and 'The meter shall start and continue to register at U_n, PF = 1 (polyphase meter with balanced loads) and a current which is equal to I_{st}' (Annex V (MI-003) point 5.5 MID). The aim of Annex V (MI-003) point 5.2 MID is to avoid a return of the indication to its initial value when the meter is operated for a given duration 'at full load'. The term 'full load' is defined as the case where the supplier provides a voltage as specified by the reference value, which is usually defined in the contract between supplier and consumer, and the consumer consumes as much active energy as possible given this voltage. In this context, the most relevant quantity is the power factor. This is also supported by EN 50470-1, which replaced 'PF' by 'power factor' ('The register shall be able to record and display, starting from zero, for a minimum of 4 000 h, the energy corresponding to maximum current at reference voltage and unity power factor.' EN 50470-1:2006 subclause 5.10). The aim of Annex V (MI-003) point 5.5 MID is to avoid the meter registering energy when the circuit that could consume energy is disconnected. This case is rare, but can occur for long durations, e.g., when a home is empty. This requirement is only consistent with the definition of I_{st} if 'PF' is assumed to mean 'power factor' (Annex V (MI-003) definitions MID).

The spelt-out term 'power factor' is used four times in Annex V (MI-003) MID: in the definition of 'I_{st}', the definition of 'PF', and, twice, in point 2 ('The voltage, frequency and power factor ranges within which the meter shall satisfy the MPE requirements are specified in Table 2.' and 'power factor range at least from cosφ = 0,5 inductive to cosφ = 0,8 capacitive'). The latter part is the only occurrence of 'cosφ' outside the definition of 'PF'. The terminological problem that both the power factor and the active factor are a real numbers that do not provide any information about whether the load is inductive or capacitive is not solved by referring to cosφ. It is common practice in the electrotechnical community to say, e.g. 'power factor 0,5 inductive' or 'cos φ = 0,5 inductive', to specify an inductive load in addition to the power factor or active factor. This convention is also used to in the EN 50470 series, where the active factor cos φ is not used other than in an informative note to the definition of 'power factor'.

Therefore, it can be assumed that the references to 'cosφ' are purely informative, as is the note in S2 and S3, and do not require the power factor to be equal to the active factor – which would be impossible to satisfy for DC active electrical energy meters.

7.3.3. Annex V (MI-003) point 2 MID *Rated operating conditions*: Frequency

The Directive requires, 'The manufacturer to specify the rated operating conditions of the meter, in particular the values of f_n, […] that apply to the meter' (Annex V (MI-003) point 2 MID). As discussed above, the quantity frequency f can and is commonly used for both AC and DC. For DC, $f = 0$, while for AC, the antonym of DC, $f \neq 0$. So it is possible and desirable to require the manufacturer to specify the reference frequency f_n for both AC and DC active electrical energy meters.

Furthermore, the Directive requires, 'The […] frequency [range] shall be at least […] $0{,}98 \cdot f_n \leq f \leq 1{,}02\ f_n$' (Annex V (MI-003) MID). For DC, with $f_n = 0$, this yields $0 \leq f \leq 0$, i.e. $f = 0$. This requirement is sensible and derives directly from the definition of DC, whose frequency $f = 0$ during the operation. While this requirement is not strictly necessary for DC active electrical energy meters since it derives in an obvious way from the definition of DC, it does make sense for a European directive that aims to be technology independent to formulate requirements in a way that does not include technology-dependent exceptions.

7.3.4. Annex V (MI-003) point 2 MID *Rated operating conditions*: Power factor

The Directive requires 'power factor range at least from cosφ = 0,5 inductive to cosφ = 0,8 capacitive' (Annex V (MI-003) point 2 MID). This requirement defines that the meter shall measure correctly when the power factor of the energy measured by the meter is within this range. At AC, the power factor can take any value between 0 and 1; the meter can be exposed to power factors in the required range. At DC, the power factor is equal to one by definition. Therefore, it is impossible to subject the meter to power factors different from one. By consequence, it is impossible to prove that a DC active electrical energy meter does not satisfy the requirements. Moreover, the manufacturer is free to specify a frequency range exceeding the minimum requirement of $0 \leq f \leq 0$. In this case, the rated operating conditions include conditions where the power factor can be different from one and a minimum requirement for the power factor range is necessary.

Again, it does make sense for a directive that aims to be technology independent to formulate requirements in a way that does not include technology-dependent exceptions.

