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ANALYSIS OF HARMONIC DISTORTION LIMITS IN IEC AND IEEE STANDARDS

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Summary: **The paper presents the harmonic distortion limits on currents and voltages in power systems recommended by the two main standard organizations: the IEC and the ANSI/ IEEE. The comparison shows some interesting differences in the philosophy and the methodology used to assess and quantify this problem, permitting comment on—and discussion of—the two approaches.**

1. INTRODUCTION

The IEEE 519, recognized as an American National Standard, is the guideline mainly used into the American market for designing electric systems in presence of nonlinear loads [1]. This publication contains also the definition of limits on the harmonic currents injected by nonlinear users in the supply network and on the harmonic voltage distortion levels at the network buses.

The IEC (International Electrotechnical Commission) presents standards on electromagnetic compatibility in several publications that cover many disturbance phenomena (harmonics, interharmonics, voltage fluctuations, voltage dips, voltage unbalance, etc.) [2]. In particular the standards containing limits on harmonics are the following:
- IEC 61000-2-2 for voltage distortion in low-voltage power supply systems [3];
- IEC 61000-2-12 for voltage distortion in medium-voltage power supply systems [4];
- IEC 61000-3-2 for harmonic current emissions in case of load currents up to 16 amps [5];
- IEC 61000-3-4 for harmonic current emissions in case of load currents greater than 16 amps [6];
- IEC 61000-3-6 for harmonic current emissions in case of equipments connected to medium and high-voltage power supply systems [7].

In a previous paper [8] the Authors presented and discussed the IEEE and IEC guidelines for harmonic analysis procedures in power systems. The IEEE 519 provides a guide for harmonic analysis which is addressed to all types of electric systems (industrial, distribution and transmission), while the present-day IEC publication [9] is mainly a guide to analyze only the industrial plants. The simulations reported in [8] and the relevant discussions have brought to interesting conclusions on the different load modeling and also on the harmonic summation criteria.

The methodologies used by the two different standard Authorities [10] for analyzing the different harmonic sources and for quantifying the levels of harmonic pollution, carry out to the definition of harmonic distortion limits. In the following sections the harmonic current emission limits and the harmonic voltage distortion limits will be presented for both IEEE and IEC Standards and some comparisons will be established on the basis of common reference parameters. Finally an example on a particular test network will underline some differences in the philosophy adopted by the two standard Authorities in setting out the limits of these disturbances.

2. LIMITS ON HARMONIC CURRENTS

2.1 References and description

The limits reported in the IEEE 519 takes into account the fact that harmonic currents injected by different users can differ in amplitude, phase angle and in their variation with time. The current distortion limits are based on the fact

Table 1. IEEE 519 Basis for harmonic current limits

Short-circuit ratio at PCC	Maximum Individual Frequency Voltage Harmonic (%)	Related Assumption
10	2.5-3.0	Dedicated system
20	2.0-2.5	1-2 large customers
50	1.0-1.5	Afew relatively large customers
100	0.5-1.0	5-20 medium size customers
1000	0.05-0.10	Many small customers

that the maximum harmonic voltage produced by a single user must not exceed the values shown in Table 1. These values vary as a function of the short-circuit ratio (Rscc) at the point of common coupling (PCC). It should be noted, however, that the same IEEE 519 publication states that even when limits are observed by customers, it may sometimes be necessary to use suitable filters to limit the voltage harmonic distortion. It is also pointed out that voltage distortion problems can increase in system resonance conditions. In these cases preventive action by the utility is necessary.

The IEEE 519 gives, furthermore, limits on the injection of harmonic current, also taking into account the total distortion demand (TDD), which is the harmonic distortion of the current expressed as a percentage of the maximum load current (15 or 30 minutes demand). Limits on current distortion depend on the size of the load compared with the size of the supply system at the PCC. As an indication, one has to consider the ratio Isc/I_L between the short-circuit current available at the PCC and the fundamental component of the maximum load current (average value of maximum demand over the previous 12 months).

The IEC standards deal with the limitation of harmonic currents in three different publications, two concerning emissions in LV networks and one concerning emissions in MV and HV networks.

