Validity of the Lightning Elimination Claim

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Abstract — Since 1971 when commercial devices that employ the point-discharge phenomenon were introduced, their manufacturers repeatedly changed their explanation regarding how such devices would eliminate lightning. This was done in response to on-going criticism from the scientific community. The name of those devices was also changed from Lightning Eliminators / Dissipation Arrays (DAS) to Charge Transfer Systems (CTS). This paper summarizes and rebuts both past and present theories that have been proposed by the manufacturers. It also discusses manufacturers' claim of success and explains why eliminating lightning is still considered to be not feasible. Finally, comments are given regarding the attempts of the manufacturers to get a standard for their devices.

Index Terms— **Lightning; Lightning Elimination; Point-discharge; Dissipation Arrays; Charge Transfer Systems; LIGHTNING PROTECTION: Substations, Power Lines, Communication Towers, Buildings.**

I. Introduction

When a thundercloud is overhead, ground objects having sharp points or edges experience the well-known point-discharge phenomenon. In the early 1970's, a company named LEA (now LEC) introduced devices having many sharp points, with the claim that the emitted charge would neutralize the clouds, thus preventing lightning strikes. Several smaller companies later entered that business. A previous paper by the author [23] reviewed this subject, confirmed that lightning cannot be eliminated, presented a theory that reconciles this fact with the existence of many "satisfied customers", and showed why such devices would be of no benefit to power lines nor substations. This paper updates the 1998 work, and it has been prepared in connection with a proposed IEEE panel presentation on this subject.

The normal process of developing science-based products consists of the following steps: a) proving validity of the proposed theory or using one that has already been proven, b) developing an apparatus for applying that theory, c) doing the necessary tests to prove that the prototype works, d) commercializing the product, and, e) developing a standard to ensure that the products of the different manufacturers meet an agreed-upon minimum performance level.

Unfortunately, the manufacturers of lightning elimination devices did not follow the above process. Instead, they started by marketing products that were claimed to be capable of neutralizing the charge in the clouds. Shortly thereafter, their devices got repeatedly struck by lightning and the scientific community told them that it was not possible to neutralize the clouds. The manufacturers initially insisted that their devices eliminated lightning but that there must be another mechanism by which this was taking place. They then proposed an alternative mechanism and kept changing it in response to on-going criticism from the scientific community. As will be shown herein, the mechanism presently proposed by the manufacturers constitutes a major downgrading of their claim. For they no longer say that their devices eliminate all lightning strokes. Instead, they are saying that "there is reason to believe that they decrease the frequency of lightning strikes".

The latest theory of the manufacturers constitutes a tacit admission that lightning will sometimes strike their devices and that it always did. On the other hand, they usually denied in the beginning that failure incidents ever occurred. Where the evidence was undeniable, they initially claimed that manufacturing defects existed in the failed units [14]. In other cases they claimed that larger charge dissipators were needed at the sites of the failures, but that they did not have an opportunity to install them, because of either the lack of space at top of the structure or its inability to withstand the related wind loading. Later, the manufacturers said that they found their initial designs to be inadequate, but that they have produced new designs that work.

The marketing of lightning elimination devices has been quite aggressive, and it sometimes involved using the threat of legal action to suppress contrary opinions and evidence. This, together with the fact that lightning theory is beyond the comprehension of most potential buyers, has enabled the manufacturers to sell thousands of such devices. This marketing success has been exploited in two ways: a) by claiming that the existence of many satisfied customers proves that the charge dissipators eliminate lightning, and, b) by claiming that this wide use justifies issuing a standard for such products. This campaign was first directed at NFPA (National Fire Protection Association). When it failed, LEC directed it at IEEE. As part of that campaign, the term Charge Transfer Systems (CTS) was introduced to avoid having to use the term Dissipation Array Systems (DAS) that LEC registered as a trademark.

In updating the author's 1998 work, this paper provides the following: a) a summary of the main lightning elimination mechanisms that have been proposed by the manufacturers over the years, and the corresponding scientific rebuttals, b) further comments on claims of success of the manufacturers, c) a discussion showing why the concept of eliminating lightning is still considered to be not feasible, and, d) a review of manufacturers' attempts to get a standard for their charge dissipators.

