A Close-Loop Conformance Testing System of IEC 61850

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Abstract —With the development of intelligent substation in China, it becoming more important that the conformance testing of IEC 61850 is used to guarantee the interoperability between intelligent electric devices. In view of the current intelligent substation IEC 61850 conformance testing did not form a closed loop, which led to the lacking of comprehensiveness and integrity, a closed-loop conformance testing system of IEC 61850 is proposed in this paper, both the software and hardware platform were designed to illustrate the implement method of the testing system. Artificial intervention was eliminated by using the automatic judging program, in order to enhance the efficiency and consistency of the testing system. Besides, the user-defined test-cases is introduced to form an opening testing platform, which can allow users to modify and add test-cases for actual use, improve the flexibility and offer a reference to related engineering practice.

Index Terms—Intelligent substation, conformance testing, IEC 61850, closed-loop testing

I. Introduction

Since IEC published IEC 61850 Ed 1.0 and defined the standard of IEC 61850 in 2003 [1], this standard has been widely used in many fields of power system. Smart substation is a very important application field of IEC 61850. With the development of smart substation, the IEDs (Intelligent Electronic Device) in it are becoming intelligent, highly integrated and complicated. However, the interoperability of IEDs is usually poor in practical project because different manufacturers comprehend the protocol and standard in different ways and also achieve them by different methods. Thus, the devices they produce may not completely accord with the standard of IEC 61850. As a consequence, it is necessary to carry out conformance test of IEC 61850 between different IEDs to ensure their interoperability [2]-[5].

IEC 61850 Part 10 has put forward strict requirements for conformance test. It claims that conformance test should include data model test, configuration file test, ACSI (Abstract Communication Service Interface) model test and service mapping test [6], [7]. At present, domestic and international scholars have carried out a great deal of research on IEC 61850 conformance test, but there are still some problems left [8]-[14]. The problems are as followed: 1) There is not a close loop between the IED under test and the testing software, so that artificial intervention is needed in the testing procedure to change some variables; 2) Some existing cases cannot be selected automatically, so that the testers need to continue the test manually according to communication message and operation log. In the case of hardware, traditional conformance testing software generally run on an ordinary PC or other equipment based on similar framework. But being limited by PC's framework, software platform cannot conduct SV and GOOSE message communication with the device under test. Therefore, a matched conformance testing hardware platform is very necessary.

Aiming at the software and hardware defects of present IEC 61850 conformance testing technology, this paper proposed a close-loop conformance testing system of IEC 61850 and studied its software and hardware platform as well. In the case of its software platform, the testing system gives consideration to both function verification and protocol testing. Users can also conduct some custom testing operation according to practical needs. In the case of its hardware platform, the testing system can guarantee a strict and reliable close-loop testing environment, which makes the conformance testing more realistic, reliable and efficient. At last, by taking the actual device as objects, this paper conducted some typical cases about the conformance testing system, whose validity is then successfully confirmed.

II. Overview of the Conformance Testing System

In traditional IEC 61850 conformance testing system, there is not a close loop between the IED under test and the testing software, which makes test-cases cannot be selected automatically and the testers need to intervene the test. As a consequence, the function of conformance testing system is not guaranteed.

The proposed IEC 61850 close-loop conformance testing system contains software platform, hardware platform and DUT (Device Under Test). In the conformance testing system, hardware platform and DUT are respectively connected to software platform through Ethernet. Hardware platform and DUT are connected through optic-fiber Ethernet and cable. By this way, this three parts can form a close-loop testing environment as is shown in Fig. 1.

In Fig. 1, the software platform of conformance testing system combines the function of communication

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simulator, analyzer and time controller. The hardware platform displaces the device emulator and it has 8 GOOSE/SV ports.

