Comparative Investigation of Silicone Rubber Composite and RTV Coated Glass Insulators Installed in Coastal Overhead Transmission Lines

Key words: glass insulators, RTV coated, leakage current, silicone rubber, composite insulators, transmission lines, substations

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This article describes the experience acquired from the long term use of room temperature vulcanized silicone rubber coated glass insulators and high temperature vulcanized composite insulators in coastal transmission lines along with the results of comparative measurements performed in an experimental high voltage test station.

Introduction

The fault-free performance of outdoor insulators is a matter of great importance for power utilities as a single insulator fault may lead to an extended outage. Several factors related to operation conditions affect the performance of outdoor insulators with pollution being probably the most significant one [1]-[3]. Coastal areas are considered heavily polluted due to the deposition of sea salt on the insulators. When the deposited salt is diluted in water through humidity, drizzle, fog, or light rain, a conductive solution is created and leakage current flows on the surface. The activity may advance, under favorable conditions, to flashover. Therefore, the local weather and climate is an important factor for the determination of pollution severity as strong winds carry more salt and frequent rains may provide natural cleaning.

One method to cope with the problem is the use of silicone based materials that suppress the phenomenon by not allowing the formation of a conductive film on the surface, and thus the flow of leakage current, due to their hydrophobic surface [1]-[6]. Room temperature vulcanization (RTV) silicone rubber (SIR) is widely used in the manufacture of coatings [5],[6] whereas high temperature vulcanization (HTV) SIR is used for the fabrication of composite insulators [7]-[10]. The usual case is the application of RTV SIR coatings on substation ceramic insulators [4],[5],[11] whereas composite insulators usually replace ceramic insulators in transmission lines [7]-[10]. However, there are several cases where coated ceramic insulators are used in transmission lines [11]-[13]. These are usually toughened glass insulators precoated with RTV, supplied as such by insulator manufacturers [11]-[13], and a growing discussion about the use of such insulators is currently in progress [11]-[15].

Further, special conditions may call for a limited installation of coated insulators in some parts of a transmission line, and such cases were met in the power network of the Greek island of Crete. Crete is equipped with an isolated 150 kV power network that suffers from intense marine pollution due to its coastal environment and local wind and rainfall patterns [16]-[20]. To suppress the problem several remedies have been employed by the Greek power utility. Composite insulators have gradually replaced ceramic ones in the network's transmission lines and large quantities of RTV coating has been used in substations [4], [16]-[20]. However, in some cases, ceramic insulators installed in transmission lines had to be coated by the utility and, in certain cases, coated and composite insulators were used in different phases of the same towers [16]. At the same time, similar research was conducted in TALOS high voltage test station [21]-[23] in order to further investigate the differences in the recorded activity between RTV coated and composite insulators with the same creepage distance, installed at the same location and being subjected to the same stress.

Comparative measurements between RTV coated glass and HTV SIR composite insulators of similar characteristics were conducted in TALOS, a coastal open air high voltage test station constructed in Iraklion, Crete along with comparative pollution measurements. The acquired results and experience are presented here along with previous network experience. The island's pollution profile, the network's design and overall utility experience is also presented in order to put the results in context.

Crete's Pollution Profile and Transmission Line Insulators

Crete is a Greek island located in the Mediterranean Sea having an elongated shape, 260 km long and 15-60 km wide, and a coastline of 1046 km. Three large mountain formations cover the central part of the island and the rural development is mostly coastal. The largest cities in descending order are Iraklion, Rethimnon, Chania, Ierapetra, and Agios Nikolaos and are located next to the coast. The route of all major transmission lines of the power system is shown in Figure 1 and as shown, the power network has followed the rural development and it is therefore mostly coastal.

The various factors comprising the island's pollution profile have been thoroughly discussed in [16]-[20], [24]-[27]. In brief, strong winds blows from a north/north-west direction and, combined with the mostly rocky coastline, result in increased salt deposition on coastal insulators. The direction of the wind also means that the northern part of the island experiences heavier pollution. This is an added problem as most substations and transmission lines are located in the northern part of the island as shown in Figure 1. Another important characteristic is the dry period that usually starts in April and lasts until the end of October, which causes a contamination build-up during the summer. The western part of the island receives almost the double the amount of rain compared to the eastern part. A different behavior is also observed in the wind pattern as the winds are generally stronger at the eastern side of the island. All these result in pollution being heavier on the eastern side of the island.

