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NOTICE

Dated 11.03.2024

The Central Electricity Authority had amended the (Technical Standards for Connectivity to the Grid), Regulation 2007 vide (Technical standards for connectivity to the Grid) (Amendment) Regulations, 2019 mandating compliance of IEEE 519-2014 Standard in regard to limit of Harmonics, methodology of measurement and other related matters

The CEA has also amended the (Technical Standards for Connectivity of the Distributed Generation Resources) Regulations, 2013 applicable to the generating companies or persons owning distribution generation resources, charging stations, prosumers or persons who are connected to or seeking connectivity with electrical system below 33 kV level to control the harmonics within prescribed limits and renamed the said Regulation as Technical Standards for connectivity below 33 kilovolts (Amendment) Regulations, 2019.

In line with the above mandates, the Commission had appointed senior consultants to frame draft Regulation for consumer loads. After due prior publication of the study reports of the consultants, the Commission had incorporated necessary provisions in the TNE Supply Code vide Notification No. TNERC/SC/7 – 47 dated 29.03.2022, in sub-regulation 4(1)(iv).

The consultants appointed by the Commission to frame regulations for generation sources also, have now furnished a consultative paper containing detailed analysis, updated standards and methodology of measurement of Harmonics in Distributed Energy Resources (DER) and Inverter based resources (IBR) of 11 kV and above running to 42 pages.

The same is attached herewith.

In order to ensure quality power to all, the same need to be implemented.

Views and comments from the stake holders are invited on the above report so as to entail implementation in compliance of the CEA Regulation and IEEE Standards by taking into consideration of remarks of stake holders.

The comments in both hard and soft forms may be sent to 'The Secretary, Tamil Nadu Electricity Regulatory Commission, 4thFloor, SIDCO Corporate Office Building, Thiru Vi Ka Industrial Estate, Guindy, Chennai-600 032. (email : tnerc@nic.in) on or before 10.04.2024.

Encl: Consultative Paper.

Sd/- 11.03.2024
Secretary
Tamil Nadu Electricity Regulatory Commission.

CONSULTATIVE PAPER ON HARMONIC CURRENT CONTROL IN INVERTER BASED RESOURCES (IBR) / DISTRIBUTED ENERGY RESOURCES (DER)

ORDER:

Lr. No. TNERC/ DDE2/F. Consultant Appointment /D.No.124

dated 29-01-2022.

CONSULTANTS:

Dr. A.S. KANDASAMY and Dr. K.R. VALLUVAN

REPORT SUBMITTED ON : 16.02.2024

LETTER NO. ASK & KRV- CONSULTANCY-
HARMONIC CONTROL – REPORT- DATED 16.02.2024

PART 1

PREAMBLE

In the past, generation of electricity has been from synchronous machines and the power has been utilized by linear loads. Synchronous machines (supply sources) produce sinusoidal wave form of voltage; the wave form of the current drawn by the linear loads from these supply sources is also sinusoidal. There are no current and voltage waveform distortions and hence there are no current and voltage harmonics.

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1.1. PROLIFERATION OF INVERTER BASED RESOURCES (IBR) AND DISTRIBUTED ENERGY RESOURCES (DER) IN THE POWER SYSTEMS

In recent times, apart from synchronous machines, Inverter Based Resources (IBR) and Distributed Energy Resources (DER) are increasingly employed for generation of electric power. For the past several decades, static converters using power electronic circuits are widely used in almost all electrical power systems. They contribute current waveform distortions (current harmonics).

Static converters are designed and used in the following topologies:

1) AC to DC converters (Rectifiers – used in Battery Energy Storage Systems (BESS), etc.)
2) DC to AC converters (Inverters – used in Solar Power Plants, etc.)
3) DC to DC converters (Choppers – used in Solar Power Plants, etc.

Due to their inherent nature of operation, static converters produce distortions both in their voltage and current waveforms. These waveform distortions cause harmonics in power system voltages and currents.

Though Power Electronic circuits, have lot of benefits, in generation, transmission and utilization of electrical energy, but incidentally bring harmonics; a pollutant to electricity, causing many ill-effects. Harmonics are thus an unavoidable evil.

1.2. LIMITING THE VOLTAGE AND CURRENT HARMONICS

Evils of current and voltage harmonics cannot be eliminated fully, due to techno-economic aspects, but can be mitigated / controlled within certain specified limits.

By bringing down the current waveform distortion, i.e. harmonic currents, from nonlinear loads, Inverter Based Resources and Distributed Energy Resources within the specified limits, the voltage waveform distortion, i.e. voltage harmonics in the entire electrical power system can normally be brought down within the specified limits.

1.3. IEEE STD. 519 – THE *DEFACTO* STANDARD

In many countries, Institute of Electrical and Electronics Engineers (IEEE) Std, 519, as amended from time to time, is being followed for Harmonic control. In India, CEA has stipulated to adopt this Standard.

The relevant **IEEE Std. 519-2022, IEEE Standard for Harmonic Control in Electric Power Systems,** emphasises the assumption aforementioned in sec.1.2. The relevant Clause 5 of IEEE 519-2022is reproduced below for ready reference:

"Because managing harmonics in a power system is considered a joint responsibility involving both end-users and system owners or operators, harmonic limits are required for both voltages and currents. The limits in this clause are based on the fact that some level of voltage distortion is generally acceptable and both system owners or operators and users should work cooperatively to keep actual voltage distortion below objectionable levels. The underlying assumption of these limits is that by limiting harmonic current injections by users, voltage distortion can be kept below objectionable levels. In the event that limiting harmonic currents alone does not result in acceptable levels of voltage distortion, system owners or operators should take action to modify system characteristics so that voltage distortion levels are acceptable. The acceptable voltage distortion levels form the basis of the harmonic voltage limits in 5.1."

1.4. Because of the above reasoning, both the IEEE standard and **Central Electricity Authority (CEA)** have imposed,

i) limits for harmonic current distortion in respect of consumer loads, IBR and DER and
ii) limits on harmonic voltage distortion in respect of system owners or operators.

1.5. In this endeavour, the Tamil Nadu Electricity Regulatory Commission (TNERC) appointed, Dr. A.S. KANDASAMY, Emeritus Professor and former Chief Engineer - Transmission and Commercial of the erstwhile TNEB and Dr. K.R. VALLUVAN, Professor, Dept. of ECE, Velalar College of Engineering and Technology and former Engineer, ABB, as Consultants vide Lr. No. TNERC/D (E)/ DDE (II) /F. Harmonics / D.No.1067 / 2020 dated 04.11.2020to frame a draft Regulation on ***Harmonic Current Control in Consumer Loads***. Accordingly, the Consultants submitted a Consultancy Report On Harmonic Current Control vide Consultants' letter ref. **ASK & KRV – Consultancy - Harmonic Control - Report- dated 22.04.2021.**

1.6. Power Quality-Its definition and issues, sources of harmonic voltage and current distortions, ill effects of harmonics and harmonic distortion limits and measurement methodology, etc. as per IEEE Std 519-2014 have been presented in a detailed manner in the aforementioned Consultancy Report.

1.7. Based on the Consultants' Report, Honourable Commission has issued **Amendments to the Tamil Nadu Electricity Supply Code** *(Notification No. TNERC/SC/7 – 47 dated 29.03.2022) (Lr. No. TNERC/Legal/1030/2022)* for current harmonic control in consumers' nonlinear loads at 11 kV and above and notified the same in the Tamil Nadu Government Gazette dt.21-09-2022.

1.8. Now, the Honourable Commission is in the process of formulating a regulation for harmonic current control in IBR / DER in accordance with CEA Regulations; based on the relevant IEEE Standards at 11kV and above. The Honourable Commission has appointed Dr. A.S. KANDASAMY and Dr. K.R. VALLUVAN as Consultants to frame a draft regulation for harmonic current distortion in respect of generation resources at 11kV and above vide the Honourable Commission's Lr. No. TNERC/ DDE2/F. Consultant Appointment /D. No. 124 dated 29 -01-2022.

1.9. To mitigate the current distortion, so as to give a quality power, the CEA Regulations stipulate current distortion limit to installations fed with 33 kV and above and installations below 33 kV.

1.10. TNERC, in its aforementioned Amendments to the Tamil Nadu Electricity Supply Code on current harmonic control, limited the applications to loads of consumers / prosumers connected to electricity system at 11kV and above and charging stations as the quantum of harmonic current distortion generated by these type of installations and their impact on the electrical power system are very significant at present.
The harmonic current distortion in medium / low voltage installations is well below acceptable level in percentage and quantum.

Motto of these Regulations of TNERC is to provide quality power to all at the earliest.

1.11. Present Scenario of Medium / Low voltage installations

At present, solar PV inverters (IBR category) are equipped with required filters and hence they may not contribute any appreciable harmonic current emissions.

Power Electronic devices/equipment are now used in a large way in medium/low voltage industries, educational institutions, commercial and domestic installations. Further energy storage systems in low voltage installations for charging batteries of electric vehicles are on the increase.