The IEC 61000-3-2 considers emissions in LV networks of equipment whose input current is less than 16A and the limits shown in it, unlike the IEEE 519, leave out the system size at the PCC. In this standard, equipment is sub-divided into four categories and the limits concerning the emission of harmonic currents depend on the category. These limits refer to harmonic currents measured under steady-state conditions, but some indications are also given for transient harmonics. The specification also covers the test conditions in which to carry out measurements of harmonics emitted and the requirements for the relevant instrumentation. It should be noted that, in the case of currents below 16A, the task of reducing harmonic currents is entrusted to the equipment manufacturer, who thus has to supply his customers with equipment whose emission levels are within the limits given by standards.

The other IEC publication dealing with LV systems is the 61000-3-4 covering emissions from equipment whose input current is higher than 16A. As the connection of this type of equipment to the supply needs either notification to or consent by the supply Authority, the above draft standard shows three consecutive assessment stages for the purposes of making such a connection. These stages are based on the magnitude of the admissible harmonic current caused by the equipment. Like IEEE 519, this draft standard considers the short-circuit ratio Rscc for the purpose of characterizing the size of the load as regards to the system size when setting limits on the emission of harmonic currents.

The next publication to be considered is the IEC 61000-3-6 which deals with emissions in MV and HV network, as well as those at very high voltages (EHV). This is a technical report or really a guide for the supply Authority, who can decide whether to permit the connection of a distorting user in line with assessments carried out at several stages.

2.2 Comparison and comments

Referring to LV levels, it is noted that the IEC does not consider the case in which $Rscc < 33$, because this case does not comply with IEC standard 61000-34. The American publication, however, examines also the hypothesis $Isc/I_L < 20$. Table 2 compares the limits on emission of harmonic currents at stage 1 of the IEC draft standard 61000-3-4 (that is the stage of connection without restriction of equipment whose input current exceeds 16A and $Rscc \geq 33$) with those stated in IEEE 519. It is observed that the limitation by the IEC is more restrictive than that by the IEEE, both with respect of odd harmonic emissions (except in the case of low orders, namely 3 and 5) and of even ones.

Concerning the limits on emission at MV and HV levels, Table 3 shows the harmonic current values indicated in the IEC 61000-3-6 at the first stage for MV (1 kV through 35 kV) and the limits shown in IEEE 519 for distribution systems (129 V through 69 kV) in cases where the ratio Isc/I_L falls within the following intervals 50–100 and 100–1000. This last assumption is derived from the fact that the limits indicated by the IEC apply to loads which meet the condition $0.1\% \leq Pi/Psc < 2\%$ (where Pi is the power of the i-th user and Psc the short-circuit power at PCC), corresponding to $50 < Isc/I_L \leq 1000$. The analysis of Table III shows that, in case of emission of harmonic currents in MV networks, the limits indicated by the IEC standard are, once again, tighter than those given by the IEEE.

As comment to this comparison, it is necessary to point out the different approaches adopted by the two standard Authorities in term of harmonic distortion limits. In the IEC standard, the limitation of harmonics is stated in terms of harmonic emissions only, thus facing the problem at its source. On the other hand, in IEEE 519, the limitation of harmonics is expressed in terms of controlling both the harmonic emissions of individual customers and the overall harmonic distortion of the voltage supplied by the utilities. The last consideration is linked with the greater severity of the IEC standard in comparison with IEEE 519 in terms of limiting the emission of harmonic currents. The example on Section 4 will underline this different methodology.

Table 2. Harmonic current emission limits: comparison between the IEEE 519 (120 V through 69 kV) and the IEC 61000-3-4 (stage 1)

	Maximum Harmonic Current in percent of the fundamental frequency component				
harmonic order n	IEC 61000-3-4 ($R_{scc} \leq 33$)	IEEE 519 ($20<I_{sc}/I_L<50$)	IEEE 519 ($50<I_{sc}/I_L<100$)	IEEE 519 ($100<I_{sc}/I_L<1000$)	IEEE 519 ($I_{sc}/I_L<50$)
3	21.6	7.0	10.0	12.0	15.0
5	10.7	7.0	10.0	12.0	15.0
7	7.2	7.0	10.0	12.0	15.0
9	3.8	7.0	10.0	12.0	15.0
11	3.1	3.5	4.5	5.5	7.0
13	2.0	3.5	4.5	5.5	7.0
15	0.7	3.5	4.5	5.5	7.0
17	1.2	2.5	4.0	5.0	6.0
19	1.1	2.5	4.0	5.0	6.0
21	0.6	2.5	4.0	5.0	6.0
23	0.9	1.0	1.5	2.0	2.5
25	0.8	1.0	1.5	2.0	2.5
27	0.6	1.0	1.5	2.0	2.5
29	0.7	1.0	1.5	2.0	2.5
31	0.7	1.0	1.5	2.0	2.5
33	0.6	1.9	1.5	2.0	2.5
≥35	0.6	0.5	0.7	1.0	1.4
even	≤8/n or ≤0.6	25% of the odd harmonic limits above			