From 1978 to 1993, 216 pollution related faults took place along the 276 km of lines in the eastern part of the island and one fault, unrelated to pollution, took place along the 132 km of lines in the western part of the island even though extensive cleaning was performed on the eastern side and not on the western side [24]. The proximity to cities is also a significant factor as it was clearly shown by a series of ESDD measurements throughout the island [20]. The general picture is that pollution is considered medium-to-heavy in coastal areas and medium-to-light in the central and eastern parts of the island, with severity related to distance from the coast and cities. In the western part of the island, pollution is considered medium-to-light even in coastal areas and next to large cities like Chania.

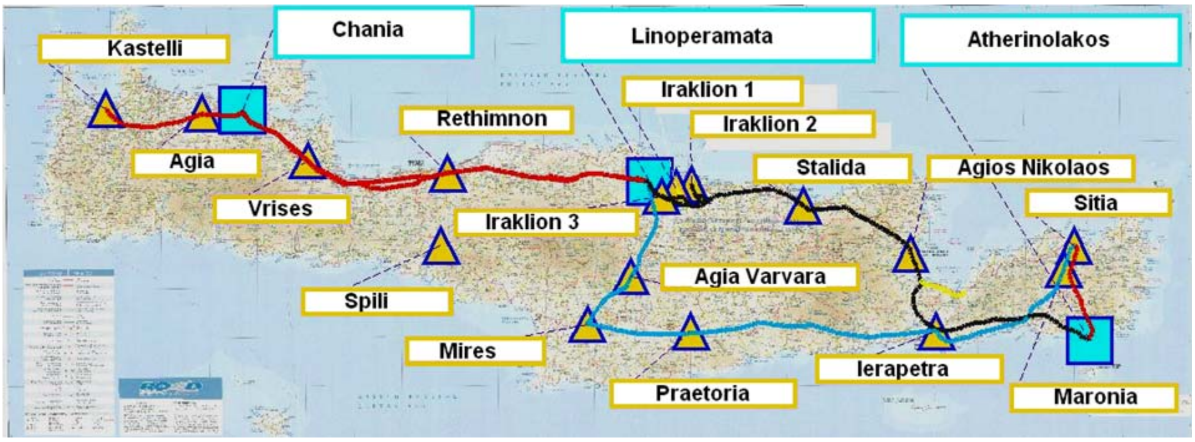

Figure 1. The power system of Crete. Squares denote step-up substation/power plants and triangles denote step-down substations.

It should be noted that pollution was historically the single factor responsible for more faults in the 80s (32.5%) and 90s (19.6%) [17], [19], [20], [24]. The decrease in outage rate is attributable to pressurized washing by ground crews which started in 1985 and by helicopters which started in 1995 [16]-[20], [24]. The gradual installation of HTV composite insulators in transmission lines started in 1993 on a trial basis on 150 kV lines with only 33 towers changed-out to 1998 [25]. As the results of silicone materials were encouraging, especially with RTV SIR in substations, large scale installation of HTV SIR insulators in transmission lines began in 2004. Table 1 shows the type of insulators now used on the major lines and the year of large scale installation of HTV SIR insulators.

The first large scale replacement of insulators took place on the Iraklion-Ierapetra and Ierapetra-Atherinolakos transmission lines in 2004 and the other lines followed as shown in Table 1. The replacement process for two of them, "Iraklion-Mires and Iraklion-Chania" was completed in 2014. The line from Mires to Ierapetra is also expected to be full yeqquiped with HTV SIR in 2015. The Chania-Kasteli line is located west of Chania and subjected to light pollution as described above and therefore is insulated with porcelain insulators and a replacement has not been scheduled as yet.

Table 1. Transmission lines and insulator type installed.