1.12. Future Situations

Hence, a time will come soon in India to extend the harmonic current distortion limits to all installations / prosumers irrespective of the voltage levels as the installations with low voltage will be contributing considerable harmonic pollution on this front.

1.13. Applicability of IEEE Std. 519

In many developed / industrialised countries, power electronic devices/equipment are put into use in a large scale even in low/medium voltage level installations. That is why, IEEE Std. 519 adopted harmonic current distortion limits applicable from 120 V and above.

1.14. Wind Turbines

Generating electrical energy from the kinetic energy present in the horizontal movement of air (wind power- a renewable energy) is an important contribution in the necessary global transition to a sustainable energy system.

The integration of wind power in the electric power system does, however, introduce a number of challenges.

One of the potential impacts of wind power installations concerns changes in harmonic voltage and current distortion. The emission of harmonic currents by the wind turbines, i.e., the current at the terminals of the wind turbines is not a sine wave but a distorted waveform. Such a distorted waveform is common for power electronic converters and wind turbines, where expected to be no exception to this rule. Wind turbines are thus an additional source of harmonic emission, especially when it concerns “non- characteristic harmonics”. Parallel resonances can amplify the emission from individual turbines.

1.15. Solar Photovoltaic Cells (simply Solar Cells – a renewable energy)

Solar cells produce DC voltage on the incidence of light from the sun due to photovoltaic effect. They generate power only during sunny day times. Electricity so produced can be directly used in DC machines and other appliances. However, most of the machines and appliances are working with the AC supply voltage. The DC voltage produced by the solar cells is therefore converted into AC voltage using inverters and can be used as usual. The inverter is the cause for generation of harmonic current distortion.

PART II

CEA REGULATIONS AND IEEE STANDARDS RELEVANT TO HARMONIC CURRENT INJECTION FROM POWER GENERATING RESOURCES

2.1. CEA REGULATIONSFOR VOLTAGE LEVEL BELOW 33KV

The CEA (Technical Standards for Connectivity of the Distributed Generation Resources) Regulations 2013 read with

The CEA (Technical Standards for Connectivity of the Distributed Generation Resources) *Amendment* Regulations 2019.

substitution in the Title/Heading of Regulation 2013 :

for the words, "connectivity of the distributed generation resources", *"connectivity below 33kilovolts*" substituted vide Amendment regulations 2019

Relevant regulations, sub regulations and their clauses of the above are extracted and presented here for ready reference:

REGULATION 2 Definitions:

Sub- Regulation (1) clause (b) substituted vide Amendment Regulation 2019, "applicant means a generating company, charging station, prosumer or a person seeking connectivity to the electricity system at voltage level below 33kV"

sub-regulation (1) clause(e)

Distributed generation resources means, a generating station feeding electricity into the electricity system *at voltage level of below 33 kV*

After sub-regulation (1) sub-clause (j) a new sub clause(ja) inserted vide Amendment Regulation 2019 namely :-

"Prosumer" means a person including energy storage system which consumes electricity from the grid and can *also inject electricity into the grid*, *using same point of connection*,

For sub-regulation (1) sub-clause (n) substituted vide Amendment Regulation 2019, namely:-

User means a charging station, prosumer or a person who is connected to the electricity system or *a generating company whose distributed generation resource* is connected to the electricity system.

REGULATION 3 substituted vide Amendment Regulation 2019, namely: -

Application of these regulations-these regulations shall apply to all generating companies or persons owning distributed generation resources, charging stations, prosumers or persons who are connected to or seeking connectivity with the electricity system below 33kV voltage level; Provided that in case, a *licensee o*wning the electricity system to which connection is to be made, also owns the distributed generation resources, charging station or prosumers, these regulations shall apply mutatis mutandis.

REGULATION 11, for the words, "Standards for distributed generation resources", "*standards for distribution generation resources and prosumers when acting as a generator*" substituted vide Amendment Regulations 2019,

Regulation 11

Sub-regulation (1)

Harmonic current injections from a generating station shall not exceed the limits specified in IEEE 519.

Sub-regulation (2)

The distributed generating resources shall not inject direct current greater than 0.5% of the full rated output at the interconnection point.

Sub-regulation (3)

The distributed generating resource shall not introduce flicker beyond the limits specified in IEC 61000.

provided that the standards for flicker shall come into effect from 1ST April 2014.

2.2. CEA REGULATIONS AT VOLTAGE LEVEL 33KV AND ABOVE

The CEA (Technical Standards for Connectivity to the Grid) Regulations, 2007 *read with*

The CEA (Technical Standards for Connectivity to the Grid) *Amendment* Regulations, *2013.*

AND

The CEA (Technical Standards for Connectivity to the Grid) *Amendment* Regulations, *2019.*

Relevant regulations, sub regulations and their clauses of the above are extracted and presented here for ready reference.

Definitions:

Sub-regulation 8

Bulk consumer means, a consumer who avails supply *at a voltage of 33 kV or above.*

Sub-regulation 14, the following paragraph added vide Amendment Regulations 2013.

In case of solar photo voltaic generating station each inverter *along with associated modules will be reckoned as a separate generating unit.*

After clause 35, the following clauses (36),(37),(38) are added vide Amendment Regulations 2019.

Sub-regulation (36)

Wind farm developer means a person who has developed or proposes to develop the wind generating station or wind generating farm comprising more than one wind generating unit owned by the developer or any other person.

Sub-regulation (37)

Solar Park developer means a person who has developed or proposes to develop the solar park or solar generating station comprising more than one solar generating unit owned by the developer or any other person.

Sub-regulation (38)

Wind-solar photovoltaic hybrid system means a system of electricity generation, which has a combination of wind and solar photovoltaic resources, with or without storage system.

Part II substituted vide Amendment Regulations 2013.

The Paragraph B in PART II again substituted vide Amendment Regulations 2019.

PART II B. Connectivity standards applicable to the wind generating stations, generating stations using inverters, wind-solar photo voltaic hybrid systems and energy storage systems

PART II B1 Requirements with respect to Harmonics, Direct Current (DC) Injection and Flicker

(1) Harmonic current injection from a generating station shall not exceed the limits specified in Institute of Electrical and Electronics Engineers (IEEE) Standard 519.

(2) The Generating station shall not inject DC current greater than 0.5% of the full rated output at the interconnection point.

(3) The Generating station shall not introduce flicker beyond the limits specified in IEC 61000.

(4) Measurement of harmonic content, dc injection and flicker shall be done *at least once in a year* in the presence of the parties concerned and the indicative date for the same shall be mentioned in the connection agreement.

Provided that *in addition to annual measurement*, if distribution licensee or the generating company, as the case may be, desires to measure harmonic content or dc injection or flicker, it shall inform the other party in writing and the measurement shall be carried out within 5 working days.

CEA REGULATIONS–

REGULATIONS ON current harmonic injection applicable to

1. distribution generation resources, prosumers when acting as a generator *below 33 kV)*(2019 Amendment Regulations-Regulation 11)
2. wind generating stations, generating stations using inverters, wind-solar photo voltaic hybrid systems and energy storage systems *at 33kV and above* (2019-Amendment Regulations -part II Paragraph B)

CEA Regulations are in accordance with IEEE Std.519-2014 as amended from time to time.

2.3. SALIENT FEATURES OF IEEE Std. 519-2022, A REVISION OF IEEE Std. 519-2014

2.3.1. Section 1.1 scope paragraph 2 and 3 newly added.

The voltage and current distortion limits in this standard shall apply at the user's Point Of Common Coupling (PCC) to overall installation containing harmonic producing loads (nonlinear equipment). Users are directed to other applicable standards such as IEEE Std. 1547™ or IEEE Std. 2800™ for current distortion limits of inverter-based resources (IBR) installations. When no other applicable standard exists, users shall continue to use footnote "c" under Table 2 through Table 4 in this standard for IBR connected to transmission systems.

2.3.2. Mix of nonlinear loads and IBR

If an installation has a mix of harmonic producing loads and IBR at the same facility, users are directed to use Figure 1 in this document to determine whether IEEE 519 limits apply at the PCC.

2.3.3. Section 1.3: word usage (newly added)

1) The word ***shall*** *indicates* mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (shall equals is required to).
2) The word ***should*** indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (should equals is recommended that).
3) The word ***may*** is used to indicate a course of action permissible within the limits of the standard (may equals is permitted to).
4) The word ***can*** is used for statements of possibility and capability, whether material, physical, or causal (can equals is able to).
   Foot note:
5) The use of the word ***must*** is deprecated and shall not be used when stating mandatory requirements, must is used only to describe unavoidable situations.
6) The use of ***will*** is deprecated and shall not be used when stating mandatory requirements, will is only used in statements of fact.

2.3.4. Normative references

The following referenced documents are indispensable for the application of IEEE 519 document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained).

For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

- **IEC 61000-4-7**: Electromagnetic compatibility (EMC)—Part 4-7: Testing and measurement techniques—General guide.

- **IEC 61000-4-15**: Electromagnetic compatibility (EMC)—Part 4-15: Testing and measurement techniques—Flicker meter—Functional and design specifications.

