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Universal High-potential Testing System for AC/DC Power Supplies in Automated Manufacturing Environments

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Amid declining birth rates and a global labor shortage, automated electrical testing has become essential for industrial development. However, many factories face technological lock-in due to long-term reliance on a single vendor's automation systems, resulting in high sunk costs and significant challenges when upgrading or switching platforms. In this paper, we propose a universal automated high-potential test system (UHPTS) designed to operate seamlessly across multiple instrument brands. The system unifies communication protocols by mapping instrument commands to standardized labels and retrieving the required instructions from a centralized database, in accordance with the selected test environment. This architecture enables cross-platform interoperability within a single testing framework. The UHPTS can also be integrated with the manufacturing execution system (MES), allowing automatic parameter loading via product barcodes and supporting fully automated, operator-independent testing. Experimental results verify that the proposed system reduces operational complexity, eliminates vendor lock-in, minimizes human error, and enhances testing efficiency and reliability. Overall, the UHPTS offers a scalable and practical solution for modernizing withstand-voltage testing in power supply manufacturing.

1. Introduction

As birth rates decline and the global labor shortage worsens, companies face increasingly serious challenges in recruiting talent. Low margins and high volumes characterize the electronics industry, while competition in the energy components market is even fiercer. To address the current revenue shortfall, it is necessary to improve product quality, production efficiency, and yield so that customers are willing to pay more for higher-quality products. Under the conditions of human resource shortages, introducing automated machines to reduce personnel workload and automate energy component testing can not only lower workforce and production costs but also enhance product quality, thereby indirectly increasing the company's revenue. Early power supplies were linear, valued for their simple design and low electromagnetic interference. Their main components were transformers and rectifiers, but they exhibited low

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power density and efficiency. It was not until 1970 that the Dutch scientist N. R. M. Rao developed a pulse-width modulation (PWM) power converter, which used PWM to control the power switch and produce a step-up or step-down output voltage.(1–3) This innovation paved the way for today's switching-mode power supplies. Although PWM technology enables the precise control of output voltage and current, it can cause interference with other devices within the system. PWM employs high-speed switching, allowing for rapid changes in voltage or current, which in turn generates additional harmonic components in inductive elements such as transmission lines, cables, and windings.(4) Therefore, in circuit design, it is essential to consider harmonics suppression and measures to prevent interference with other devices.(5)

In addition to harmonic interference, electromagnetic interference (EMI) is also becoming increasingly severe. As printed circuit board technology has matured, it has progressed from single-layer to double-layer, and more recently, to multilayer, printing. More electronic components can be packed into the same unit area, thanks to technological advancements. However, the components may interfere with each other, causing the parts to malfunction.(6) Alternatively, EMI from the power supplies of the different electronic devices may be the cause. The easiest way to reduce EMI is to enclose the power supply in a metal shell. However, doing so may pose a risk of electric shock, so any exposed metal must be physically isolated from the high-voltage part.(7) In this case, a voltage withstand test is required to ensure that the metal and the high-voltage part have sufficient insulation strength to prevent voltage breakdown.

When discussing the withstand high-potential (Hi-Pot) test, it is also essential to address the series of test procedures performed on the power supply before factory release. After the power supply is assembled, it must undergo an aging test, also known as a heat test or burn-in test. The primary purpose of aging tests is to identify defective products in advance by simulating actual usage conditions, as most electrical component failures occur during the early stages of use and at the end of the warranty period.(8) By simulating actual use, defective electronic components can be identified early. Additionally, since the test simulates actual use, a significant amount of power will be consumed. Therefore, many people have studied energy-saving or recyclable loads that store electrical energy initially dissipated as heat in batteries or that connect to the company's power grid for recycling.(9,10) After the initial elimination of defective products, basic electrical characteristics testing will be carried out. In practice, it is referred to as a comprehensive test or an instrument test platform using an automatic test equipment (ATE) or automatic test system (ATS).(11) It includes power factor testing, no-load efficiency, full-load efficiency, and other relevant measurements. In addition to electrical characteristics, short-circuit protection, overvoltage protection, and other parameters are tested. Although circuit feasibility is verified through simulation software during design, all products must undergo actual testing before delivery to customers to prevent defective products from being shipped.(12,13) The final step in the test is the withstand Hi-Pot test. The primary purpose of the withstand Hi-Pot test is to verify that the product's insulation capacity is sufficient in a high-voltage environment, ensuring that users are not at risk of electric shock in the event of an accident.