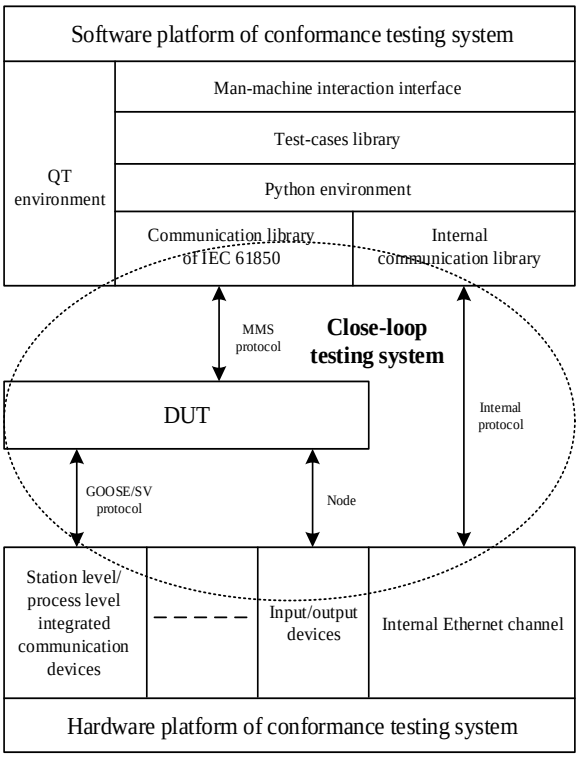

Fig. 1. The diagrammatic sketch of closed-loop conformance testing structure based on IEC 61850.

What follows is the general idea of the proposed close-loop IEC 61850 conformance testing system. Firstly, software platform will make communication with DUT to conduct several tests including reporting service test, control service test and setting service test. While GOOSE service and SV service test are being implemented, conventional and digital physical quantities were sent from software platform to hardware platform via internal protocol. Then by means of the interaction between hardware platform and DUT, the conformance test is completed. The typical process is: (1) The software platform reads test-cases and sends test signal to the hardware platform meanwhile; (2) The hardware platform simulates corresponding simulation environment, which is then output to DUT; (3) DUT receives hardware platform's response and returns MMS message to software platform; (4) The software platform analyzes the MMS message and makes a conclusion and starts the next test. By this way, a close loop and consecutive test is formed.

III. Hardware Platform of Conformance Testing System

The hardware platform of conformance testing system is made up by several station level/process level integrated communication devices, conventional input/output devices and internal high speed Ethernet channel. It is mainly used to provide a simulation environment to DUT. To be specific, in order to meet the needs of different types of IED, the hardware platform provides GOOSE/SV digital signal output ports and conventional input/output function.

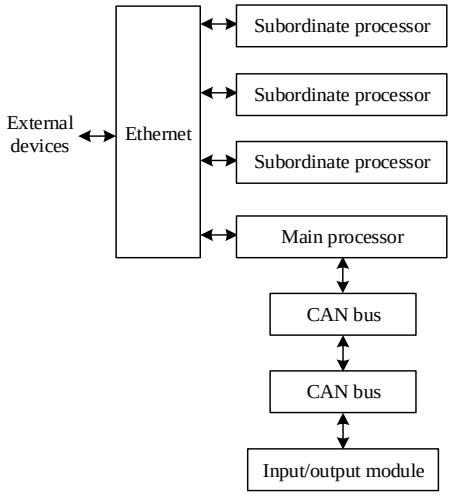

Fig. 2. Framework of the hardware platform of conformance testing system.

Station level/process level integrated communication device is a multifunctional device which combines the function of communicational encoding and decoding, communication interface, communication management, parameter configuration and man-machine interaction interface. It uses DSP and ARM-based dual core processor, FPGA and network exchange chip as hardware framework. It uses Linux2.6, QT, SQLite database, virtual memory virtual CAN as software framework. The con-ventional input/output device is connected with DUT through traditional cable. It is used to get DUT's input condition and output control signal to DUT. Each part of hardware platform can communicate with each other through internal high speed Ethernet channel.

For the conformance testing system, it is possible for it to test several IEDs at the same time. When this situation happens, in order to increase the testing efficiency, the hardware platform needs to test several IEDs while the software platform implements one case. Therefore, multi-CPU framework based on embedded ARM platform is introduced in the design of the conformance testing system. This framework can make the whole system more automatic, efficient and low-cost as well. Fig. 2 shows the framework of the hardware platform of conformance testing system.

IV. Software Platform of Conformance Testing System

The software platform of conformance testing system is used to record and process the test result responded by DUT. It's function also includes monitoring the errors during testing period, collecting and analyzing IEC 61850 information flow on Ethernet, recording network events, monitoring network security, establishing connection and checking system configuration etc.