- **IEC 61000-4-30**: Electromagnetic compatibility (EMC)—Part 4-30: Testing and measurement techniques—Power quality measurement methods.
- **IEEE Std. 1453™-2015**, IEEE Recommended Practice for the Analysis of Fluctuating Installations on Power Systems.

- **IEEE Std. 1547-2018**, IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces.

- **IEEE Std 2800-2022**, IEEE Standard for Interconnection and Interoperability of Inverter-Based Resources (IBR) Interconnecting with Associated Transmission Electric Power Systems.

2.4. IEEE STANDARDS APPLICABLE TO CURRENT DISTORTION LIMITS

IEEE Std. 519-2022 introduced additional IEEE Standards to deal with *harmonic current distortions in IBR and DER* viz. IEEE Std. 2008-2022 and IEEE Std. 1547-2018 respectively.

1. Combined site IBR/DER rated generation *less than 10%*of annual average load demand -IEEE Std. 519-2022.

2(a) Inverter Based Resources-IEEE Std. 2800-2022.
2(b) Combined site *IBR* rated generation *greater than 10%*of annual average load demand -IEEE STD. 2800-2022.

3(a) Distributed Energy Sources-IEEE STD.1547-2018.
3(b) Combined site *DER* rated generation *greater than 10%* of annual average load demand IEEE STD.1547 -2018.

2.5. MEASUREMENT METHODLOGY

For the purposes of assessing harmonic levels for comparison with the limits, any instrument used shall comply with the specifications of IEC 61000-4-7 and IEC 61000-4-30, Class A. IEC 61000-4-30 defines two classes of instruments: Class A and Class S. For Class A instruments, measurements are required to be made at least up to the 50^{th} order. However, Class S instruments require measurements only to the 40^{th} order. For purposes of IEEE 519 evaluation, measurements shall be made at least up to the 50th order.

2.5.1. Measurement window width for 50Hz systems

The width of the measurement window used by digital instruments employing Discrete Fourier Transform techniques shall be 10 cycles (200 ms) for 50 Hz power systems. With this window width, spectral components will be available every 5 Hz (e.g., 0, 5, 10…50, 55,60, 65, 70,… Hz). For the purposes of this IEEE 519 document, a harmonic component magnitude is considered to be the value at a center frequency (50, 100, 150, etc. Hz for 50 Hz power systems) combined with the two adjacent 5 Hz bin values. The three values are combined into a single rms value that defines the harmonic magnitude for the particular center frequency component.

2.5.2. Very short time harmonic measurements

Very short time harmonic values are assessed over a 3-second interval based on an aggregation of 15consecutive 10 cycle windows for 50Hz power systems. Individual frequency components are aggregated based on an rms calculation as shown in Equation (1) where *F* represents voltage (*V*) or current(*I*), *n* represents the harmonic order, and *i* is a simple counter. The subscript '*vs'* is used to denote "very short."In all cases, *F* represents an rms value.

$$F_{n,vs} = \sqrt[2]{\frac{1}{15}\sum_{i=1}^{15} F_{n,i}^2} \qquad \text{… Equation (1)}$$

2.5.3. Short time harmonic measurements

Short time harmonic values are assessed over a 10-minute interval based on an aggregation of 200consecutive very short time values for a specific frequency component. The 200 values are aggregated based on an rms calculation as shown in Equation (2) where *F* represents voltage (*V*) or current (*I*), *n* represents the harmonic order, and *i* is a simple counter. The subscript *sh* is used to denote "short." In all cases, *F* represents an rms value.

$$F_{n,sh} = \sqrt[2]{\frac{1}{200}\sum_{i=1}^{200} F_{(n,vs),i}^2} \qquad \text{… Equation (2)}$$

2.5.4. Statistical evaluation

Very short and short time harmonic values shall be accumulated over periods of one day and one week, respectively.

For very short time harmonic measurements, the 99th percentile value (i.e., the value that is exceeded for 1% of the measurement period) shall be calculated for each 24-hour period for comparison with the limits in Clause 5 of IEEE 519-2022.

For short time harmonic measurements, the 95th and 99th percentile values (i.e., those values that are exceeded for 5% and 1% of the measurement period) shall be calculated for each 7-day period for comparison with the limits in Clause 5.

These statistics shall be used for both voltage and current harmonics with the exception that the weekly 99th percentile short time value is not recommended for use with voltage harmonics.

Percentile values shall be computed using a linear interpolation algorithm.

2.6. VOLTAGE AND CURRENT DISTORTION LIMITS AS PER IEEE 519-2022

2.6.1. Voltage distortion limits

At the PCC, system owners or persons shall limit line -to -neutral voltage harmonics as follows:

-Daily 99th percentile very short time (3 s) values shall be less than 1.5 times the values given in Table 1.
- Weekly 95th percentile short time (10 min) values shall be less than the values given in Table 1.

All values shall be in percent of the rated power frequency voltage at the PCC. Table 1 applies to voltage harmonics whose frequencies are integer multiples of the power frequency up to and including the 50th harmonic.

Table 1—Voltage distortion limits

Bus voltage V at PCC	Individual harmonic (%) h ≤ 50	Total harmonic distortion THD (%)
$V \leq 1.0$ kV	5.0	8.0
1 kV < $V \leq 69$ kV	3.0	5.0
69 kV < $V \leq 161$ kV	1.5	2.5
161 kV < V	1.0	1.5[a]

[a]High-voltage systems are allowed to have up to 2.0% THD where the cause is an HVDC terminal whose effects are found to be attenuated at points in the network where future users may be connected.

2.6.2. Current distortion limits

The current distortion limit shall apply to a user's PCC *primarily with harmonic producing loads*.

For installations with *primarily inverter-based resources*, users are directed to other applicable standards such as IEEE Std.1547-2018 or IEEE Std. 2800-2022.

For installations where there is *a mix of both loads and inverter-based resources*, the decision tree in figure 1 shows when IEEE Std. 519 limits apply at the installation PCC.

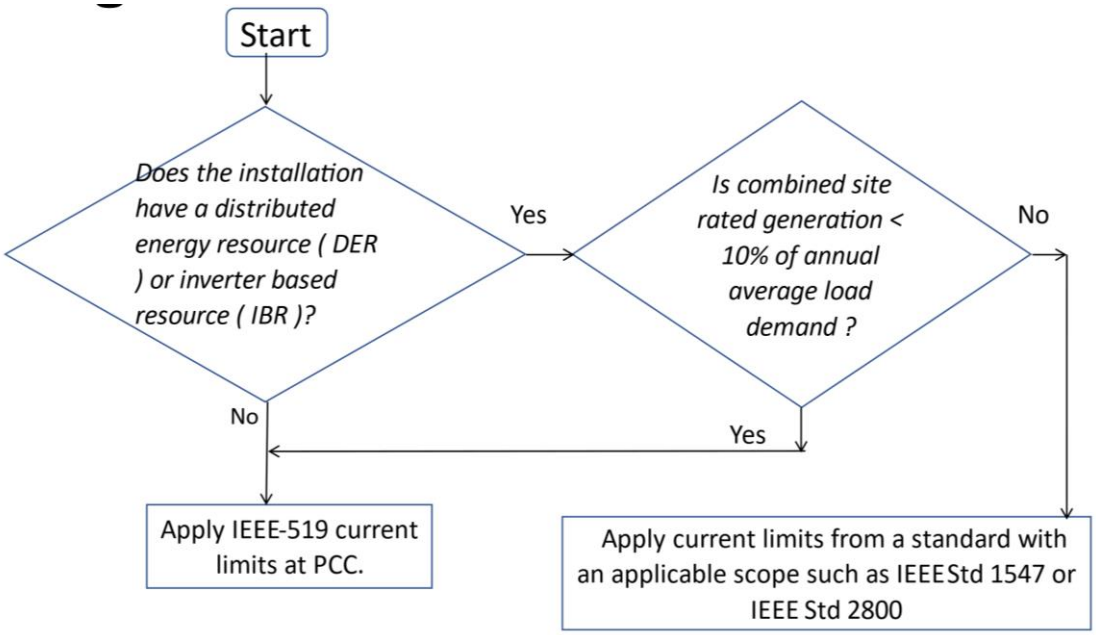

Figure 1- Decision tree for applying current distortion limits at PCC

2.6.3. Current Distortion limits for systems nominally rated 120V through 69 kV

The limits in this sub-clause apply to users connected to systems where the rated voltage at the PCC is 120 V to 69 kV. These limits shall not be used for the evaluation of an individual nonlinear load, but rather, for the evaluation of the installation containing such nonlinear loads.

At the PCC, users shall limit their harmonic currents as follows:

- Daily 99th percentile very short time (3 s) harmonic currents shall be less than 2.0 times the values given in Table 2.
- Weekly 99th percentile short time (10 min) harmonic currents shall be less than 1.5 times the values given in Table 2.
- Weekly 95th percentile short time (10 min) harmonic currents shall be less than the values given in Table 2.

All values shall be in percent of the maximum demand load current, I_L and shall be established at the PCC.

Table 2 applies to harmonic currents whose frequencies are integer multiples of the power frequency.