II. LIGHTNING PREVENTION THEORIES

A. Discharging the Clouds

When the lightning prevention concept was first proposed by Czech scientist Prokop Divisch in 1754, the mechanism then claimed was "silently discharging the thunderclouds" [16]. That was the mechanism adopted by the manufacturer(s) when lightning prevention devices were introduced in the early 1970's. In support of this first theory, Carpenter [9] claimed that a thunderstorm was observed to degenerate upon passing over NASA's site on Merritt Island, Florida, which was equipped with five Dissipation Arrays.

In view of the above, the first rebuttal by scientists focused on the physical impossibility of the above mechanism. The related reasons are as follows [16, 19]: a) The quantity of charge that can be released by such systems is too small to affect the electrical properties of a thundercloud [17]. b) The velocity of positive ions is low. Hence they would not reach the base of the cloud in a timely manner.

Scientific measurements of the total charge produced by the dissipators confirmed that its value was small compared to that of a cloud. This forced the manufacturers to downgrade their claim to "partially discharging the cloud". This was often expressed as "holding the cloud charge below that required for discharge while in the area" [8], or decreasing the potential between the cloud and the protected object. In proposing this revised theory, the manufacturers were in effect still insisting that the emitted charge will reach the cloud.

The proponents of lightning elimination devices have now conceded that the concept of "discharging the clouds" was invalid. For example, Zipse [27] described it "as not making any sense". More importantly, based on a quantitative analysis, the Russian scientists retained by LEC itself (Aleksandrov et al.) concluded that the magnitude of the emitted charge was insignificant compared to that of both the cloud and individual strokes, and that the emitted ions will not reach the clouds [2].

B. Neutralizing the Downward Leader

Upon acceding to scientists' position that the emitted charge will not reach the clouds, LEC were left with the unhappy conclusion that downward lightning leaders will continue to develop as usual. They then suggested that elimination will take place by neutralizing the leader. For this to occur, they claimed that the dissipator will create, in the period preceding each downward flash, a large overhead layer of space charge. The leader would then be neutralized upon encountering that charge, and thus would not reach the structure.

To design a dissipator based on this revised mechanism, LEC assumed that the leader will have a charge of 5 Coulomb, and that the dissipator will have a period of 10 seconds between consecutive flashes to generate an equal charge. This means that the average corona current over the 10-second period would be 0.5 Ampere. From knowledge of the corona current I_1 that has been measured from a single point , LEC in essence suggested that the required number of points in the dissipator would be: $N = 0.5/I_1$.

The flaws in the above approach are: a) the corona current from a dissipator having a 1000 points is not 1000 times larger than that produced by a single point. Actually, it is often not much larger than that produced by a single point [3]. b) The total emitted charge will be small compared to that of the lightning leader. c) The emitted charge will not form a stationary layer of space charge directly above the dissipator. Instead, it is likely to break into several small pockets of space charge that will be blown around by the wind.

When it was observed in some cases that a current of, say, 20 kA flowed into the down leads of the dissipator, LEC initially refused to accept that their device was struck by lightning. They claimed instead that the space charge must have been not adequate, and that the dissipator rushed to supplement it when it sensed the approaching leader. However, there is no difference between this scenario and the impact of a 20-kA stroke terminating on an unprotected structure. Hence the above explanation in effect implied that the space charge, if effective at all, will only neutralize the leaders having smaller charges, and will let the big ones hit the structure. As discussed later herein, such a scenario renders the lightning elimination system not feasible on economic grounds.

The mechanism of "neutralizing the leader" is the one used by Zipse's in both his draft standard [sections 5.2 and 7.4 of 29] and in his November 2001 article [28]. The proponents of CTS must now abandon this mechanism because the LEC-Russian scientists [2] found it to be invalid based on the reasons listed hereafter. First and as mentioned above, the emitted charge is small compared to that of the leader. Second, the field 'carried' by the tip of a negative leader is huge: in the streamer zone it amounts to 800-1000 kV/m. On the other hand, the field generated by the layer of space charge is less than 10 kV/m at 100 m from the dissipator in case of a 100-m tower. The effect of such a weak electric field will be negligible. Third, the electric field created by the injected space charge is aligned with the electric field of the thundercloud. Hence it tends to accelerate the leader toward the dissipator rather than decelerate it or stop it. Fourth, in the words of Aleksandrov et al.: "It is beyond reason to believe that the leader penetration into the corona space charge will affect the charge of the leader cover".