The software platform of conformance testing system is coded in Python. It is composed of QT environment, Python environment, test-case script, internal communication library and MMS communication library. QT environment is actually an environment container of Python, test-case and all kinds of communication library. It supports cross-platform rapid transplant, including man-machine interaction interface, global testing parameter, script management, model management test result output and alarm output.

The test items of software platform include connecting service, control service, setting service, reporting service, file service and GOOSE service etc. In the test of connecting service, control service, reporting service and file service, the software platform can directly make communication with DUT in PC through Ethernet. In terms of GOOSE/SV message test, this paper introduced MMS message in the test. By communicating with IED directly using MMS message, the software platform can obtain corresponding MMS message and conduct auxiliary analysis. With the cooperation between software platform and hardware platform, the automatic analysis of conformance test result in IEC 61850 smart substation is successfully achieved.

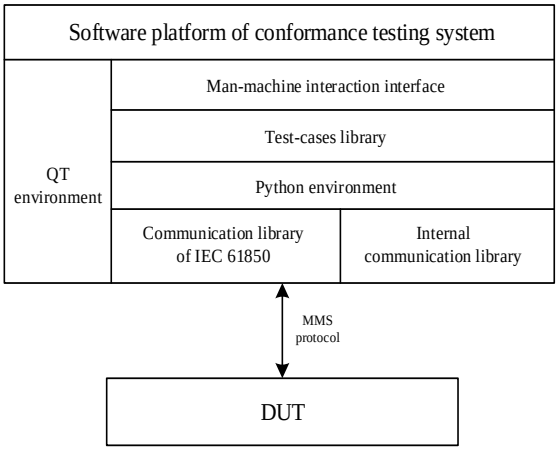

Fig. 3. Framework of the software platform of conformance testing system

To realize the software platform of conformance testing system, this paper used cross-platform language and scripting language. Users can also build custom testing logic and testing methods. The software platform supports IEC 61850-10, and it can obtain results automatically according to the condition set up by test-cases. In general, the main function of software platform is communication simulating, interacting with hardware platform and obtaining and analyzing MMS message. Fig. 3 shows the framework of the software platform of conformance testing system.

V. Testing Method of Conformance Testing System

The typical process of close-loop IEC 61850 conformance test is shown in Fig. 4 and it includes:

A. Build a Standard Test-Case

According to communication library function, package function and positive/negative testing logic of IEC 61850-10, write testing method in the man-machine interface of conformance testing system to form the test-case library.

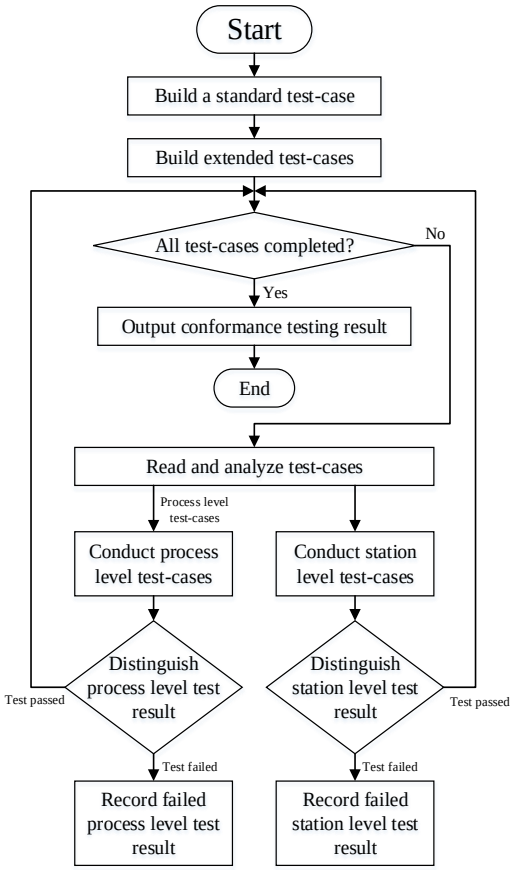

Fig. 4. Flowchart of close-loop IEC 61850 conformance test.

B. Build Extended Test-Cases

According to communication library function, package function and positive/negative testing logic of domestic smart-grid standard, write testing method in the man-machine interface of conformance testing system as supplement to the standard test-case library.