Table 2—Current distortion limits for systems rated 120 V through 69 kV

Maximum harmonic current distortion in percent of I_L						
Individual harmonic order[b]						
I_{SC}/I_L	$2 \le h < 11$[a]	$11 \le h < 17$	$17 \le h < 23$	$23 \le h < 35$	$35 \le h \le 50$	TDD
< 20[c]	4.0	2.0	1.5	0.6	0.3	5.0
20 < 50	7.0	3.5	2.5	1.0	0.5	8.0
50 < 100	10.0	4.5	4.0	1.5	0.7	12.0
100 < 1000	12.0	5.5	5.0	2.0	1.0	15.0
> 1000	15.0	7.0	6.0	2.5	1.4	20.0

[a] For $h \le 6$, even harmonics are limited to 50% of the harmonic limits shown in the table.

[b] Current distortions that result in a dc offset, e.g., half-wave converters, are not allowed.

[c] Power generation facilities are limited to these values of current distortion, regardless of actual I_{sc}/I_L unless covered by other standards with applicable scope.
where:
I_{sc} = maximum short-circuit current at PCC
I_L = maximum demand load current at PCC under normal load operating conditions

2.6.4. Current distortion limits for systems nominally rated above 69 kV through 161 kV

The limits in this sub-clause apply to users connected to systems where the rated voltage V at the PCC is 69 kV < V ≤ 161 kV. These limits shall not be used for the evaluation of an individual nonlinear load, but rather, for the evaluation of the installation containing such nonlinear loads. At the PCC, users shall limit their harmonic currents as follows:

- Daily 99th percentile very short time (3 s) harmonic currents shall be less than 2.0 times the values given in Table 3. □
- Weekly 99th percentile short time (10 min) harmonic currents shall be less than 1.5 times the values given in Table 3. □
- Weekly 95th percentile short time (10 min) harmonic currents shall be less than the values given in Table 3.

All values shall be in percent of the maximum demand load current, I_L and shall be established at the PCC. Table 3 applies to harmonic currents whose frequencies are integer multiples of the power frequency.

Table 3—Current distortion limits for systems rated above 69 kV through 161 kV

Maximum harmonic current distortion in percent of I_L						
Individual harmonic order[b]						
I_{sc}/I_L	$2 \le h < 11$[a]	$11 \le h < 17$	$17 \le h < 23$	$23 \le h < 35$	$35 \le h \le 50$	TDD
< 20[c]	2.0	1.0	0.75	0.3	0.15	2.5
20 < 50	3.5	1.75	1.25	0.5	0.25	4.0
50 < 100	5.0	2.25	2.0	0.75	0.35	6.0
100 < 1000	6.0	2.75	2.5	1.0	0.5	7.5
> 1000	7.5	3.5	3.0	1.25	0.7	10.0

[a] For $h \le 6$, even harmonics are limited to 50% of the harmonic limits shown in the table.

[b] Current distortions that result in a dc offset, e.g., half-wave converters, are not allowed.

[c] Power generation facilities are limited to these values of current distortion, regardless of actual I_{sc}/I_L unless covered by other standards with applicable scope.
where
I_{sc} = maximum short-circuit current at PCC
I_L = maximum demand load current at PCC under normal load operating conditions

2.6.5. Current distortion limits for systems nominally rated above 161 kV

The limits in this sub-clause apply to users connected to general transmission systems where the rated voltage V at the PCC is greater than 161 kV. These limits shall not be used for the evaluation of an individual nonlinear load, but rather, for the evaluation of the installation containing such non-linear loads.

At the PCC, users shall limit their harmonic currents as follows:

- Daily 99th percentile very short time (3 s) harmonic currents shall be less than 2.0 times the values given in Table 4.
- Weekly 99th percentile short time (10 min) harmonic currents shall be less than 1.5 times the values given in Table 4.
- Weekly 95th percentile short time (10 min) harmonic currents shall be less than the values given in Table 4.

All values shall be in percent of the maximum demand load current, I_L and shall be established at the PCC. Table 4 applies to harmonic currents whose frequencies are integer multiples of the power frequency.

Table 4—Current distortion limits for systems rated > 161 kV

Maximum harmonic current distortion in percent of I_L						
	Individual harmonic order[b]					
I_{sc}/I_L	$2 \le h < 11$[a]	$11 \le h < 17$	$17 \le h < 23$	$23 \le h < 35$	$35 \le h \le 50$	TDD
< 25[c]	1.0	0.5	0.38	0.15	0.1	1.5
$25 < 50$	2.0	1.0	0.75	0.3	0.15	2.5
≥ 50	3.0	1.5	1.15	0.45	0.22	3.75

[a] For $h \le 6$, even harmonics are limited to 50% of the harmonic limits shown in the table.

[b] Current distortions that result in a dc offset, e.g., half-wave converters, are not allowed.

[c] Power generation facilities are limited to these values of current distortion, regardless of actual I_{sc}/I_L unless covered by other standards with applicable scope.

where

I_{sc} = maximum short-circuit current at PCC

I_L = maximum demand load current at PCC under normal load operating conditions

CONSULTANTS' NOTE:

As per note "c", power generation facilities are limited to these values of current distortion, regardless of actual I_{SC}/I_L , unless covered by other standards with applicable scope.

First row of the matrix of tables 2 or 3or 4 alone is applicable to combined site installations with rated generation less than 10% of annual average load demand.

2.6.6. Recommendations for increasing harmonic current limits

The individual harmonic limits in table 2, table 3, and table 4 may be increased by a multiplying factor *when actions are taken by a user to reduce lower -order harmonics.*

The multipliers given in the second column of table5 are applicable when steps are taken to reduce the harmonic orders given in the first column.

Table 5—Recommended multipliers for increases in harmonic current limits

Harmonics orders limited to 25% of values given in Table 2, Table 3, and Table 4	Multiplier
5, 7	1.4
5,7,11,13	1.7
5,7,11,13,17,19	2.0
5,7,11,13,17,19,23,25	2.2
↓	Multiplier = $\sqrt{\frac{p}{6}}$

NOTE—p is the pulse number order of a three-phase rectifier-based converter.

CONSULTANTS' NOTE*:*

Table 5 is NOT applicable to measured individual harmonic values.

By enhancing the measured individual harmonic values with the corresponding multiplier, the design and manufacturing the filters for the increased values may able to bring values of individual harmonic within the specified limits on measurement.

2.7. IEEE STD. 2800-2022 FOR IBR

2.7.1. Relevant portions are extracted and given below for ready reference

1. Overview

1.1 General: The global increase in penetration levels of inverter-based resources (IBRs) is expected to significantly change the dynamic performance of the power grid. As the penetration levels of inverter-based resources increase and the technology of inverter-based resources evolves, specifications and standards are needed to address the performance requirements of inverter-based resources…

1.2 Scope This standard establishes the required interconnection capability and performance criteria for inverter-based resources interconnected with transmission and sub-transmission systems.

1.4 General remarks and limitations

The criteria and requirements in this document are applicable to all inverter-based resource technologies interconnected to transmission systems (TSs) (i.e., both meshed/networked and radial transmission and sub transmission) voltage levels.

The application of this standard may be limited to IBR plants for which interconnection requests are submitted after the date by which this standard is enforced by the responsible authority governing interconnection requirements (AGIRs); this standard may not apply to IBR plants that are either already interconnected or for which interconnection requests had been submitted prior to the standard's enforcement date (grandfathering). Any substantial changes in an existing IBR plant, e.g., the "repowering" of a wind power plant, may require retrofitting that IBR plant to meet all of the requirements of this standard. The stated capability and performance requirements are universally needed for interconnection of IBR plants to transmission and sub-transmission systems and their interoperability, and will be sufficient for most installations…

Foot note below section 1.4 page 19 of IEEE Std. 2800-2022 document:

10. Requirements *apply* to inverter-based resources *(IBRs) only*, e.g., solar photovoltaic, wind, and energy storage systems or combinations of such. This *excludes any systems* that are not resources, e.g., flexible ac transmission systems (FACTS) and synchronous condensers, and *any resources* that are not inverter-based, e.g., *gas and steam power plants with synchronous generators*.

CONSULTANTS' NOTE:

Since biomass and bagasse based power plants are steam driven synchronous generators, these are not applicable to them.