C. Reducing the Ground Level Electric Field under the CTS

Drabkin and Carpenter [13] used the model in Fig. 1, and suggested that the dissipator would be effective "if it maintains the electric field at ground level below it at a level lower than the air gap breakdown value". The value of 500 kV/m is mentioned in the paper though not numerically applied in any example. The electric field at ground level below the dissipator is taken as the sum of the fields produced by the shown four charges, three of which are in line. The charge of the downward leader is assumed to be constant per meter of its length, and is produced by causing an equal reduction in the negative charge of the cloud. Charges other than that of the downward leader are assumed to be point charges, with the charge generated by the dissipator assumed to reside at top of the structure. This no-movement assumption contrasts with the mechanism in section *A* above in which the charge was assumed to travel upwards all the way to the cloud. With the leader developing in the vertical direction at a constant velocity, its total charge increases linearly with time. The length of step of the leader in the iteration is taken equal to 50 m. After each step, the total field is estimated and a corresponding new value of the corona current is calculated. Q_{CTS} is assumed to be the sum accumulated in all preceding steps, and to increase with number of needles. Based on the above, Drabkin et al. submit that, if the number of needles was large enough, the electric field in the area below the dissipator will be low enough, thus preventing lightning strikes to that area. Our rebuttal of this mechanism is as follows:

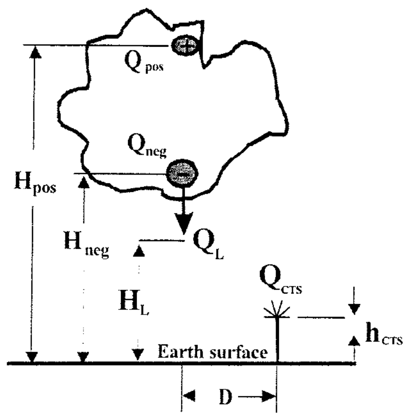

Fig. 1. LEC's model regarding effect of the dissipator.

First, having a low electric field at ground level near a structure does not preclude the field from being high enough at the peak of the structure so as to initiate an upward streamer, thus leading to a strike. Second, the subject calculation method underestimates the electric field of the downward leader by assuming the charge density to be constant along its length. In contrast, Golde [16] took the charge density to drop exponentially as we move away from the tip of the leader. Third, LEC exaggerates the electric field created by the space charge by assuming the total charge to be proportional to number of needles, by exaggerating the magnitude of the charge generated by each needle, and by assuming the whole charge to be located at top of the structure rather than some distance above it.

With the publication of the LEC-Russian papers [1,2], of which both Drabkin and Carpenter are listed as co-authors, it is apparent that LEC has now abandoned the above mechanism.

D. Inhibiting the Development of Upward Leaders

The LEC-Russians [1, 2] suggested that any possible impact of the emitted space charge will be by reducing the electric field at the top of the structure, thus making it more difficult to induce an upward leader. Two types of such leaders exist: the leaders associated with upward discharges, and the connecting leaders that are induced from the ground object by downward lightning leaders. The latter type is called "counter leaders" by Aleksandrov et al. The related arguments of the LEC-Russians and the author's rebuttal are given hereafter.

Upward discharges: In departure from LEC's long-held claim, Aleksandrov et al conceded that installing needles on an electrode does not significantly increase the emitted charge. Referring to Fig. 4 of [2], only a small difference exists despite the fact that the dissipator was 10 times larger than the single rod (5 m in radius versus 0.5 m). They claim, however, that the multi-pointed system gives a more favorable charge distribution in the gap, and that this decreases the electric field near the corona-forming surface. They further argue that stability of the streamer-free corona is enhanced when the same total corona current is broken into a large number of small emissions, each produced by one of the many needles of the dissipator. (It is not clear to the writer why the tips of several low-current corona filaments would not be 'brought together' by an approaching leader to give a combined current that is large enough to effect the transition to a streamer.) Based on an analysis of the voltage distribution generated by the combined effect of the charges in the cloud and the layer of space charge, Aleksandrov et al. suggest that all upward discharges will be suppressed.