3. LIMITS ON HARMONIC VOLTAGES

3.1 References and description

The IEEE 519 shows the limits on the maximum voltage distortion at the point of common coupling. These limits should be used as system design values for the „worst case" in regular operation (conditions lasting longer than one hour). For shorter periods the limits may be exceeded by 50%. In addition, periodic measurements of harmonics must be carried out and if limits are exceeded, suitable provisions are adopted for limiting the harmonics: such as the installation of filters by the user or by the distributor or the strengthening of the power supply.

The IEC standard 61000-2-2 and the future IEC standard 61000-2-12 are concerned with the levels of electro-magnetic compatibility (EMC), that is the maximum values of electromagnetic disturbances (hatmonics amongst others) which can be expected in public distribution networks at low and medium voltages respectively.

Table 3. Harmonic current emission limits: comparison between the IEEE 519 (120 V through 69 kV) and the IEC 61000-3-6 (1 kV through 35 kV)

	Maximum Harmonic Current in percent of the fundamental frequency component — Harmonic Order				THD (%)
	5	7	11	13	
IEC 61000-3-6 ($50<I_{sc}/I_L \leq 1000$)	5	3	1.5	1	6
IEEE 519 ($50<I_{sc}/I_L<100$)	10	10	4.5	4.5	12
IEEE 519 ($100<I_{sc}/I_L<1000$)	12	12	5.5	5.5	15

In addition the IEC standard 61000-2-4 [11] considers the compatibility levels at the point of internal coupling (PIC) inside industrial networks or other private networks at low and medium voltages. This standard also stresses that meeting the degree of compatibility at the PIC does not necessarily mean that emission requirements are met at the PCC.

It must be remembered that the values for compatibility levels given by these three IEC standards have a certain tolerance and precisely a probability of 95 % of not being exceeded. This means that, during a year, one can expect them to be exceeded during a total of 400 hours.

The draft IEC 61000-3-6, which also concerns emissions in MV and HV systems, shows the levels of voltage distortion which are to be referred to when laying down limits on harmonic emissions. In addition to compatibility levels for LV (IEC 61000-22) and MV (draft of IEC 61000-2-12),the 61000-3-6 indicates other levels, named „planning levels", which are then used in this publication to evaluate the impact of the loads connected to MV and HV power supply systems. These are quality objectives which can be set in advance by the distributor and which give values equal to or lower than those given by compatibility levels. Even though the values provided for the planning levels in the IEC 61000-3-6 are suggested and not mandatory—because they can vary on a case by case basis depending on various network characteristics—the values are used herein to make a comparison between the IEEE and IEC standards which also extends to HV.

Table 4. Harmonic voltage distortion limits: comparison between the IEEE 519 and the relevant IEC standards (Un is the nominal voltage)

	THD (%)	Individual Voltage Distortion (%)								
		Odd order						Even order		
		3	5	7	9	11	13	2	4	12
IEEE 519 (129V<Un≤69kV)	5.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
IEC 61000-2-2 (LV) fut. IEC 6100-2-12 (MV)	8.0	5.0	6.0	5.0	1.5	3.5	3.0	2.0	1.0	0.2
IEC 61000-2-4 (industrial plants) (class 1)	5.0	3.0	3.0	3.0	1.5	3.0	3.0	2.0	1.0	0.2
fut. IEC 61000-3-6 (MV) (planning levels)	6.5	4.0	5.0	4.0	1.2	3.0	2.5	1.6	1.0	0.2
IEEE 519 (69V<Un≤161kV)	2.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
fut. IEC 61000-3-6 (HV) (planning levels)	3.0	2.0	2.0	2.0	1.0	1.5	1.5	1.5	1.0	0.2

3.2 Comparison and comments

The comparison between limits on voltage distortion is shown in Table IV.