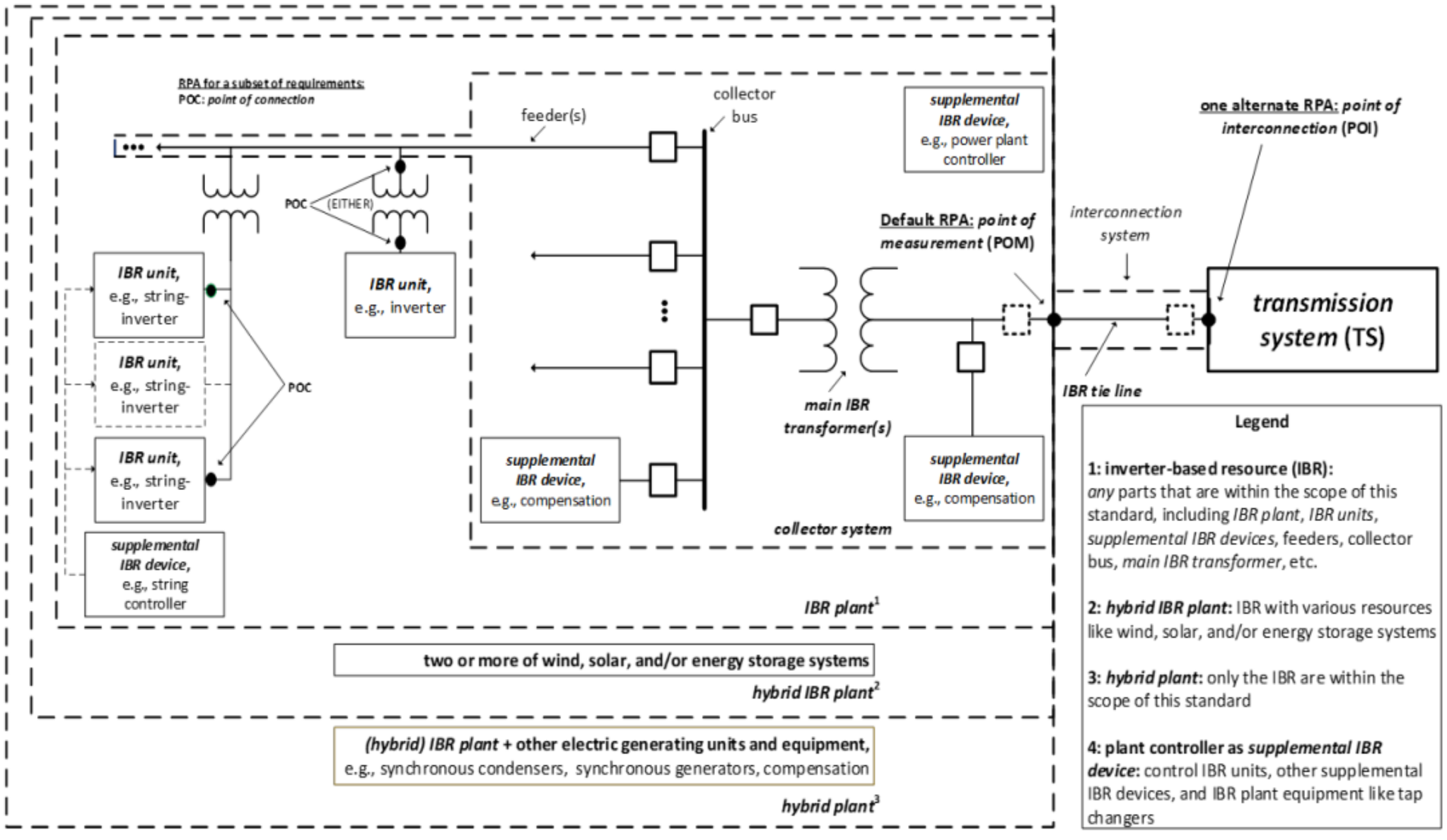

Figure 2—Illustration of defined terms for ac-connected inverter-based resources (IBRs)

NOTE 1—The POM is the default RPA. Moving the RPA from the POM to the POI may exceed the technical minimum requirements specified in this standard and may require deliberate consideration of the pros and cons. For example, the ability of IBR plants to meet the performance requirements in this standard may be impacted if the IBR owner is not allowed to install their measurement and control equipment at the POI substation.

NOTE 2—The POC may be at either side of the IBR unit transformer, if present.

2.7.2. Definitions:

Point Of Interconnection (POI):

The point where the interconnection system connects an inverter-based resource (IBR) to the transmission system (TS). Note 1—See Figure 2.

Point Of Measurement (POM):

A point between the high-voltage bus of the inverter-based resources (IBRs) and the interconnection system. (Adapted from NERC Reliability Guideline—BPS connected inverter-based resource performance)

Note—The POM may be at the transmission system (TS) side terminals of the main IBR transformer, the connection point of a supplemental IBR device, or the TS side of a protective device, whichever is closer to the IBR tie line.

Point Of Connection (POC):

The point where an inverter-based resource unit (IBR unit) is electrically connected to a collector system, as specified by the IBR owner. Syn: terminal.

Note 1—See Figure 2.

Note 3—The POC may be at either side of the IBR unit transformer, if present.

Reference Point of Applicability(RPA):

The location where the interconnection and interoperability performance requirements specified in this standard apply. (Adapted from IEEE Std. 1547™-2018)

Solar Photovoltaic System (Solar PV):

An inverter-based resource unit producing electrical energy from solar radiation directly by photovoltaic effect. (Adapted from IEC Std. 60050).

Total Rated-Current Distortion (TRD):

The non-fundamental frequency RMS current flowing (including harmonics, inter-harmonics, and noise) between the transmission system (TS) and the inverter-based resource (IBR) plant with respect to the rated RMS current capacity *(I_{rated}).*(Adapted from IEEE Std. 1547™-2018).

Wind Turbine Generator (WTG):

An inverter-based resource unit which converts the kinetic wind energy into electric energy. (Adapted from IEC 60050).

Note 1—A wind turbine generator generally uses one of the following electric generator configurations:

- Direct Connected Asynchronous Generator (Type I),
- Asynchronous Generator With External Resistance Control (Type II),
- Doubly-Fed Generator (DFG) (Type III),
- Full-Rated Power Converter (Type IV), Or
- Direct-Connected Synchronous Generator with Torque/Speed Converter (Type V).

For the purposes of this standard, only WTGs that use power electronic inverters/converters for interconnection to the grid are considered (e.g., type III and type IV).

Note 2—Types III and IV are the most common configurations for modern wind turbine generators.

2.8. HARMONIC CURRENT DISTORTION

Harmonic current distortion, with the exception of the 2nd, 4th, and 6th order harmonic current distortion, inter harmonic current distortion, and Total Rated-Current Distortion (TRD) at the RPA shall not exceed the limits stated in the following paragraph and in Table 17.

Current distortion at the 2nd, 4th, and 6th harmonics shall be the lesser of the values specified in Table 17 and Table 18, and as stated in the following paragraphs.

Any aggregated harmonic current distortion between $h \pm 5$ Hz, where h is the individual harmonic, shall be limited to the associated harmonic or h limit in Table 17.

Any aggregated inter-harmonics current distortion between $h + 5$ Hz and $(h + 1) - 5$ Hz shall be limited to the lesser magnitude limit of h and $h + 1$ harmonic or in Table 17.

Current distortion limits shall be *absolute, inclusive* of any harmonic currents due to the harmonic sources in the TS and harmonic current due to the IBR plant.

Upon mutual agreement between the TS owner and the IBR owner, the IBR plant may have current distortion in excess of limits specified in Table 17 and Table 18, whichever applicable, such as when it is used as an *active filtering device* or when *passive filtering* exists in the IBR plant, or where harmonic voltage distortion at the RPA does not exceed limits specified by the TS owner under 8.2.2

2.8.1. Harmonic voltage distortion

This standard does not specify harmonic voltage distortion limit values.

The Transmission System (TS) owner should specify voltage harmonic limits for an IBR plant at the reference point of applicability (RPA) subject to the general remarks and limitations stated in Clause 1.4 of the Std. document.

If the TS owner specifies such limits,

a) The *IBR plant* may, based on mutual agreement between the *TS owner* and the *IBR owner*, not be subjected to the individual harmonic current limits specified in Clause 8.2.1and

b) The *IBR owner* should coordinate remedy measures, as needed, with the *TS owner* to meet the harmonic voltage distortion requirements.

Tables 17 and 18 *read with clause 8*of the Std. document.

Table 17—Maximum current distortion in percent of rated current (I_{rated})[121, 122]

RPA LL voltage (kV)	Individual harmonic order h			Total rated current distortion (TRD) percent (%)
	$h < 11$ percent (%)	$11 \leq h < 17$ percent (%)	$17 \leq h \leq 50$ percent (%)	
≤ 69	4.0	2.0	1.5	5.0
69.001 to 161	2.0	1.0	1.0	2.50
> 161	1.5	1.0	1.0	2.0

Table 18—Maximum current distortion at certain even harmonics in percent of rated current (I_{rated})[123]

Certain even harmonic order *h*		
h = 2 percent (%)	*h* = 4 percent (%)	*h* = 6 percent (%)
1.0	2.0	3.0

CONSULTANTS' NOTE*:*

IEEE 2800-2022 did not stipulate voltage distortion limits for IBR.

2.9. IEEE STD. 1547-2018 for DER

"7.3 Limitation of current distortion
Harmonic current distortion, inter-harmonic current distortion, and total rated-current distortion (TRD) at the reference point of applicability (RPA) shall not exceed the limits stated in the following paragraph and in Table 26 and Table 27.

The methodology for measuring harmonic and inter-harmonic values in this requirement is defined in IEEE Std 519.

Note that Table 26 and Table 27 differ from any table in IEEE Std 519.