C. Read and Analyze the Test-Case

The software platform of conformance testing system can recognize syntactic and semantic errors in test-cases. It can realize some function like analyzing script logic, recording test log and invoking functions of communication libraries. The test-cases of station control layer and process layer are classified and conducted respectively.

D. Conduct Test-Cases of Station Control Layer

This step includes model service, connecting service, control service, reporting service, setting service and file service. The software platform of conformance testing system interacts with DUT directly, then DUT returns test result to it.

E. Conduct Test-Cases of Process Layer

This step includes GOOSE service and SV service. Firstly, the software platform communicates with the hardware platform via internal protocol. Then the hardware platform emulates the simulation environment and interacts with DUT via GOOSE protocol and SV protocol. At last the test result of DUT is received.

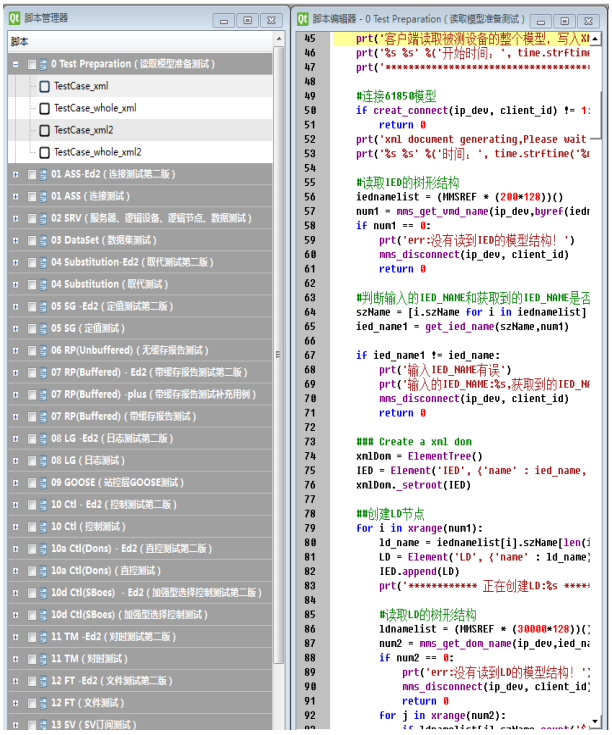

Fig. 6. Software platform of conformance testing system

F. Judge the Results of Test-Cases

The program judges the test results automatically and records the results which failed the conformance test according to the information like intermediate results, test interaction message and so on.

G. Output the Results of Test-Cases

The software platform of conformance testing system lists each result of test-cases and outputs the list. Then the conformance test report is completed.

VI. Run and Test of Conformance Testing System

The proposed software platform of conformance testing system is shown in Fig. 5.

In this paper, conformance testing system of IEC 61850 mainly includes connecting service, control service, reporting service, file service, setting service, GOOSE service, SV service etc. Among them, GOOSE service and SV service are limited by network and PC framework, so they need hardware platform to assist them to complete the test. The rest can be directly carried out by the communication between software platform and DUT.

Following are some service test results. The DUT used here is a certain set of protection device for extra-high voltage transmission line.

A. Connecting Service

Connecting service is mainly used to test the correlation capabilities of DUT's IEC 61850 model. Its basic test-cases include 3 positive cases and 4 negative cases. Appendix A shows the implementation of connecting service test. This test-case is used to test the correlation and TPAA correlation release of DUT. After the test-case is conducted, the software will give test result automatically.

B. Data Service

Data service is used to verify the DUT's Server, Logical-Device, Logical-Node, Data and DataAttribute models. Its basic test-cases include 8 positive cases and 4 negative cases. Appendix B shows the implementation of data service test. The software automatically checks and judges error messages replied from DUT and comes to a conclusion. It is noteworthy that according to the test result, the DUT failed the test. Although the DUT refused data writing, the returned result was different from expectation. Here the test error gave the conclusion: write floating-point data into bitstring data successfully, but it will cause error and the returned reason code is incorrect.

C. Control Service

Control service is used to verify the DUT's Control model. Its basic test-cases include 5 positive cases, 9 negative cases and 22 additional cases. Appendix C shows the control service test when CTLmodel=4. The software platform attempted to send a $SBOw choice, and a $Oper implementation. Then change a bool date from F state to T state remotely. After that, the software read control report to obtain control result and make judgement according to the result.