Transmission line	**Insulator type**	**Year of HTV large scale installation**
Atherinolakos-Ierapetra	HTV SIR, RTV SIR coated (upper phase of certain towers, bridging part of certain towers)	2004
Iraklion-Ierapetra	HTV SIR, RTV SIR coated (certain poles, all phases)	2004
Atherinolakos-Sitia	HTV SIR	2006
Ierapetra-Sitia	HTV SIR, RTV SIR coated (bridging parts of certain towers)	2010
Iraklion-Mires	HTV SIR	2013
Iraklion-Chania	HTV SIR	2013
Mires-Ierapetra	Glass	-
Chania-Kasteli	Porcelain	-

RTV Coated Glass Insulator Experience

It should be noted that until today not a single pollution related fault has been recorded on HTV composite insulators. This is reflected in the total number of faults per 100 km recorded in the Cretan network which has fallen from 75 in the 80's to 51 in the 90's and 24 in the 00's [20].

As described above, the standard approach followed by the Greek Public Power Corporation (PPC) in Crete, is the installation of HTV SIR composite insulators in transmission lines and RTV coatings on substation insulators. However, there were, and still are, some special cases where coated glass insulators were installed in 150 kV lines. These insulators were coated by PPC, now Hellenic Electricity Distribution Network Operator (HEDNO), personnel and even though some imperfections in the coating were evident, there have been no problems reported since the first installation in 2004. It should be noted that the PPC/HEDNO crew is highly experienced in coating insulators, experience that was gained through extensive coating of substation insulators [4].

The entire insulator including the hardware was coated even though it has been proposed that the cement portion of the insulators should not be coated as the coating may lift off from the cement and cause false alarms [11]; however, no such problems have been reported. Another issue that arose prior to coating was the corrosion of an insulator pin on a porcelain insulator on the line between Rethimnon and Chania that caused the line to drop and this was also taken into consideration in order to decide to coat the insulator hardware. One special case where coated glass insulators were used was the newly constructed line connecting the Atherinolakos substation with Ierapetra, where clearance issues did not allow the use of the available composites in all three phases of 41 suspension towers. Therefore, it was decided to use coated glass strings in the upper phase. Another case was near the archeological site of Knossos and near the Iraklion 2 substation which is located in the city grid of Iraklion. In both it was decided to use hollow metal poles mainly to reduce the visual impact of the structures. However, almost from the start there were complaints about the noise level as the hollow metal posts amplified the noise. Further, an unacceptable failure rate was also documented in the insulators installed in these areas. Therefore, it was decided to coat the installed insulators thereby solving both of these problems.

On the eastern side of the island where strong winds are encountered, the terminal and tension towers of the Atherinolakos-Ierapetra line and of the line connecting Ierapetra with Sitia experienced line trips due to the wind blowing the HTV SIR insulators into the crossarms. To increase the weight of the insulators, weights were installed on several towers and heavier coated glass strings were also installed in the bridging part of tension and terminal towers.

Finally, the last issue that should be mentioned is that in some areas birds attacked the HTV insulators causing significant damage to the sheds. These birds seem to have developed a preference for certain composite insulators and not for others, and the reason for this is not known. The problem was eventually solved by trial and error using HTV insulators from different manufacturers but can be solved using coated ceramic insulators.

Comparative Leakage Current Measurements

The simultaneous installation of coated glass strings and composite insulators at the same towers, underlined the need of further research on the comparative performance of such insulators. HEDNO operates an open air high voltage test station (TALOS) in Iraklion, Crete. The TALOS test station (Figure 2) is located right next to the coast within the Linoperamata Substation. Initially, only of bay was installed for testing 150 kV post and suspension insulators but the station was upgraded in 2011 and now has three bays for testing of 21 kV and 150 kV post and suspension insulators [23], [25]. During the first stage of operation, one RTV coated glass string and one HTV SIR composite insulator was installed in the test station and monitored from July to October in which prior research has shown that surface activity meets its peak during this period and that the vast majority of pollution related outages has been recorded during these months. The monitored insulators had similar characteristics with those installed in the towers of the Atherinolakos-Ierapetra line and their basic characteristics are outlined in Table 2.

Figure 2. Photograph of the TALOS insulator test station in Iraklion Crete (21 kV bay)

Table 2. Characteristics of the two insulator types installed on the lines and monitored at TALOS.

Insulator	A	B
Type	HTV SIR	RTV Coated Glass
Creepage Distance	6255 mm	6240 mm
Specified Insulation Level	41.7 mm/kV	41.6 mm/kV

Leakage current was monitored using an Online Leakage Current Analyzer (OLCA) measuring system manufactured by CTlab [22]-[23] and the measurements were imported into MATLAB® for improved visualization and additional processing.