Is not proportionate to reject meters designed for the minimum frequency range specified in Annex V (MI-003) point 2 MID, i.e. $0 \leq f \leq 0$, for the single reason that the laws of physics make it impossible to generate power factors different from one in order to prove compliance or non-compliance with the MPEs (Annex V (MI-003) point 3 MID). It is not necessary either, since the same laws of physics make sure that the meter is not subject to power factors different from one when in use.

7.3.5. Annex V (MI-003) point 4 MID *Permissible effect of disturbances*

Annex V (MI-003) point 4.1 MID explains 'the electromagnetic environment and permissible effects reflect the situation that there are disturbances of long duration which shall not affect the accuracy beyond the critical change values'. A disturbance is defined as follows: 'An influence quantity having a value within the limits specified in the appropriate requirement but outside the specified rated operating conditions of the measuring instrument. An influence quantity is a disturbance if for that influence quantity the rated operating conditions are not specified' (Definitions of Annex I MID). Given that for DC active electrical energy meters, DC currents and DC voltages are inside the specified rated operating conditions, neither DC currents nor DC voltages are disturbances for DC active electrical energy meters. Otherwise, the critical change values for these disturbances would be applicable at rated operating conditions and contradict the MPEs at rated operating conditions (Table 2).

Annex V (MI-003) point 4.2 MID, Table 3, details the critical change values for disturbances of long duration. It specifies critical change values for the disturbances 'harmonic contents in the current circuits' and 'DC and harmonics in the current circuit'. Since DC cannot be present in the current circuit as a disturbance by the Directive's definition of disturbance, the disturbance 'DC in the current circuit' cannot occur in a DC active electrical energy meter. The terminology sources S1 and S3 define 'harmonic' and 'harmonic component' as synonymous terms for 'the component of order greater than 1 of the Fourier series of a periodic quantity' (IATE item 1372396; IEC 60050 item 103-07-25). The terminology source S2 defines the term 'harmonic component' as 'sinusoidal component of a periodic quantity having a harmonic frequency' (EN 50470-1:2006 terminology entry 3.6.17; IEC 60050 item 551-20-07). The terms 'harmonic' and 'harmonic frequency' are defined in S3, but not in S2. 'Harmonic frequency' is 'frequency which is an integer multiple greater than one of the fundamental frequency or of the reference fundamental frequency' (IEC 60050 item 551-20-05). For all practical purposes, the meaning of these different definitions of 'harmonic' and 'harmonic component' in S1 to S3 are thus

equal. Since all integer multiples of zero are equal to zero, the concept of harmonics is not useful in this context.
However, for the same reasons, all harmonics fall into the specified rated operating conditions, i.e., these, too, cannot be disturbances for DC active electrical energy meters.

For electromechanical electricity meters, the critical change values are not defined for these disturbances (Annex V (MI-003) point 4.2 MID, Table 3, footnote 1). This is not because these disturbances cannot be present, but because it is not desired to define critical change values for this technology.

In consequence, the corresponding critical change values are never applicable. This situation is, however, not specific to DC active electrical energy meters. It is generally accepted that single-phase meters are active electrical energy meters and therefore within the scope of the Directive, even though Annex V (MI-003) point 4.2 MID, Table 3, specifies critical change values for the disturbance 'reversed phase sequence'. The terminology source S1 defines the term 'phase sequence' as 'the order in which the successive members of the set reach their positive maximum values' (IATE item 1406266). The terminology sources S2 and S3 do not contain a definition of this term. For single-phase meters, there is only one single phase, which cannot have a sequence for lack of other phases. In the absence of a sequence, there cannot be a disturbance 'reversed phase sequence'.

Again, it does make sense for a directive that aims to be technology independent to formulate requirements in a way that does not include technology-dependent exceptions.

7.3.6. Conclusion

The Directive 2014/32/EU (MID) does not define requirements that cannot be fulfilled by DC active electrical energy meters. The phrasing shows that the Directive aims to provide technology-independent metrological requirements for active electrical energy meters. Given that Annex V (MI-003) MID is essentially unchanged since 2004, despite the recast of 2014, it is a remarkable achievement that the Directive is fit for purpose even for DC active electrical energy meters, which are mainly used in electric vehicle charging stations, an application that was not even in its infancy in 2004.