D. Setting Service

Setting service is used to verify the DUT's setting group control model. Its basic test-cases include 4 positive cases and 4 negative cases. Appendix D shows the setting service test. Because there were 30 setting groups in the DUT used here, the result display interface was too long. So only the test results were attached. The software automatically read the path and number of custom areas and conducted the test. Test conclusion was drawn according to the results. There is no need of manual intervention in the whole testing process.

VII. Conclusions

This paper summarized the deficiencies of commonly used IEC 61850 conformance testing system in smart substation. A close-loop conformance testing system of IEC 61850 was proposed. Both software platform and hardware platform were designed, besides, the close-loop conformance testing methods were also given.

Aiming at the requirement of IED's conformance test in smart substation, the proposed conformance testing system could obtain test results automatically and no manual intervention was needed during the test process.

Both efficiency and quality of test were improved significantly. The test-cases of the conformance testing system covered all the services in IEC 61850 standard and domestic important technical specification. Users can also design and add custom test-cases. The proposed conformance testing system established technical foundation of the extension for domestic conformance test.

APPENDIX A: TEST OF CONNECTING SERVICE

```
=========== 01 ASS-Ed2 结束 ===========

########### 01 ASS ###########
< TestCase_Ass1 >
TestCase_Ass1
客户端请求建立连接、客户端请求释放连接
开始时间：06-30 15:42:25
***************
当前执行次数：1
连接装置ip:198.120.0.32 连接实例:1
连接建立成功

断开装置ip:198.120.0.32 断开实例:1
连接断开成功当前执行次数：2
连接装置ip:198.120.0.32 连接实例:1
连接建立成功

断开装置ip:198.120.0.32 断开实例:1
连接断开成功
当前执行次数：3
连接装置ip:198.120.0.32 连接实例:1
连接建立成功

断开装置ip:198.120.0.32 断开实例:1
连接断开成功
当前执行次数：4
连接装置ip:198.120.0.32 连接实例:1
连接建立成功

断开装置ip:198.120.0.32 断开实例:1
连接断开成功
当前执行次数：5
连接装置ip:198.120.0.32 连接实例:1
连接建立成功

断开装置ip:198.120.0.32 断开实例:1
连接断开成功
结束时间：06-30 15:42:56
返回值 1！
=========== 01 ASS 结束 ===========
```

APPENDIX B: TEST OF DATA SERVICE

```
########### 02 SRV ###########
< TestCase_SrvN3 >
TestCase_SPS_SrvN3
客户端对一个数据对象使用SetDataValues服务
写入一个不同的类型数值
开始时间：06-30 16:30:40
***************
连接装置ip:198.120.0.32 连接实例:1
连接建立成功

整型数据内无法写入浮点型数据
检测返回原因
    原因序号：3
    实际原因：object-access-denied
    应当原因：object-non-existent
返回错误原因码不正确！

bool数据内不能写入浮点型数据
检测返回原因
    原因序号：2
    实际原因：tem-anavail
    应当原因：object-non-existent
返回错误原因码不正确！

err：能向bitstring数据内写入浮点类数据，
但会造成写入出错

结束时间：06-30 16:30:40
返回值 0！
=========== 02 SRV 结束 ===========
```

APPENDIX C: TEST OF CONTROL SERVICE

```
########### 10 Ctl ###########
< TestCase_Ctl1_SB0es >
TestCase_Ctl1_SB0es
开始时间：06-30 16:47:55
***************
远控投入成功
连接装置ip:198.120.0.32 连接实例:1
连接建立成功

控制对象：PL2202PR0T/LLN0$C0$LEDRs$0per
控制对象：PL2202PR0T/LLN0$C0$FuncEnal$SB0w
控制对象：PL2202PR0T/LLN0$C0$FuncEnal$0per

***ctlModel=4下的控制测试***
数据类型:Bool
初始状态:F    控制目标:T
遥控选择成功！
遥控执行成功！
ctlModel=4，读取到的遥控报告个数：1
InformationReport_numbers：1
LLN0$C0$FuncEnal$0per
 Object Name: PL2202PR0T/LLN0$C0$FuncEnal$0per
AccessResults:
        CtlVal：1
        Origin：
            0rCat：1
            0rIdent：33
        Ctrl_num：3
 Utctime：2012-07-06 16:43:18 000
  Timequality：00
        Test：0
        Check：00
控制结束状态:T
ctlModel=4,先发送控制对象$SB0w选择，
再发送控制对象$0per执行，控制成功

结束时间：06-30 16:48:00
返回值 1！
=========== 10 Ctl 结束 ===========
```