In this standard, the new term "Total Rated-current Distortion (TRD)" was introduced and used instead of TDD (in Table 26) and the even order current distortion limits above the second order are relaxed for DER (in Table 27). Any aggregated harmonics current distortion between h ± 5 Hz, where h is the individual harmonic order, shall be limited to the associated harmonic order h limit in Table 26 and Table 27. Any aggregated inter-harmonics current distortion between h + 5 Hz and (h + 1) − 5 Hz shall be limited to the lesser magnitude limit of h and h + 1 harmonic order in Table 26 and Table 27.

These current distortion limits shall be exclusive of any harmonic currents due to harmonic voltage distortion present in the Area EPS without the DER connected. Upon mutual agreement between the Area EPS operator and the DER operator the DER may inject current distortion in excess of these tables, such as when it is used as an active filtering device.

Tables 26 and 27 *read with Clause 7.3*.

Table 26—Maximum odd harmonic current distortion in percent of rated current (I_{rated})[a]

Individual odd harmonic order h	$h < 11$	$11 \leq h < 17$	$17 \leq h < 23$	$23 \leq h < 35$	$35 \leq h < 50$[109]	Total rated current distortion (TRD)
Percent (%)	4.0	2.0	1.5	0.6	0.3	5.0

[a] I_{rated} = the DER unit rated current capacity (transformed to the RPA when a transformer exists between the DER unit and the RPA).

Table 27—Maximum even harmonic current distortion in percent of rated current (I_{rated})[a]

Individual even harmonic order h	$h = 2$	$h = 4$	$h = 6$	$8 \leq h < 50$
Percent (%)	1.0	2.0	3.0	Associated range specified in Table 26

[a] I_{rated} = the DER unit rated current capacity (transformed to the RPA when a transformer exists between the DER unit and the RPA).

The total rated current distortion (TRD) in Table 26, which includes the harmonic distortion and inter-harmonic distortion, can be calculated using Equation (3):

$$\%\,TRD = \frac{\sqrt{I_{rms}^2 - I_1^2}}{I_{rated}} \times 100\% \quad \text{…Equation (3)}$$

Where,
I_1 is the fundamental current as measured at the RPA,
I_{rated} is the DER rated current capacity (transformed to the RPA when a transformer exists between the DER unit and the RPA),
I_{rms} is the root-mean-square of the DER current, inclusive of all frequency components, as measured at the RPA.

Reference point of applicability (RPA): The location where the interconnection and interoperability performance requirements specified in this standard apply.

Total rated-current distortion (TRD): The total root-sum-square of the current distortion components (including harmonics *and inter-harmonics*) created by the DER unit expressed as a percentage of the DER rated current capacity.

2.10. Annex G (informative): Power quality (PQ) clause concepts and guidelines

G.4 Current distortion limits

In this standard only current distortion limits are defined. *The methodology for setting current distortion limits and for distortion measurement are adopted*

*from IEEE Std 519.*There are a few intentional, and notable, differences. The first is a change from Total Harmonic Distortion (THD) limits, used in 2003, to Total Rated Current Distortion (TRD). The reason for this change is to capture inter-harmonics in the total distortion calculation. This method is described in a footnote in the normative requirements. The second difference from IEEE Std 519 is regarding the limits on even harmonics. The technical basis for tighter limits (i.e., 25% of odd harmonic limits) for even harmonics in IEEE Std. 519 was researched. The key concern is the *DC offset effect of even harmonics that have the potential to cause mis-operation of electronic switching by impacting zero crossing and other control logic. Practically, this DC offset effect is mainly caused by the 2nd harmonic and the effect of higher order harmonics diminishes rapidly*. Additionally, the tighter limits for even harmonics for the higher order harmonics are found to fall outside the specified accuracy of PQ meters. Therefore, in this document, the limits for the higher order (8^{th} and higher) harmonics have been relaxed to be the same as those for corresponding odd harmonics and the limits for the 2^{nd} harmonic have not been relaxed at all. However, a stepped approach was taken for the 4^{th} and the 6^{th} and they have been relaxed to 50% and 75% of the corresponding odd harmonic limits respectively. It may be noted that limits for overall distortion have not been relaxed at all to act as the overall check on the distortion. *Voltage distortion limits are not defined for the DER* and the current distortion limits are intended to be *exclusive* of harmonic currents due to harmonic voltage distortion present in the Area EPS without the DER connected.

CONSULTANTS' NOTE*:*

IEEE 1547-2018 did not stipulate voltage distortion limits for DER.

2.11. POINT OF MEASUREMENT in respect of each IEEE STD.

1.**Point of Common Coupling (PCC)**defined in IEEE 519-2022.

2.**Point Of Measurement (POM):** defined in IEEE 2008-2022.

A point between the high-voltage bus of the inverter-based resources (IBRs) and the interconnection system. (Adapted from NERC Reliability Guideline—BPS connected inverter-based resource performance)

NOTE—The POM may be at the transmission system (TS) side terminals of the main IBR transformer, the connection point of a supplemental IBR device, or the TS side of a protective device, whichever is closer to the IBR tie line.

2.12. IEEE 1547 -2018

3.1 Definitions

Point Of Common Coupling (PCC): The point of connection between the Area EPS and the Local EPS. NOTE 1—See Figure 2. in section 1.4 General remarks and limitations)

Point Of Distributed Energy Resources Connection(point of DER connection– PoC): The point where a DER unit is electrically connected in a Local EPS and meets the requirements of this standard exclusive of any load present in the respective part of the Local EPS. NOTE 1—See Figure 2

Reference points of applicability (RPA): The characteristics of the Local EPS and DER shall determine the reference point of applicability (RPA). Except as otherwise stated in this standard, the RPA for all performance requirements of this standard shall be the point of common coupling (PCC).

PART III

HARMONIC MEASUREMENTS IN IBR/DER BY TANGEDCO

TNERC has communicated the sample measurements, taken by TANGEDCO for the Consultants' perusal and also convened a meeting between the Consultants and concerned TANGEDCO officials on 23.01.2024 @ 14.30. vide its letter Lt. No. TNERC /DE / DDE2 /F Harmonics /D.No.15/ 2024 dated 04-01-2024.

While perusing the harmonic current measurements by TANGEDCO officials, it is observed that all HARMONIC CURRENT measurements have shown as failed. It is learnt that measurements in IBR/DER are not taken by applying the relevant newly introduced IEEE Stds. viz. IEEE Std. 2800 or IEEE 1547 2018.

The minutes, of the above meeting addressed to the Chairman and Managing Director, TANGEDCO with copy to the Consultants, is given below.

TAMIL NADU ELECTRICITY REGULATORY COMMISSION

4th Floor, SIDCO Corporate Office building,
Thiru.Vi.Ka Industrial Estate, Guindy, Chennai - 600 032.
Phone Nos : ++91-044-2953 5806 / 2953 5816 Fax : ++91-044-2953 5893
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The Chairman and Managing Director,
TANGEDCO,
144, Anna Salai,
Chennai-600002

Lr.No.TNERC/DE/DDE2/F. M.P.27 of 2021/D. 185 /2024 dt.05-02-2024

Sir,

Sub: TNERC – Minutes of the meeting held in the Commission on 23-01-2024 regarding the measurement of harmonics in generating resources – Communicated.

*****

I am directed to communicate the minutes of the meeting held in the Commission on 23-01-2024 regarding the measurement of harmonics in generating resources as enclosed.

Secretary,
Tamil Nadu Electricity Regulatory Commission.

Encl.: As above

Copy to:

1. The Director Distribution/TANGEDCO (Email)
2. The Chief Engineer /R&D & DSM (Email)
3. The Chief Engineer/ NCES (Email)

Consultants:

4. Dr.A.S.Kandasamy (Email)
5. Dr.K.R.Valluvan (Email)

PARTICIPANTS:

TNERC :

1. Dr.C.Veeramani, Secretary
2. Thiru.S.JohnSundararaj,Director (Engg)
3. Thiru. J.Prabhakaran, Deputy Director(Engg)
4. Thiru.M.Thanigivelu, Deputy Director(Engg)
5. Thiru.L.Rajendra Kumar, ADSA.
6. Thiru.E.Pugazhenthi, ADC.

TANGEDCO :

1. Thiru.R.K.Vinothan, CE/NCES
2. Thiru.P.Mahendran, EE/WPP/NCES.
3. Tmty.M.Bhuvaneshwari,EE/Solar Projects.
4. Tmty.Aruna Muralidharan, EE/R&D.
5. Tmty.D.Sangeetha, AEE/ Wind/NCES.
6. Tmty.R.Sathya, AEE/R&D.
7. Thiru.R.Kathiresan, AE/MRT/NCES/Tily.

1.0 The Consultants presented a detailed power point presentation on current distortion limits of Inverter Based Resources (IBR) and Distributed Energy Resources (DER).

SALIENT POINTS OF THE PRESENTATION ARE GIVEN BELOW:

2.0 CEA and TNERC Regulations on current harmonics control were framed based on IEEE 519 - 2014 as amended from time to time.