The use of the terms 'power factor' and 'PF' could be more consistent and definition of the term 'PF' could be improved. However, this is mainly a question of aesthetics that does not seem to justify a modification of the Directive.

7.4. Conclusions

1. Both AC and DC active electrical energy meters are within the scope of the Directive given the definition of 'active energy' used consistently by the Directive, the Commission, IATE (Interactive Terminology for Europe, the EU's terminology database), harmonised standards and the International Electrotechnical Vocabulary (IEC 60050).
2. The requirements of the Directive can be fulfilled by both AC and DC active electrical energy meters.
3. The Commission's standardisation mandate M/541 requests one or more new standards for AC and DC active electrical energy meters in support for the implementation of the present MID. This confirms that active electrical energy meters for both AC and DC are within the scope of MID.

8. Guidance for conformity assessment

For traditional active electrical energy meters, EN 50470-1 and EN 50470-3 give guidance for conformity assessment and presumption of conformity with MID for AC. For DC, EN 50470-4 is in preparation. Pending the publication of EN 50470-4, LegalEVcharge and NordCharge prepared a temporary standard.

Those standards do not cover the specificities of use in EVCS such as a hardware implementation of the display that is not included in the meter's housing and the correction for cable losses. State of the art cryptographic signatures can be used to show that the measurement result that is the basis for the price to pay is authentic even after being transferred through a hostile environment such as the internal data network for the EVCS or even the internet. The conformity assessment in the domain of legal metrology may therefore be limited to the meter itself.

For comparison, self-service vending machines can also sell pre-packaged goods. Those are subject to legal metrology in many Member States. The implementation of the self-service vending machine is also relevant to the transaction. The price shown near the product must match the price programmed into the machine. If a receipt is issued, the data on the receipt must match the data of the transaction, namely with respect to the price. The labelling of machine's drawers must match to programming to make sure the consumer supplied with the intended product and not another one. If a credit card is used for the payment, the transaction data must be correctly handled all the way to the monthly bill from the credit card company. However, these properties have been satisfactorily implemented by the manufacturers and users without involvement of legal metrology beyond the correct labelling of the prepackages.

Therefore, many Member States do not see a need to subject EVCS as a whole to legal metrology and no conformity assessment is necessary except for the electricity meter part.

9. Guidance for manufacturers and users

9.1. Guidance related to the installation

9.1.1. General

Meters for electric vehicle charging stations (EVCS) must be outdoor meters.

Meters for EVCS often have a range of U_n rather than a single value. In this case, tests shall be carried out both for the minimum and the maximum of the range.

Meters shall be installed such that it is not possible to divert the measured quantity in normal conditions of use unless it is readily apparent. This may require the meter to have suitable features such as hardware or software sealing provisions.

Many states have requirements for the resolution of the display, e.g. 0,01 kWh or 0,001 kWh.

In case of power supply failures in direct sales applications, it is convenient to be able to conclude the transaction. This requires means to save and display the legally relevant data such as an emergency power supply. Consumer protection regulation in many states do not allow for billing to be based on estimations or fixed prices in case of power failures.

If power supply failures are unlikely, it may be commercially favourable not to bill consumers in case of a power supply failure during the transaction. In this case, means such as an emergency power supply are not necessary if evidence about the presence of a power supply failure is available. Such evidence can consist of time since the last restart of the meter or the timestamp of the last restart systematically included in the legally relevant data.

9.1.2. Display

As required by MID, the result of the measurement to be made available to the consumer in a

- transparent – the consumer can compare the measurement result indicated by the measuring instrument with the corresponding value on the bill and without having to trust the other party;
- trustworthy – the authenticity of the indicated result is assured;
- non-discriminatory – no party can block the access to the authentic indication of the measurement result by sealing the interface, setting a password or requiring a tool that is not easily available to the other party.

This requirement applies to the meter in its intended practical working conditions.

Often, meters are installed in closed and locked electrical cabinets where access is restricted to skilled persons for safety reasons. In this case, a meter where the hardware implementation of the display is integrated the meter housing does not satisfy the requirements when in use. The indication of the result shall be done such that the requirements are met, in this case outside the meter's housing.