Previous studies on withstand testing for Hi-Pot tests have primarily focused on wires, motors, power-generation equipment, and similar devices.(14–17) However, beyond wires, motors, and power generation equipment, household appliances commonly found in daily life, such as ovens, refrigerators, and coffee machines, must also undergo voltage resistance testing because they come into contact with humans.(18) Electric vehicles also require such tests, as do the power supplies of medical devices.(19) In a hospital environment, leakage current can pose a risk to patients, especially in specialized areas such as operating rooms and intensive care units, where patients are under anesthesia and have diminished or absent defense mechanisms. If a 10 mA current passes directly through a patient's heart, it can cause an electric shock called a microshock. Therefore, strict electrical safety measures are required.(20) For a healthy person, a current of only 50 mA flowing through the heart can cause cardiac arrest. Therefore, the insulation capacity of power supply products is crucial; better insulation reduces leakage current during an incident.

As a fundamental component of electronic equipment, the safety and reliability of power products significantly impact the operation of the entire electronic system. When products are intended for the global market, compliance with the safety standards of various countries' regulations is required for power supply manufacturers. Because safety regulations for electronic and electrical products vary by country, manufacturers often need to ensure that their products comply with multiple regional safety standards before entering international markets. Common worldwide certification bodies and standards include Underwriters Laboratories (UL) and Federal Communications Commission (FCC) in the United States, Product Safety Electrical Appliance & Material (PSE) in Japan, Conformité Européenne (CE) in the European Union, and Bureau of Standards, Metrology, and Inspection (BSMI) in Taiwan. These certifications address product electrical safety, electromagnetic compatibility, energy efficiency, and market acceptance. To meet these certification standards, power supply products must undergo rigorous testing before shipment.

Major test categories include burn-in testing to identify early failures; output and input characteristic testing to assess voltage/current accuracy and tolerance to voltage, frequency, surge, and EMI; stability and transient performance evaluation; inspection of protection mechanisms (overvoltage, overcurrent, and short circuits); and Hi-Pot testing to confirm insulation robustness. Manual testing is inefficient and error-prone, particularly as product variety and production volume increase. Thus, most manufacturers adopt ATE, integrating instrument control, data acquisition, fault analysis, and automated reporting to enhance test consistency, production efficiency, and safety compliance while reducing labor dependence. However, as test systems age, manufacturers may face technology lockdown issues from equipment suppliers, who may discontinue legacy support and impose costly upgrades. Because of hardware–software incompatibility, users are often required to reinstall equipment, rewrite test scripts, retrain personnel, and revalidate processes, resulting in high reinvestment costs and operational interruptions. In this paper, we examine withstand-voltage testing (also known as insulation-resistance testing) and propose a universal, automated withstand Hi-Pot test system that can operate across multiple instrument platforms. This system addresses incompatibility issues among test instruments and mitigates the current system's cumbersome operation and difficulty in interpreting test results. Furthermore, it reduces the inconvenience and operational errors that operators previously faced.

2. Problem Formulation

The following is the current standard operating procedure (SOP) for Company S's power-supply withstand-voltage testing. (1) The operator sets the corresponding test specifications in the instrument according to the instructions on the process card; (2) the product is connected to the instrument's test leads; (3) the product barcode is scanned, and then the test program initiates the test; (4) after the test is complete, the results are stored on the local computer; (5) the product is removed, and the process returns to step 2 to test the following product; (6) the next day, all product test data from the previous day are transferred via USB drive to the engineer's computer for further product analysis or customer reference.