The positive and negative peak values of the leakage current for the two insulators is shown in Figure 3 and the RMS current is shown in Figure 4. In both, the time window is two minutes. The peak value shows similar activity; however, it is seen that the activity recorded on the coated string is more intermittent. This is better shown in the zoomed section of the Figure. The difference in the activity results in the RMS current being a little larger in the case of the composite insulator as shown in Figure 4. What is interesting is that the activity during September and October is evident on the coated insulator whereas it is essentially absent on the composite insulator. However, what's most important is that the level of activity on both insulators is very small and the performance of both insulators can be thus considered satisfactory. This is important as from experience, these are the months of increased risk for un-coated insulators.

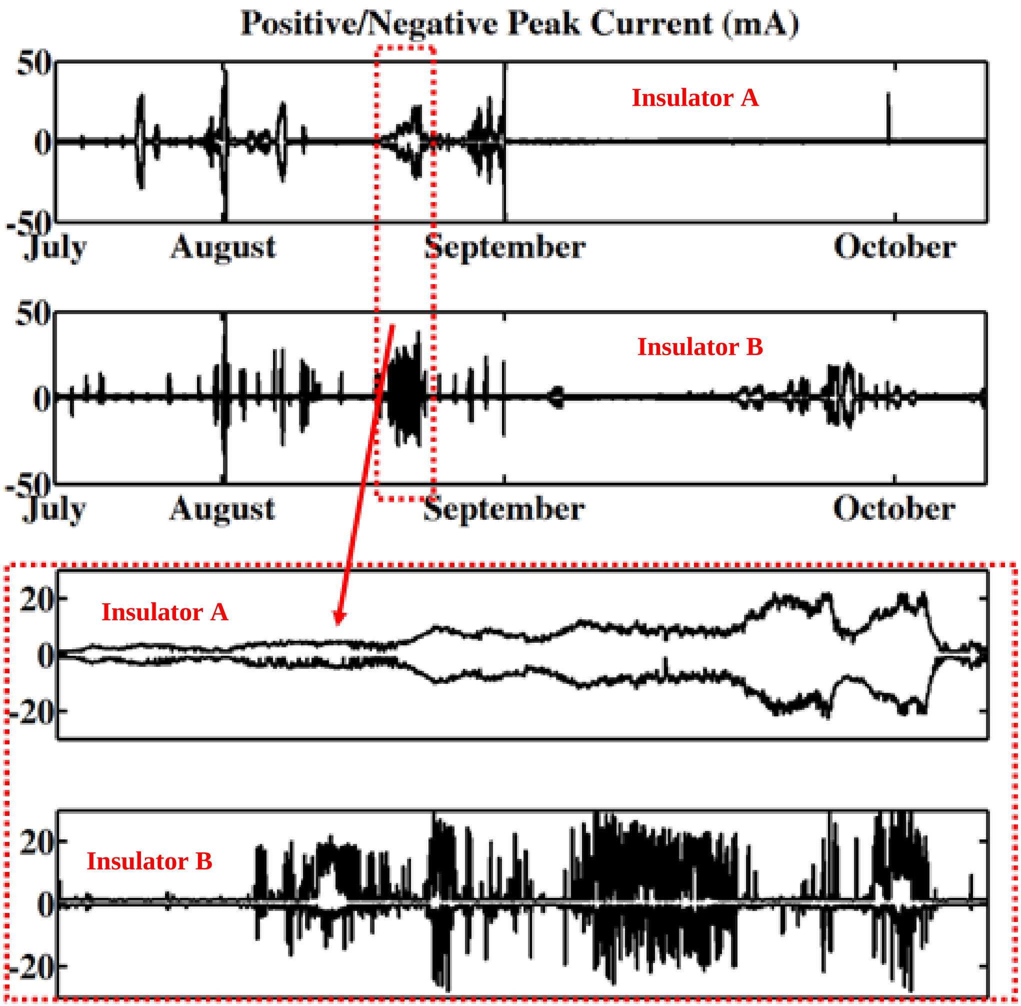

Figure 3. Positive/Negative Peak Current recorded for insulators A (upper plot) and B (lower plot) (wide view and close-up).