3.0 IEEE 519-2014 was revised as IEEE 519-2022.

4.0 IEEE 519-2022 has the following major changes from IEEE 519-2014:

4.1 The generation resources may be categorized as Inverter Based Resources (IBR) and Distributed Energy Resources (DER).

4.2 For mix of non-linear load and generation where generation (IBR/DER) is < 10% of annual average load demand, then the applicable IEEE standard for defining harmonic limits is IEEE 519-2022.

4.3 For mix of non-linear load generation, where generation (IBR/DER) is > 10% of annual average load demand, then the applicable IEEE standard for defining harmonic limits is IEEE 2800-2022 for IBR generators and 1547-2018 for DER generators.

4.4 Total Rated Current Distortion (TRD) limits specified in IEEE 2800-2022 and IEEE 1547-2018 are different from TDD specified in IEEE 519-2022.

4.5 TDD is dependent on short circuit ratio, but TRD depends up on rated current of IBR / DER. Total Rated-current Distortion (TRD) was introduced and used instead of TDD.

4.6 As per IEEE 2800, Current distortion limits shall be absolute, inclusive of any harmonic currents due to the harmonic sources in the Transmission Systems (TS) and harmonic current due to the IBR plant.

4.7 As per IEEE 1547, current distortion limits shall be exclusive of any harmonic currents due to harmonic voltage distortion present in the Area Electric Power System (EPS) without the DER connected.

5.0 The methodology for setting current distortion limits and for distortion measurement are to be adopted from IEEE Standards 519 - 2022.

6.0 STEPS TO BE FOLLOWED BEFORE MEASUREMENT:

a. Select any Instrument used for measurement that complies with the specifications of IEC 61000-4-7 edition 2.0 class I and IEC 61000-4-30 edition 3.0 Class A.
b. Identify the generation resource of IBR/DER.
c. Adopt relevant IEEE Standard for current distortion limits to suit for IBR / DER / mix.
d. Check the compatibility of measuring instrument to the relevant IEEE Standard.
e. Configure the measuring instrument as per the applicable IEEE Standard.
f. Identify the point for measurement: PCC/ POM / POC relevant to the IEEE Standard.
g. Ensure the adequacy of utility-grade voltage and current sensors accuracies.

7.0 REMARKS / DIRECTIONS BY HON'BLE CHAIRMAN, TNERC TO TANGEDCO:

a. In respect of IBR/DER, conduct a test isolating the generation source from Grid but connected with a linear load and subm it the test results to the Commission.

b. Regarding the measurements, the different make measuring instruments may be simultaneously connected at the same PCC / POM to find their compatibility with IEEE 519 Standard and compare their accuracy, as advised by the consultants and submit the report.

In this connection, the Consultants pointed out that, IEEE stipulates (G.4.1 of IEEE 1547) that *"the practice to accept type and production testing results, and then address any field anomalies on a case-by-case basis, may be preferred"*.

Secretary,
Tamil Nadu Electricity Regulatory Commission.

To

The CMD/TANGEDCO

The Director Distribution/TANGEDCO

The Chief Engineer /R&D & DSM

The Chief Engineer/ NCES

Copy to the Consultants:

1. Dr.A.S.Kandasamy
2. Dr.K.R.Valluvan.

PART IV
RECOMMENDATIONS

4.1. Harmonic current distortions in generating resources alone is covered in this Consultancy Report as per the HONOURABLE COMMISSION'S directions.

4.2. CEA Regulations and their Amendment Regulations are dependent on IEEE Std.519-2014 as amended from time to time. The IEEE Std. 519 -2014 revised as IEEE Std. 519 -2022is the basis for this Consultants' Report.

4.3. As per the revised IEEE 519-2022, major changes are:

a) IEEE Std. 2800-2022 Tables of harmonic current distortion limits shall be followed in respect of IBR.

b) IEEE Std. 1547-2018 Tables of harmonic current distortion limits shall be followed in respect of DER.

c) For installations where there is mix of loads and generation resources, respective IEEE Std.(IEEE Std. 519 or IEEE Std.2800 or IEEE Std.1547)tables of harmonic current distortion limits shall be followed as per the decision tree in figure 1 of IEEE 519-2022.

d) Instrument used for measuring harmonic current distortion shall comply with the specifications of IEC 61000-4-7 CLASS 1 Edition 2and IEC 61000-4-30 CLASS A Edition 3.

e) Measurement methodology shall be carried out as per IEEE Std. 519 with configurating the instrument as per the applicable IEEE Std. i.e., IEEE Std. 519 or IEEE Std. 2800 or IEEE Std.1547. Also, compatibility of the above instrument for the applicable IEEE Std. shall be ensured.

f) Measurement shall be made at the Point Of Common Coupling (PCC) / Point Of Measurement (POM) as defined / specified in the respective IEEE Std.

g) The licensee shall use the licensee's portable instrument for one week for each IBR /DER.

h) In this connection, the regulations pertaining to harmonic current injections mentioned earlier in PART II are reproduced for ready reference.

CEA RegulationsFOR BELOW 33 kV:

Regulation 11

Sub regulation (1) :

" Harmonic current injections from a generating station shall not exceed the limits specified in IEEE 519."

Sub regulation (2)

"The distributed generating resources shall *not inject direct current* greater than 0.5% of the full rated output at the interconnection point."

Sub regulation (3)

" The distributed generating resource shall *not introduce flicker* beyond the limits specified in IEC 61000."

" provided that the standards for flicker shall come into effect from 1st April 2014."

CEA REGULATIONS FOR 33 kV AND ABOVE

PART II B. Connectivity standards applicable to the wind generating stations, generating stations using inverters, wind-solar photo voltaic hybrid systems and energy storage systems,

PART II B1 Requirements with respect to Harmonics, Direct Current (DC) Injection and Flicker.

(1) Harmonic current injection from a generating station shall not exceed the limits specified in Institute of Electrical and Electronics Engineers (IEEE) Standard 519.

(2) The Generating station shall not inject DC current greater than 0.5% of the full rated output at the interconnection point.

(3) The Generating station shall not introduce flicker beyond the limits specified in IEC 61000.

(4) Measurement of harmonic content, dc injection and flicker shall be done at least once in a year in the presence of the parties concerned and the indicative date for the same shall be mentioned in the connection agreement;

Provided that *in addition to annual measurement, if distribution licensee or the generating company, as the case may be, desires to measure harmonic content or dc injection or flicker, it shall inform the other party in writing and the measurement shall be carried out with in 5 working days.*

CONSULTANTS NOTE:

In the above-mentioned regulations,*" the measuring and metering of harmonics shall be continuous process with an instrument as referred in 11A and PART IV"* are not stipulated.

Further regulations 11 A of CEA for below 33 kV and PART IV Paragraph(3)(ii) are applicable to consumer loads..refer also clarification w.r.t part IV of CEA Regulation -applicability vide ANNEXURE I (2013).

Further , part 4 sl. no. 16, page 54 of the Consultants' Consultancy Report on Harmonic Control may be referred; based on which TNERC supply code regulation 4 iv) e) of current harmonic control was provided.

CEA Regulation stipulates annual measurement.

Hence the question of providing the instrument by the owners of IBR and DER does not arise.

i) CEA Regulations do not stipulate any penalty for consumer loads and for distributed generation resources/ IBR.

But lenient view in respect of consumer loads to give enough time to measure the harmonics, filters' design, manufacture , install and test , 6 months' notice period+12 months penalty period + 1 month disconnection notice period was permitted. PART 4 sl no. 11 page 54 of the consultants' consultancy report on harmonic control may be referred; based on which TNERC supply code regulation 4. iv) g) to k)of current harmonic control was issued.

The above same procedure cannot be applied to IBR/DER as the IBR/DER operates at its first day of functioning at its machine/device rating. Further such generation resources are mostly installed with harmonic filters. Pollution cannot be permitted at the generation source itself for a longer period (6+12+1=19 MONTHS) as in the case of consumer loads.

j) In the case of consumers availing supply from the distribution electrical system or Grid, they are drawing/consuming electrical power required for their loads. While drawing the load current from the source supply, drawn current is distorted due to the nonlinear characteristics of the consumer loads.

But in the case of generation resource, it is supplying power to distribution electrical system or Grid; while doing so, these supply sources emit harmonic currents, due to their electronic circuits and electronic devices associated with their generation, into the distribution electrical system and Grid. While planning, designing and manufacturing, harmonic emissions by these electronic circuits and electronic devices are taken into consideration.

To mitigate the problem of harmonic emissions from such generation resources, the manufacturer has to naturally provide the means such as filters etc., to the generation resources.

In the case of consumer loads, a few loads may be linear and some other may be nonlinear and different loads may operate at different times., thus not as a single unit. But in the case of a generation resource, the generation resources shall work at its rated capacity to attain its full efficiency and benefits from the first day of operation.

Harmonics is a pollutant in an electrical system. pollution is accompanied with generated power from generation resource whereas pollution is generated by nonlinear loads of consumers while consuming power from the supply source. Hence both cannot be treated on the same platform while framing regulations, as pollution starts at the source of supply itself.

Further CEA Regulations stipulate only disconnection for non-compliance of the regulations.