The author's rebuttal is as follows: a) The LEC-Russians assume that upward discharges are generated by the slow-rising electric field that is produced by the 'static' charges in the thundercloud. This is false. Field observations establish that upward discharges are induced by the large transient that is generated by a nearby cloud-to-cloud or cloud-to-ground strike [4, 5, 6, 20]. Referring to the measurements in Fig. 6 of [21], Moore et al. found that transient in one incident to be about 400 kV/m. This is much higher than the 30 kV/m ambient field on which Fig. 3 of [2] is based. As admitted by the LEC-Russians themselves in [1], the dissipator cannot suppress upward leaders when such transients occur. b) The example used by the LEC-Russians to prove their point constitutes an extreme case because: the tower was 540 m high, the ambient field was assumed to rise to 30 kV/m over a 30-second period, the 30 kV/m value was assumed to apply from ground level up to the peak of the 540-m tower, and the dissipator was taken as a huge umbrella having a radius of 5 m.

Counter leaders: The LEC-Russians concede that downward flashes can strike a tower that is equipped with a dissipator. This is because a downward leader that is arriving directly above the tower or close to it will produce a large electric field at the dissipator that will overcome the retarding effect of the space charge. On the other hand, downward leaders that occur so far away that the field they produce at the dissipator is small would not be able to induce counter leaders. Hence they would not terminate on the tower. While the above qualitative analysis is definitely valid, the LEC-Russians claim, based on a cursory quantitative analysis, that the 'evaded' strokes include most the stroke that would strike the tower in the absence of the dissipator. The author rejects the above claim for the reasons given hereafter.

First, the LEC-Russians focused on the effect of the dimensions of the needles on reducing the electric field at the surface of the hemispherical electrode to which they are attached. In reality, no such surface exists because the umbrella array consists of a barbed wire that is wound on a frame [see Fig. 1B of 23]. More importantly, their approach implies that they think that the object to be protected is the hemispherical array rather than the building on which it is installed. That building will not necessarily be enclosed within a single hemispherical electrode. Hence retarding the development of counter leaders from the dissipator could cause them to develop from the building instead. That appears to be what happened during the 1988 test at Tampa airport [7].

Second, the LEC-Russians calculate the attractive range (R_{eq}) of the dissipator for a single value of the charge of the downward leader: that corresponding to a uniform density of 10^{-3} C/m. They then compare this to the observed attractive range of unprotected structures which they assert to be 3 times the height (h) of the tower. [The ratio R_{eq} /h is called the Protective Ratio (PR)]. Such a comparison entails several errors. a) The observed PR of a tower, especially a tall one, includes both upward and downward flashes of both polarities. b) For negative downward strokes, the observed PR results from the combined action of all possible stroke amplitudes, as determined by their frequency distribution, rather than by a single stroke amplitude. c) The assumption that the charge in the downward leader will be uniformly distributed along its length is not realistic [16] and hence is expected to give erroneous results. d) Most importantly, the PR for a mast is not constant, but rather varies with height.

To clarify the above, we used the predictions of the electrogeometric model (EGM) as given in the third row of Table 7-14 of [22]. This gives PR values equal to 3.2, 1.2 and 0.62 for mast heights of 30 m, 100 m, and 200 m, respectively. In contrast, the corresponding PR values given by the LEC-Russians are: 2.15, 1.6 and 1.4, respectively. Hence the LEC-Russian values for the cases of 100- and 200-m masts are larger than those predicted by the EGM. This suggests that all the strokes that terminate on the tower in the absence of the DAS produce fields strong enough to induce connecting leaders from the DAS-equipped tower. In other words, the DAS prevents no downward flashes whatsoever. Regarding the case of the 30 m mast, after allowing for the errors in the LEC-Russian estimate that may have been caused by the first three of the above factors, it cannot be said that the dissipator will reduce the number of strikes to the tower. This statement is further strengthened by the opinion of the LEC-Russians themselves that dissipators are expected to be less effective in case of the shorter towers.

Further to the above, the LEC-Russian exaggerate the effect of the emitted charge by neglecting effect of the wind, assuming the field at ground level to rise to at least 20 kV/m over a 20 second period, and assuming the density of aerosol ions to be only 10^5 cm^{-3}. (Aerosol ions decrease the injected space charge.) On the other hand, wind may break the layer of space charge into several small pockets and disperse them, the field might rise to only 10 kV/m, and the density of aerosols might be higher.