State of the art technology allows for a cost-effective implementation this requirement. For example, the measurement result can be shown on a screen outside the meter for information while the legally relevant data is cryptographically signed and send by mail or e-mail. The required information for verifying the authenticity of the data, e.g., a public key, can be made available in a human readable, e.g., clear text, and a machine readable format, e.g., a QR code, on the charging station. Many states require these data to be available remotely, e.g., in an independently run database of charging stations, to allow the consumer to verify the data when receiving the bill. The cryptographically signed legally relevant data shall include not only the measurement result, but also information required to identify the transaction (Annex I point 11.2 MID). Such information is namely the identification of the meter as well as time and date the measurement result was taken. The measurement result includes the reading of the energy register, information about the corrections that were taken into account (see subclause A.3) and warnings about relevant problems, e.g., power supply failures (see subclause A.1).

If the consumed energy is calculated outside the meter based on the values of the cumulative energy register at the start and at the end of the transaction, the legally relevant data that need to be made available to the consumer are these two values of the cumulative energy register. For convenience of the consumer and in order to bill the consumed energy, the supplier may calculate the difference and make it available to the consumer. This difference has no legal value. Transparency requires this to be made known to the all concerned parties (Annex I points 10.4 and 10.5 MID).

9.1.3. Durable proof

Since the indication of the display is volatile, it cannot be used indefinitely. Typically, it vanishes when the display is reset to zero for the next transaction or when the total energy changes due to continuing consumption. A durable proof is needed when checking bills or in litigation.

Consequently, MID requires a durable recording and a durable proof (Annex I point 11 MID).

11. **Further processing of data to conclude the trading transaction**

11.1. A measuring instrument other than a utility measuring instrument shall record by a durable means the measurement result accompanied by information to identify the particular transaction, when:

(a) the measurement is non-repeatable; and

(b) the measuring instrument is normally intended for use in the absence of one of the trading parties.

11.2. Additionally, a durable proof of the measurement result and the information to identify the transaction shall be available on request at the time the measurement is concluded.

For the durable proof to be durable and made available, the data must be transferred to the possession of the consumer and allow them to archive them effectively and without relying on the supplier or any proprietary system after the transfer. For instance, mail or e-mail is acceptable while access using a proprietary smart phone app is not.

For the durable proof to be a proof, it must satisfy the same requirement of trustworthiness as a display.

9.1.4. Cable

In EVCS, the active electrical energy to be measured is the energy transferred across the property boundary between supplier and consumer. Especially when the cable is part of the EVCS, the losses between a convenient point to measure the energy and the property boundary can be significant. In any case, uncorrected losses are always to the disadvantage of the consumer, which is a violation of clause 7. The cable loss is generally assumed not to systematically favour any party if, after correction, it does not exceed one-sixth of the MPE at reference conditions.

If the cable losses exceed this threshold, a correction is required. One possible technical solution is a four-wire measurement at the property boundary. Another solution is a mathematical correction with knowledge of the properties of the cable. In this case, the properties of the cable, e.g., a type designation, need to be marked on the cable and on the meter in the same or similar way as the transformer ratio in case of a transformer operated meter. Depending on the technical solution and the national requirements on the maintenance of the stability, a verification in legal metrology may be required after changing a cable, especially when the four-wire measurement technique is not used.

9.1.5. Operating temperature

The EVCS must be designed such that the instructions of the meter manufacturer are respected. This includes the operating temperature when the EVCS is installed as intended by the EVCS manufacturer.

9.2. Guidance on practical aspects of maintenance of stability

9.2.1. Introduction

In most Member States, measuring instruments are subject to procedures for maintenance of their metrological stability after their putting into use, such as subsequent verification or statistical surveying. The details are subject to non-harmonised regulation. While this does not change the requirements for making available on the market and the requirement “a measuring instrument shall be designed so as to allow ready evaluation of its conformity with the appropriate requirements of [MID]” (Annex I point 12 MID) does not clearly state which part of the related effort is to be borne by the manufacturer and which part by the authorities in charge of the procedure for maintenance of the metrological stability, this section gives some insight into some practical problems. Even though the manufacturers may not be required to take these points into account, in most Member States, charges for procedures for maintenance of the metrological stability must cover their cost. Often, there is an economic advantage for meters designed in a way that minimises the cost of the procedures for maintenance of the metrological stability and hence the related charges.

Furthermore, in many Member States, users of measuring instruments, i.e., in general, the owners, need to provide the authorities with required equipment free of charge unless it is commonly used.