The IEC standard 61000-2-4 is, in practice, a classification of ac power supplies associated with private industrial networks. These supplies are divided into three classes. It seemed interesting to include also, in Table IV, the levels of compatibility shown in this standard for class 1, which is the class to apply to protected LV power supplies and whose levels are lower than those given by the IEC for the public network.

It can be noted that, for odd harmonic voltages, the comparison stops at the 13th harmonic, as higher orders are not considered significant. For high even orders, the 12th has been shown as an example. From the analysis of Table IV it appears that the harmonic distortion limits for networks with a voltage lower than 69 kV shown in IEEE 519 are (with the exception of the ninth harmonic and the even ones) more severe than the compatibility levels for low and medium voltages indicated by the IEC. Only in the particular case of protected power supplies the IEC levels of compatibility are, more or less, equal to those shown in the American publication. Although they are given for information only and do not possess the status of standards, the planning levels also constitute an interesting item in the comparison if it is considered that they furnish lower values than those given by IEC compatibility levels.

The values shown in IEEE 519 referred to network voltages contained in the interval 69 kV < Un ≤ 161 kV are used in the comparison with the planning levels for HV networks indicated by the IEC. It is observed that, in this case of HV networks, the values indicated by the American standard are again more restrictive, but in this case the differences are slight.

4. EXAMPLE

The test network of Fig. 1 is considered as an example of MV distribution plant. The HV transmission network with short-circuit power of 3500 MVA supplies through the transformer T and the line L a busbar where six polluting loads rated S_i =2 MVA are connected. Data on the distribution components are reported in Fig. I. It is a simple system where we can apply the following hypotheses:

— absence of considerable power factor correction capacitors and long cable lines ($\Sigma C \cong 0$),
— the equivalent impedance of the network seen from the PCC is mainly inductive,
— each polluting user is considered as nonlinear load and modeled by ideal harmonic current generators,
— the nonlinear loads are 6-pulse converters and we limit the analysis to the 13^{th} harmonic order,
— the harmonic currents generated by the nonlinear load are the maximum emission values permitted by the standards.

The apparent short-circuit power at bus PCC($S_{sc\ Pcc}$) is 104 MVA and the relevant short-circuit current ($I_{sc\ Pcc}$) is 3kA. With these values, for determining the harmonic current emission limits we can respectively refer to:

— IEC 61000-3-6 (level 1) for MV systems and load with $0.1\% < S_i \leq S_{sc} < 2\%$
— IEEE 519 for system with voltage ≤ 69 kV and $50 < I_{sc}/I_L < 100$.

Table V shows the values of the harmonic currents associated to each nonlinear load when the two different standard are considered.

It must be noted that in the case 2 (IEEE 519) the limits suggested by the Standard (see Table III) are suitably reduced to not exceed the relevant THD as mentioned in the standard itself.

The corresponding values of the harmonic voltages at PCC (if the harmonic voltage background of the network is considered equal to zero) for each load are reported in Table VI.

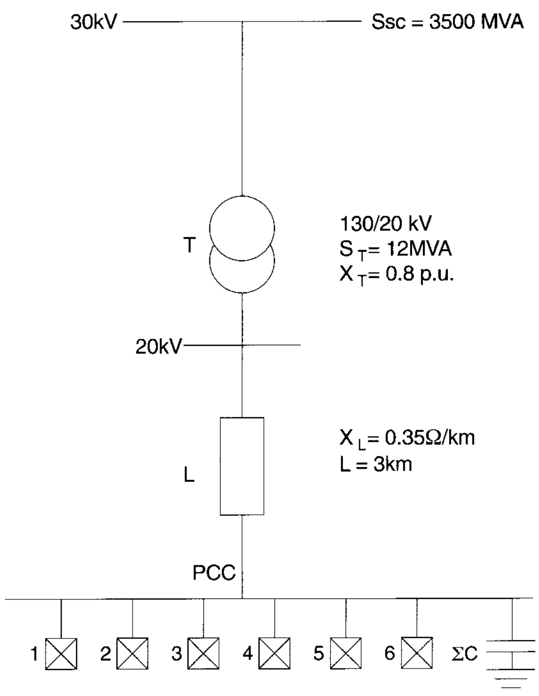

Figure 1. Test network considered as an example

For evaluating the harmonic voltage distortion (individual and total) at PCC when the six polluting loads are simultaneously in operation, it is necessary to refer to some summation criteria for these disturbances.