Finally, it should be noted that the theoretical findings of the LEC-Russians are contradicted by the field observations of Kuwabara et al. [18]. In that latter study, the frequency distribution of the amplitudes of the strokes that were collected after installing the CTS was basically similar to what was measured before installing them.

III. Manufacturers' claims of success

Before discussing the claims of success of the manufacturers, the following should be mentioned [24]:

a) In addition to the many failures previously reported by the author in [23], a list including 11 other sites was recently published. Multiple strokes were experienced at some of those sites. It is interesting that the failure sites include PDVSA, the Petroleum Company of Venezuela, which has often been cited by the proponents of CTS as proof of the effectiveness of their devices [28]. On the other hand, the experience of PDVSA with CTS was so bad that they decided to use Franklin rods in new installations.

b) CTS were recently investigated in Japan [18], in Ireland and at New Mexico Tech. All studies concluded that the lightning elimination claim was false and that CTS were ineffective.

Despite being clearly told from the beginning that "lack of damage to a facility does not prove absence of lightning strikes" [3, 14], the manufacturers continued to heavily rely on this false argument. They went further by compiling their own statistics based on this flawed criterion, and accordingly claimed achieving a protection efficiency of over 99%. This claim ignores the fact that any properly installed conventional lightning protection system also prevents damage and does so at much lower cost [15].

Visitors to the LEC factory in Boulder, Colorado, are usually shown a lab test which is claimed to prove that dissipators prevent lightning. In that test, an energized overhead net is used to represent the cloud. The net is initially energized at a low dc voltage to represent the pre-strike condition. The applied voltage is then increased via a regulator that supplies the transformer of the test set. With a grounded Franklin rod in the test gap, flashover occurs at a certain voltage. When this is replaced by an umbrella dissipator while maintaining the same length of the air gap, flashover does not occur when the regulator is made to apply the maximum available voltage.

The lack of flashover to the umbrella dissipator in the LEC test has nothing to do with the claimed ability to prevent lightning. It is rather a consequence of the following: a) As a result of the well-known effect of the gap factor [26], the flashover voltage for a given gap length is significantly higher for the net-to-umbrella configuration compared to the net-to-rod configuration. b) The maximum voltage available from the LEC test set is high enough to break down the net-to-rod gap but below that needed to break down the net-to-umbrella gap.

During 1999, LEC produced a lightning ground strike map of the Memphis airport area, pointed to a "hole" in it, and claimed that this proves that dissipators prevent lightning. The equipment in question [27] consists of a concentration of

270 units installed for the facilities of FedEx (a courier company). The Memphis map does not prove LEC's claim as can be seen from the following:

1) Several other "holes" exist in the subject map at locations where no dissipators exist.

2) The map is based on lightning strikes that occurred within a relatively short period (1994-1998). The observed pattern may change when the observation period is longer.

3) According to Bill Cook, from Atlantic Scientific Corporation, only post 1996 data is usable for the Memphis Airport area because a detection problem existed in the system used in prior years [12].

4) According to Dr. W.A. Chisholm [11], the waveform of the lightning current in tall towers exhibits a second peak which often causes the detection system to reject the data and not record the strike. Such detection failures were observed at the CN Tower in Toronto, Canada.

5) According to the electrogeometric model, a tall tower collects most of the strokes that arrive over the surrounding area. The detection system may fail to detect these as stated above. As to the strokes which miss the tower, these will have low amplitudes and hence may not be detected because of the limited sensitivity.

6) The runway area is flat and it is surrounded by a tower and many trees. This and other topographical features may cause most lightning to miss the runway area regardless of the existence of the dissipators.

7) The detection error is not uniform and it may be biased in the sense that strokes occurring inside the airport are being systematically assigned to points outside it.

8) LEC's dissipators are used on a large number of tall towers all over the USA. If the claim regarding their effect at Memphis airport is real and not caused by extraneous factors, then why did LEC fail to show similar effects elsewhere?

9) The real test of validity would be by showing that the ground strikes pattern at Memphis was different before the dissipators were installed, or that it would change if the dissipaters were replaced by conventional systems.