APPENDIX D TEST OF SETTING GROUP SERVICE

```
PL2202PR0T/PT0C5$SG$StrVal的实际值为：0.60
PL2202PR0T/PT0C5$SG$0pDlTmms的实际值为：300
PL2202PR0T/PT0C6$SG$StrVal的实际值为：0.40
PL2202PR0T/PT0C6$SG$0pDlTmms的实际值为：2000
PL2202PR0T/PT0C9$SG$StrVal的实际值为：0.50
PL2202PR0T/RREC1$SG$SPRecTmms的实际值为：800
PL2202PR0T/RREC1$SG$TPRecTmms的实际值为：800
PL2202PR0T/RREC1$SG$RecDifAng的实际值为：30.00
PL2202PR0T/PDIF1$SG$CTBrkVal的实际值为：1.00
```

PL2202PR0T/PDIS11SGStrVal的实际值为：5.00
PL2202PR0T/PDIS1SGK0Fact的实际值为：0.66
PL2202PR0T/PDIS1SGAng0fsPG的实际值为：0.00
PL2202PR0T/PDIS1SGAng0fsPP的实际值为：0.00
PL2202PR0T/PRSB1SGBlkValASG的实际值为：30.00
PL2202PR0T/PDIF1SGEnable的实际值为：1
PL2202PR0T/PDIF2SGEnable的实际值为：1
PL2202PR0T/PDIF1SGCTBlkEna的实际值为：0
PL2202PR0T/PSCH1SGIntClkMod的实际值为：1
PL2202PR0T/PSCH4SGIntClkMod的实际值为：1

PL2202PR0T/TVTR1SGLinTVMod的实际值为：1
PL2202PR0T/RPSB1SGEnable的实际值为：1
PL2202PR0T/PDIS1SGEnable的实际值为：1
PL2202PR0T/PDIS2SGEnable的实际值为：1
PL2202PR0T/PDIS3SGEnable的实际值为：1
PL2202PR0T/PT0C9SGEnable的实际值为：1
PL2202PR0T/PT0C6SGDirEna的实际值为：1
PL2202PR0T/PTRC5SGTPTrModB的实际值为：0
PL2202PR0T/PT0C5SGBlkRecEna的实际值为：1
PL2202PR0T/PTRC5SGMPFBlkRec的实际值为：1
PL2202PR0T/RREC1SGRecChkSyn的实际值为：0
PL2202PR0T/RREC1SGRecChkDea的实际值为：0
PL2202PR0T/RREC1SGSPRecMod的实际值为：1
PL2202PR0T/RREC1SGTPRecMod的实际值为：0
PL2202PR0T/RREC1SGInhRec的实际值为：0
PL2202PR0T/RREC1SGStopRec的实际值为：0
PL2202PR0T/RREC1SG0pnStrSPR的实际值为：1
PL2202PR0T/RREC1SG0pnStrTPR的实际值为：0
PL2202PR0T/PDIF1SGCCCEna的实际值为：0
PL2202PR0T/PSCH7SGStrEnaRT的实际值为：1
PL2202PR0T/PDIS11SGEnable的实际值为：1
PL2202PR0T/PDIS1SGRisLodEna的实际值为：1
PL2202PR0T/PDIS2SGSpdupEna的实际值为：1
PL2202PR0T/PDIS3SGSpdupEna的实际值为：1
PL2202PR0T/PDIS12SGAccRTrpEna的实际值为：0
结束时间：06-29 16:48:35
返回值 1！
========== 05 SG 结束 ==========

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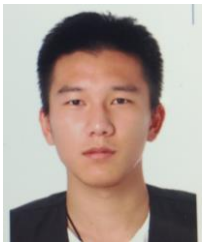

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