Two methods are indicated in [7] to carry out this summation, while the IEEE 519 does not suggest any procedure and advises to solve the addition by using suitable correction factors not stated in the publication.

The two methods described in the IEC publication are summarized and discussed in [8]. These methods introduce the diversity factor K, defined as the ratio between the vectorial sum and the arithmetic sum of the individual contributions of the harmonic sources. Method 1 gives an estimate of the K based on the value of the rated power of the load referred to the total rated power associated to the nonlinear loads in the plant. Method 2 is based on a statistical approach considering that the compatibility level has to be met with a probability of 95 % or better.

The reader can refer to [8] for the different values assumed by K following the two methods. Even in the case 2, as the IEEE publication does not indicate particular summation criteria, the two methods of [7] were applied.

The result of the calculation performed with the two methods in both considered cases is summarized in Table VII, which refers to the harmonic voltage distortion at PCC when the six nonlinear load are in operation.

It is interesting to develop now a comparison between the harmonic distortion values of Table VII and the relevant harmonic voltage limits indicated by the two standard Authorities, and reported here in Table IV. To help the reader in this comparison the calculated values that exceed the relevant limits appear in bold in Table VII.

Case 1. Considering the harmonic current emission levels of the loads equal to the maximum values permitted by the IEC Standard, the corresponding individual and total harmonic voltage distortions respect the compatibility levels (IEC 61000-2-12) and the planning levels (IEC 61000-3-6).

Case 2. Considering the harmonic emission levels of the loads equal to the maximum values permitted by the IEEE Standards, in some cases the harmonic voltage distortion values at PCC exceed the limits established by the same IEEE 519. In particular (see Tab. VII and Tab. IV), with the summation method 1 the value of the 5^{th}, 7^{th} and 13^{th} harmonic voltage and the THD value are greater than the maximum IEEE 519 limits. Also with the second summation method the 7^{th} harmonic voltage and the THD are out of the standard limits even if in this case the values are more close to those permitted by the standard.

This example shows that in the IEEE Standard the limitations on harmonic current emissions could not guarantee the respect of the prescription indicated for the voltages at PCC. It can be deduced that the harmonic control in the network, following the IEEE philosophy, involves both users and utilities, that in the case must provide filters.

Table 5. Harmonic currents associated to each nonlinear load in percent of the fundamental current at rated condition, that corresponds to the maximum load.

	harmonic order			
	5	7	11	13
Case 1 IEC 61000-3-6 [%]	5	3	1.5	1
Case 2 IEEE 519 [%]	7.5	7.5	3.8	3.8

Table 6. Harmonic voltage at PCC associated to each nonlinear load in percent of the fundamental frequency nominal voltage.

	harmonic order				THD %
	5	7	9	13	
Case 1 IEC 61000-3-6 [%]	0.48	0.40	0.32	0.25	0.74
Case 2 IEEE 519 [%]	0.72	1.01	0.80	0.95	1.76

Table 7. Harmonic voltage (in percent of the fundamental nominal voltage) at PCC associated to the operation of the six nonlinear loads. The values are obtained for both cases with the two summation methods suggested in [7].

Summation Method 1	harmonic order				THD %
	5	7	9	13	
Case 1 IEC 61000-3-6 [%]	2.30	1.68	1.15	0.90	3.20
Case 2 IEEE 519 [%]	**3.46**	**4.24**	2.88	**3.42**	**7.07**

Summation Method 2	harmonic order				THD %
	5	7	9	13	
Case 1 IEC 61000-3-6 [%]	1.73	1.44	0.78	0.61	2.46
Case 2 IEEE 519 [%]	2.59	**3.63**	1.96	2.33	**5.40**

The strategy adopted by the IEC, on the contrary, consists on the limitation of the load emissions for obtaining acceptable level of harmonic voltages in the network: if the harmonic currents generated by the user are within the assigned limit, the corresponding harmonic voltages at PCC respect the compatibility levels.