IV. FEASIBILITY OF LIGHTNING ELIMINATION

A. Economic versus Technical Feasibility

In [2], the LEC-Russians summarized the findings of their theoretical study regarding the impact of umbrella dissipators on natural downward flashes as follows: "There is reason to believe that (umbrella) dissipators decrease the number of lightning strikes to ground objects". While this limited claim is still faced with strong technical objections, the outcome is immaterial because the lightning elimination claim has now lost its feasibility on economic grounds. For if lightning will still hit the structure at least some of the time, then the structure has to be able to cope with that event. And if it is hardened to accomplish this, then the same measures would suffice even if no strokes whatsoever were eliminated. This being the case, the lightning elimination system becomes redundant and there is no economic justification for using it.

B. Implications of the LEC-Russian Study

1) Despite the rather limited impact of CTS that was found in the subject theoretical study [1, 2], and assuming that it will indeed materialize despite the strong criticism levied against that study, such a limited impact requires uniform ionization over relatively large hemispherical surfaces. This can be seen from the fact that the smallest device considered was an umbrella dissipator having a diameter equal to 2 m. While not explicitly stated in the LEC-Russian study, this implies that the following types of dissipators are rather useless: the ionizer wires used on power lines (called Dual Dissipator System), paragon arrays, conic roof arrays, parapet arrays, trapezoid arrays, and ball dissipators (called Spline Balls and Ion Plasma Generators). The above in effect excludes most of the configurations listed in Zipse's draft standard [29]. It also excludes about 80% of the products that have been sold by LEC to its many customers over the last 30 years.

2) Since umbrella dissipators are not used on power lines nor substations, it follows from the above that lightning elimination devices are of no benefit to substations nor power lines. This confirms the earlier conclusion of the author [23].

V. A STANDARD FOR CTS?

Standards for commercial products serve consumers by assuring them that the goods meet certain minimum standards. They also serve manufacturers by facilitating trade and competition in the market place. Of course, a fundamental underlying premise is that the goods accomplish the intended purpose, which in turn requires that any underlying theory be valid. That is why we do not have standards for creams that prevent baldness nor for medicines for preventing aging.

On the other hand, when a product is based on a questionable theory, and the claims of performance are controversial, then any attempt to include it in a standard would be a subversion of the standardization process. For the only objective would then be to buttress claims that cannot withstand scientific scrutiny on their own, and to help the manufacturers in misleading the consumers. The damage to public interest would be greater if the standard was issued by a learned society like the IEEE as compared to a trade organization like NEMA.

As explained above, it is now established that the theory, upon which Zipse set out to produce an IEEE standard for CTS, is invalid. It follows that the subject project (P1576) should have never been issued. The above fact also proves the position of the critics that Zipse's action tarnished the reputation of the IEEE as a learned society.

CTS proponents had a long history of failure in attempting to get their products covered by a standard. Ref. [25] discusses this and shows why Zipse's application to the IEEE Standards Association should have never been approved. A most serious point is that the IEEE may be jointly liable, together with Zipse and LEC, for the damages suffered by LEC's customers.

VI. CONCLUSIONS

1) CTS manufacturers have so far reduced their claim from "guaranteeing to eliminate all lightning strikes" to "having reason to believe that their devices decrease the frequency of lightning strikes".

2) Regardless of the technical validity of the present reduced version of the lightning elimination claim, the subject devices are no longer feasible on economic grounds.

3) The basis of Zipse's draft standard has now been proven to be invalid. This confirms that Zipse's project P1576 tarnished the reputation of the IEEE and exposed it to liability to the misled customers of LEC.

4) If scientists did not fight the false lightning elimination theories, CTS manufacturers would still be claiming today that "their devices eliminate all lightning strokes by discharging the clouds". In playing their role, scientists faced repeated denials of dissipator failure incidents, attempts to prevent them from publishing their findings to the point of using threats of legal action, and even the laughable accusation that "scientists are refusing to believe because it does not fit their pattern of thinking" [10]. As they gradually downgraded their claim, the manufacturers never acknowledged that their prior acts of belligerence were unjustified nor apologized to the aggrieved scientists. Hopefully, the above history should be a lesson to third parties who find themselves as arbitrators in future disputes that are initiated by manufacturers against scientists.

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VIII. BIOGRAPHY

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