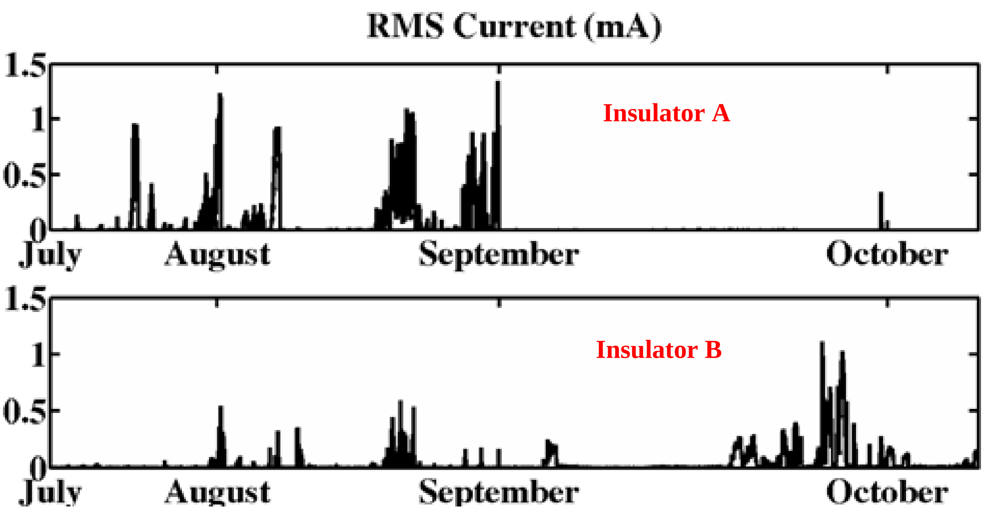

Figure 4. RMS Current variation for insulators A (upper plot) and B(lower plot)

Comparative Pollution Measurements

TALOS is equipped with a structure (arch) that is used for hanging insulators to compare insulator contamination in terms of equivalent salt deposit density (ESDD) and non-soluble deposit density (NSDD) levels [25], [29]. Photographs of the structure are shown in Figure 5.

The insulators were hanged for over a year and ESDD and NSDD measurements were conducted in the middle-to-upper part of each SIR insulator and RTV coated string in March to May, 2014 as a part of a larger project that is currently in progress [25], [29].

Figure 5. The ESDD-NSDD arch in TALOS.

Although further measurements have to be conducted before a definite conclusion is drawn, the results from this first series of measurements shows that the ESDD values are similar for both insulators but the coated glass insulator generally shows larger NSDD values as shown in Figure 6. This was to be expected if one considers the surfaces of each SIR material, as the RTV coated surfaces are generally rougher. It should be noted that initially the increased NSDD values on the coated insulators were attributed to several imperfections on the coated surface as formed by the spray paint application by the utility's personnel.

The latest pollution measurement test series initiated in June 2014 included a factory precoated glass insulator, on which the coating was very uniform, that was installed in the arch, in the place of the far-left insulator shown in Figure 5. This insulator string was hanged before for over one year at TALOS accumulating significant amount of pollutants, especially sand. After its installation on the arch, all insulators were washed with low pressure water with a hose in order to initiate a new set of measurements. During this washing it became evident that all insulators were easily cleaned with the exception of the pre-coated one as sand could not be fully removed, and in fact using a sponge became necessary to remove the sand from the surface. Therefore, the increased NSDD measurement seems to be more related to the nature of the surface of the RTV coating and not as much to the coating procedure.