Anyway, it is important to note that harmonic voltage recommended distortion limits in the IEEE 519 are lower than those suggested by the IEC and in addition the American publication indicates the values as no surmountable limits, while the IEC standard gives distortion values expected at PCC with a low probability ($\leq 5\ \%$) to be exceeded.

5. CONCLUSIONS

The paper analyzes the different harmonic current emission limits and harmonic voltage distortion limits stated in the two major standard Institutes: the ANSI/IEEE mainly addressed to the American market and the IEC generally adopted in the European technical fteld. Some comparisons are made on the suggested values and an example of a MV test system permits further remarks on the different approaches adopted by the two Institutes. The American publication attempts to reduce the effect of harmonics involving both users and utilities. To this end, it lays down limits regarding suitable harmonic indices referring to currents and voltages to be applied at so-called points of common coupling (PCCs). These limits involve, on one hand, the users who have to limit their harmonic emissions in order not to produce unacceptable levels of voltage distortion and, on the other electrical utilities which must limit the overall voltage harmonic distortion in the power supply system. The IEC standards aim at reaching the requested levels of electromagnetic compatibility on the user side and the approach adopted is that of obtaining harmonic limitation by fixing limits on the emissions of harmonic current sources only.

6. REFERENCES

1. IEEE Std 519-1992, *"IEEE Recommended Practices and Requirements for Harmonic Control in Elecrical Power Sytems"*, IEEE, New York, 1993.
2. IEC 61000-2-1 (1990), *"Electromagnetic compatibility. Part 2: Environment. Section 1: Description of the environment—Electromagnetic environment for low-frequency conducted disturbances and signalling in public power supply systems"*, Genève (Switzerland), 1990.
3. IEC 61000-2-2 (1990), *"Electromagnetic Compatibility. Part 2: Environment. Section 2: Compatibility levels for low frequency conducted disturbances and signalling in public low-voltage power supply systems"*, Genève (Switzerland), 1990.
4. Draft IEC 61000-2-12, *"Electromagnetic Compatibility. Part 2: Environment. Section 12: Compatibility levels for low-frequency conducted disturbances and signaling in public mediumvoltage power supply systems"*, Committee Draft 77A/266/CD, Genève (Switzerland), April 1999.
5. IEC 61000-3-2 (1995), *"Electromagnetic Compatibility. Part 3: Limits. Section 2: Limits for harmonic current emissions. (Equipment with input current ≤ 16A per phase)"*, Genève (Switzerland), 1995; and consolidated Edition 1998.
6. Draft IEC 61000-3-4, *"Electromagnetic Compatibility. Part 3: Limits. Section 4: Limits for harmonic current emissions. (Equipment with input current > 16A per phase),"* Committee Draft 77A/169/ CDV, Genève (Switzerland), April 1997.
7. Draft IEC 61000-3-6, *"Electromagnetic Compatibility. Part 3: Limits. Section 6: Limitation of emission of harmonic currents for equipments connected to medium and high voltage power supply systems,"* Committee Draft 77A/135/ CDV, Genève (Switzerland), July 1995.
8. R. Lamedica, A. Prudenzi, E. Tironi, D. Zaninelli: *"Harmonic analysis procedures: a comparison between IEEE and IEC guidelines,"* 8th IEEE International Conference on Harmonics and Quality of Power, Athens, Greece, 14–16 Oct. 1998.
9. IEC 61000-2-6 (1995), *"Electromagnetic Compatibility. Part 2: Environment. Section 6: Guide to the assessment of the emission levels in the power supply of industrial plants as regards the low-frequency conducted disturbances,"* Genève (Switzerland), 1995.
10. A. Domijan, D. Zaninelli: *"IEC and IEEE standards on harmonics and comparisons,"* Proceedings of the National Science Foundation Conference on Unbundled Power Quality Services in the Power Industry, Key West (FL), USA, 17–19 Nov. 1996.
11. IEC 61000-2-4 (1994), *"Electromagnetic Compatibility.Part 2: Environment. Section 4: Compatibility levels in industrial plants for low-frequency conducted disturbances,"* Genève (Switzerland), 1994.

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