9.2.2. Separation of current and voltage circuits

Active electrical energy meters for AC used to have separated current and voltage circuit that could be linked in the installation in a very simple way. When both circuits are separated, many meters can be tested simultaneously with all voltage circuits in parallel and all current circuits in series, e.g., in the framework of a verification in legal metrology.

Since isolation current transformers for meter test equipment became available with suitable specifications, simple AC active electrical energy meters are designed with a permanent connection between current and voltage circuits.

However, no isolation current transformers exist for DC. Therefore, only meters with separated current and voltage circuits can be tested efficiently.

While most states do not require a separation, the cost of verification is usually charged to the applicant. The measurement takes a given time, causing a certain cost. If the current and voltage circuits of the meter are linked, this cost is incurred for each meter. If the current and voltage circuits of the meter are separated, this cost is incurred only once for each batch of meters that can be measured together, e.g., 40 meters.

9.2.3. Separation from the charging system

Usually, meters are tested on dedicated tests systems where any combination of voltage and current can be applied to the meter. Only in exceptional cases, usually in the framework of investigation after complaints, the meter is tested when connected to the public electricity grid.

Therefore, it is straightforward to test meters for EVCS used in their voltage and current circuits can be separated from the EVCS itself and challenging otherwise. Inability to separate the meter from the EVCS's voltage and current circuits translates into increased cost of the procedures for maintenance of the metrological stability. Therefore, manufacturers are encouraged to design the EVCS in a way that allows for testing of the meter using external voltage and current sources.

From a practical point of view, it can be interesting to design the EVCS such that the meter can be replaced, e.g., to replace the meter to be tested by another, equivalent meter on site by a service technician. This avoids sending the whole EVCS to the test laboratory when the meter is to be tested. The economic trade-off is out of scope of legal metrology and likely to depend on the size and cost of the EVCS. What is interesting for a large DC EVCS might not be interesting for a small 11 kW AC EVCS.

9.2.4. Efficient access to register

Often, most tests are based on the pulse output. However, at least one test checks the relation between the pulse output and the registers. Therefore, registers must be read during the verification and the provision of an efficient way of reading the registers efficiently is advisable. Use of standardised interfaces and methods is highly advantageous. If a register can be read automatically, the associated cost is equal to the required equipment – to be paid once. Otherwise, manual reading implies staff costs. Depending on the test programme required by non-harmonised national regulation, it may not be possible for the staff to perform other activities during the test due to the required, frequent interaction. Consequently, the hourly rate increases from the hourly rate of the equipment to the sum of the hourly rates of the equipment and the staff. Often, this triples the charges.

9.2.5. Resolution of register; Pulse constant

For quantities that are measured instantaneously, such as mass, volume and voltage, the resolution of the display is fixed. Assume, for example, a volume of 10 L to be measured with a maximum permissible error of 0,5 % and a display resolution of 0,05 %, one-tenth of the maximum permissible error. The display must be able to show 10 L and have a resolution sufficient to show 0,05 % × 10 L = 0,005 mL. So the display must at least have sufficient digits to show 10,005 L.

Energy, in turn, is not an instantaneous value, but a function of instantaneous values and the duration of the measurement. It is possible to achieve any desired resolution by choosing the duration of the measurement. In the practical, intended use, the energy to be measured will be in the order of kilowatt-hours transferred during the transaction which takes some minutes or longer. During the procedure for maintenance of the metrological stability, e.g., subsequent verification, the energy to be measured will be, at least for most test points, as small as possible provided the resolution is sufficient to show conformity or non-conformity with the accuracy requirements. Assume a meter of class B with a display resolution of 0,1 %, one-tenth of the maximum permissible error. If the display resolution is 1 Wh, this corresponds to ≤0,1 % if the energy to be measured is ≥1 kWh. If the display resolution is 0,1 Wh, the energy to be measured may be ten times smaller, ≥0,1 kWh – the measurement is ten times faster to carry out. Note that section 6.3.1 (p. 21) also deals with display resolution, but in a different context.

Traditionally, energy meters have a pulse output such as a rotating disk or an LED. Here, the same principle applies. In order to reach a resolution of ≤0,1 %, ≥1000 pulses are required. If the pulse constant is 1000 kWh^{-1}, the energy to be measured is ≥1 kWh. If the pulse constant is 10000 kWh^{-1}, the energy to be measured is ≥0,1 kWh, ten times smaller.

10. Bibliography

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11. Lists of figures and tables

11.1. List of figures

11.2. List of tables