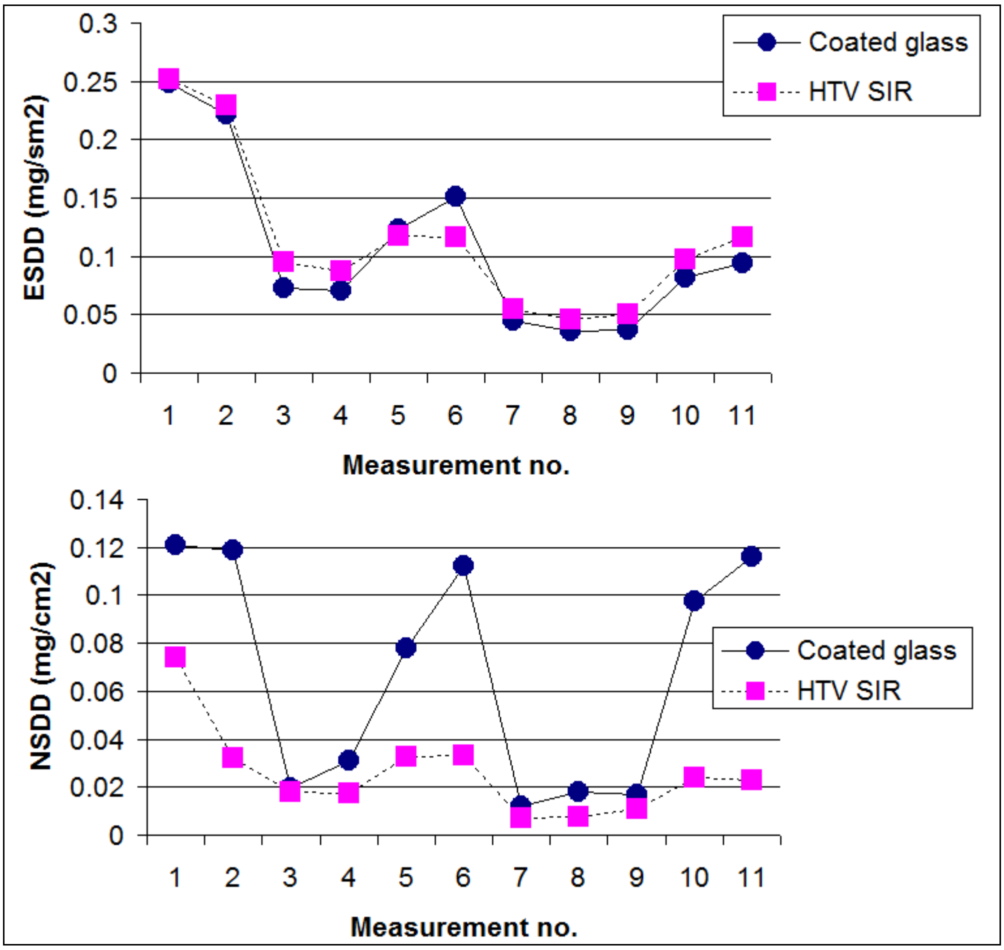

Figure 6. March to May 2014 ESDD and NSDD measurements at TALOS.

Summary

The fault free performance of outdoor high voltage insulators is of major importance for power utilities. Pollution is considered a significant factor affecting the performance of outdoor insulation with the sea salt considered a primary source. Silicone materials are used to manufacture composite insulators and coatings and thus provide a significant improvement in pollution performance over traditional ceramic insulators. In Crete, HTV SIR composite insulators are mostly used in transmission lines whereas RTV SIR coatings have been widely used in substations, which has been the common practice. However, there is also a growing discussion regarding the use of RTV coated insulators in transmission lines, with several manufacturers providing pre-coated insulators. This article adds to the discussion with the experience acquired in the power system of Crete, which provides a rather interesting case study due to the severe pollution problems. Comparative pollution and leakage current measurements have been conducted in TALOS between such insulators of similar characteristics. The findings presented in this article illustrate the following:

1. RTV coated glass insulator strings have operated fault-free for a decade now in the network and in some cases they have been installed on the same tower along with HTV SIR composite insulators.
2. The coating has been applied by the utility's personnel and even although imperfections in the coating surface exist stemming from the application, they do not seem to have any significant effect on the insulator performance.
3. Comparative pollution measurements performed in TALOS show an increased deposition of non-soluble deposits on pre-coated glass insulators compared to the HTV SIR which is thought to be

due to the nature of the RTV applied to the insulators.

4. All insulator parts were coated and this reduces the corrosion of the hardware.
5. Both HTV SIR composite and RTV coated glass insulators exhibit comparable leakage current peaks; however, the coated insulator shows more intermittent current measurements.

In summary, RTV coated ceramic insulators can provide a reliable alternative to HTV SIR composite insulators for use in overhead transmission lines in polluted areas. In addition, these insulators can be used in a case-by-case basis to provide a solution to local issues as was the case in Crete. Although further research is needed, the experience and the initial results from the comparative studies show that they exhibit a different yet similar performance to HTV SIR composite insulators.

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