As such, in respect of existing generation resources, disconnection of connectivity of generation resources for non-compliance after giving 6 months' notice period reckoned from the date of measurement, for installation of filters will be proposed.

In respect of applicants seeking new connectivity or extended connectivity, connectivity shall be permitted only if the harmonic current limits are found on measurement within the specified limit of the respective IEEE STD.

For consumer loads, average maximum demand current is required to arrive the short circuit ratio to select the row matrix of the current distortion limits of the respective voltage level table.

.

For generation resources, average maximum demand current is not required, only voltage level in the case of IEEE 519 and IEEE 2800 and in case of IEEE 1547 even the voltage level is not required.

As the maximum demand current and hence the short circuit ratio is not required to select the harmonic current distortion limits in the tables of respective IEEE and penalty is not proposed in the draft regulation, sample measurements are not required to frame the regulations. In these circumstances, Consultants are in a position to frame the required draft regulation and submit it to the Honourable Commission.

Hydro, thermal and nuclear power stations are the major sources of alternating current supply; wherein synchronous generators are only used. These synchronous generators will only generate sine wave form emf without much distortion. These generators will not produce primary current harmonics emission (as their interfacing with the grid is not involved with electronic devices) into the network to which they are connected. BAGASSE AND BIOMASS based generating stations are using only synchronous generators with its prime movers run by steam by burning bagasse and biomass gas burnt in internal combustion engines respectively. Hence generators of these generating stations will not produce primary current harmonic emissions and the question of regulation for primary harmonic current distortion limits of synchronous generators without electronic interfacing does not arise.

To emphasis this aspect, IEEE STD. 2800 -2022, foot note 10 under section 4.1, page 19 , is reproduced for ready reference:

"10. Requirements apply to inverter-based resources (IBRs) only, e.g., solar photovoltaic, wind, and energy storage systems or combinations of such. This excludes any systems that are not resources, e.g., flexible ac transmission systems (FACTS) and synchronous condensers, and any resources that are not inverter-based, e.g., gas and steam power plants with synchronous generators".

However, this aspect may be ensured by the licensee by conducting measurements on these synchronous generators.

The regulations 3 of CEA Amended regulations 2019 for below 33kv is applicable to all generating companies or persons owning distributed generation resources, prosumers when acting as a generator, licensee owned distributed generation resources

Part II of schedule paragraph B of CEA Amended regulations 2019 for voltage at 33 kV and above is applicable to the wind generating stations, generating stations using inverters, wind-solar photo voltaic hybrid systems and energy storage systems capable of exporting power to the power system

Hence a draft regulation is proposed to cover all the above generation resources.

PART V

DRAFT REGULATIONS

Existing TAMILNADU ELECTRICITY SUPPLY CODE Regulation 4(1)(IV) current harmonic control is renumbered and renamed as Regulation 4(1)(IV) A current harmonic control FOR CONSUMERS' LOADS AT 11KV AND ABOVE

NEW DRAFT REGULATION 4(1)(IV) B harmonic current control FOR GENERATION RESOURCES AT 11KV AND ABOVE *added below regulation* 4(1)(IV) A as:

4(1)(IV) B HARMONIC CURRENT CONTROL FOR GENERATION RESOURCES:

a) Central Electricity Authority (Technical standard for connectivity to the Grid) Regulations, 2007 and its Amendment Regulations 2013 and 2019 , Central Electricity Authority (Technical Standards for Connectivity below 33 kilovolts) Regulations, 2013 and its Amendment Regulations 2019apply to wind generating stations, generating stations using inverters, wind-solar photovoltaic hybrid systems, energy storage systems and distribution generation resources , prosumers acting as generators stipulate that the limits of harmonic current injections , point of harmonic measurement, harmonic measurement and other related matters, shall be in accordance with the IEEE 519-2014 standards, as amended from time to time.

b) IEEE 519-2014 is revised as IEEE 519-2022.According to the revised IEEE,

i) current distortion limits shall applicable to inverter-based resources (IBR) as per tables and point of measurement as specified in IEEE 2800-2022.
ii)current distortion limits shall applicable to distributed energy resources (DER) as per tables and point of measurement as specified in IEEE 1547-2018.
iii) combined site rated generation of IBR/DER is less than 10%, applicable IEEE 519-2022, greater than 10% applicable IEEE 2800/1547 respectively.

c) Instrument used for harmonic measurement shall comply with specifications ofIEC61000-4-7 and IEC 61000-4-30 CLASS A.

d) The licensee shall use his portable instrument for the measurement of harmonic current injection at the referred point of measurement of the IBR / DER.

e) Measurement methodology as detailed in IEEE 519-2022 shall be followed.

f) If current distortion is exceeded the limits specified in the respective IEEE Std, a notice shall be issued to the owner of the generation resource by the licensee to install adequate means/ filters within 6 months. The notice shall also convey that in case of non-compliance, the connectivity of the generation resource shall be disconnected after expiry of 6 months period without any further notice, under report to the Commission.

g) In case if the owner of generation resource provided the required means /filters within 6 months and intimated the fact in writing to the licensee and after confirmation by the licensee by measurement, the disconnection of connectivity shall not be resorted to.

   The owner of generation resource shall pay the fee in advance for the harmonic measurement for the second and subsequent time if necessitated. The fee will be collected as fixed by the Commission.

h) In case of seeking new or expanded electrical plant connectivity, a self-declaration by the applicant that adequate harmonic filters will be installed, shall be enclosed with the application requesting connectivity. While giving connectivity, harmonic measurement shall be done. If the measurement reveals that the harmonic exceeds the prescribed limit, connectivity shall not be given till the harmonic distortion brought to limits.

i) The licensee is at liberty to conduct current harmonic distortion limit at periodic interval at generation resource installation to check as to whether the consumer is maintaining current harmonic distortion within limits.

j) This regulation shall apply to all generation resources, including wind generating stations, generating stations using inverters, wind-solar photovoltaic hybrid systems, energy storage systems (for exporting power) and prosumers(when acting as generators) all having or seeking new /extended electrical plant connectivity at 11kV, and above.

Note1: This regulation shall not be applicable to generating stations with synchronous generators interfacing with the electric power system without any associated electronic circuits etc. However this can be ensured *by the licensee* by measuring primary harmonic current emissions if any.

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ANNEXURE – CONSULTANTS' PROFILES

Dr. A.S.KANDASAMY, BE, ME, PhD.

- Emeritus Professor
- Member, State Advisory Committee TNERC, Chennai
- Former Chief Engineer Transmission and Commercial, TNEB
- 36 years' field experience in the erstwhile TAMILNADU ELECTRICITY BOARD.
- 23 years teaching experience in Engineering Institutions.
- Represented India in the energy summit held at Washington(DC), USA in the year 2000.
- Served as an expert committee member for preparation of various manuals including manual for energy accounting and audit in power system, Ministry of Power Govt. of India, New Delhi-2000-2001
- Served as a Member in the steering committee of accelerated power development programme, Ministry of Power Govt. of India, New Delhi
- Author of the book, ELECTRICITY -Theory and Practice, published by AMITY University, New Delhi in 2021.

Dr. K.R. VALLUVAN, BSc, BTech, DIISc, ME, PhD.

- Obtained PhD from Anna University for the thesis **titled "*Implementation Of ADALINE on DSP and FPGA For Measurement Of Harmonics*"**
- Worked in industries like ABB for 11 years and teaching for past 27 years.
- Has written six books on fundamental concepts on Electrical and Electronics Engineering .

Paper Published by the Consultants on harmonics:

K.R.Valluvan, A.S.Kandasamy, A.M.Natarajan "A Survey of Voltage and Current Harmonics in Various Industries Connected to a State Electrical Grid" International. Journal of Applied Engg. Research Vol. 3 No.6, June 2008, pp. 801-816.

Consultancy Works on harmonics done by the Consultants:

1. Harmonic measurements in various HT / EHT industries at the request of TNEB conducted in 2005.
2. Presentation on harmonics and their ill-effects to the Honourable TNERC MEMBERS in 2005.
3. Training course on **"Harmonics and Their Ill-Effects"** to **Engineers of TNEB** in 2005.
4. Harmonic study and its effects on 500 MVA alternator at Neyveli Lignite Corporation in 2006.
5. Presentation on harmonics and their ill-effects to the Engineers of Neyveli Lignite Corporation in 2006.
6. Presentation on Harmonics And Their Ill-Effects to various Engineering Institutions in Tamil Nadu from 2006.
7. Measurement of harmonics while carrying out Energy Audit in various industries from 2004 till now.
8. Submitted a Consultancy Report on Harmonic Current Control to TNERC based on which The Honourable Commission published the **Amendments to the Tamil Nadu Electricity Supply Code** *(Notification No. TNERC/SC/7 – 47 dated 29.03.2022) (Lr. No. TNERC/Legal/1030/2022)* for current harmonic control in consumers' nonlinear loads at 11 kV and above and notified the same in the Tamilnadu Government Gazette dt.21-09-2022.

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Sd/- 11.03.2024
Secretary
Tamil Nadu Electricity Regulatory Commission.