This test procedure has several problems, as outlined below. (1) The information on the process card is manually copied from the web page by technicians, which is prone to errors or unclear handwriting; (2) operators may select the wrong test specifications, affecting test accuracy; (3) the current detection program cannot determine whether the product has been correctly connected to the test lead. Suppose the operator scans the product barcode and starts the test before the test line is connected. In that case, it may not only cause personal safety risks such as electric shock but also make the instrument produce incorrect test results, impacting the accuracy of product quality assessment; (4) test data is not uploaded promptly, causing relevant personnel to be unable to obtain product test results immediately. All these issues will directly or indirectly affect production yield, especially when the company faces pressure to meet orders. During the peak season, several batches of different products must be produced daily, significantly increasing the likelihood of problems.

Because of the above issues, we aim to optimize and refine the power supply withstand Hi-Pot test process to enhance accuracy, safety, and the timely dissemination of information. An automated testing program will be developed to support multiple instrument brands, thereby reducing the company's dependence on a single equipment supplier. In the future, when an instrument malfunctions, companies can flexibly procure the appropriate equipment on the basis of their actual needs, without incurring conversion costs or downtime associated with replacing instruments and test software. At the same time, this design reduces manual work, lowers the learning threshold for operators, improves overall production efficiency, and automatically uploads test data to the database for instant querying and subsequent analysis. To address the safety concern, a new "product positioning confirmation" function is expected to be added. Even if the barcode is scanned first, the system will not start the test until the product has reached the positioning checkpoint. The test will only start after confirming that the product has been correctly positioned, thereby ensuring personnel safety during the operation. To improve timeliness and information traceability, the proposed test system automatically uploads test results to the database upon completion of the inspection. It simultaneously reports the product's test results to the integrated manufacturing execution system (MES). This not only allows quality control personnel to conduct real-time queries and analysis but also helps production managers monitor manufacturing progress, thereby improving overall production efficiency and quality control. In addition, this universal withstand Hi-Pot test system provides a reserved Hypertext Transfer Protocol (HTTP) network interface to facilitate future data exchange or integration with other systems. This enables the control of product loading and unloading through fixed-format communication commands. Once the test is complete, the universal automated high-potential test system (UHPTS) communicates with the central control system, which then controls the product's loading and unloading.

3. Design of Universal Withstand Hi-Pot Test

Figure 1 shows the experimental architecture diagrams for the proposed Hi-Pot test system. The overall system is controlled by a computer connected to the Hi-Pot test instrument via an RS-232 interface to execute test commands and receive test results. At the same time, via the RS-485 communication interface and the remote I/O device connection, the digital input (DI) contact status reading and digital output (DO) contact switch control functions can be implemented. The device functions are described below. (1) The computer can control the withstand Hi-Pot instrument and the remote DI/DO device, and read their test results and device status. When the computer receives the product barcode and the product is correctly positioned, it activates the instrument to initiate the test. After the test is completed, the results are uploaded to the company database. (2) The remote DI/DO receives the short-circuit signal of the positioning checkpoint and controls the status of the three-color light. The computer will query the remote DI/DO for the contact status via Modbus communication and will not proceed to the next step until the positioning checkpoint is short-circuited. Additionally, the computer will control the remote DO output contact via Modbus to regulate the three-color light's status. (3) The three-color light displays the current operating status of the system. The yellow light indicates standby, the green light indicates operation, and the red light indicates system abnormality. (4) The withstand Hi-Pot instrument can perform withstand Hi-Pot, insulation resistance, ground resistance, and other tests on motors and electronic equipment. It can send commands to control the instrument via RS232 and return the current test results. (5) The object under test can be a power supply, any motor equipment, or electronic parts.

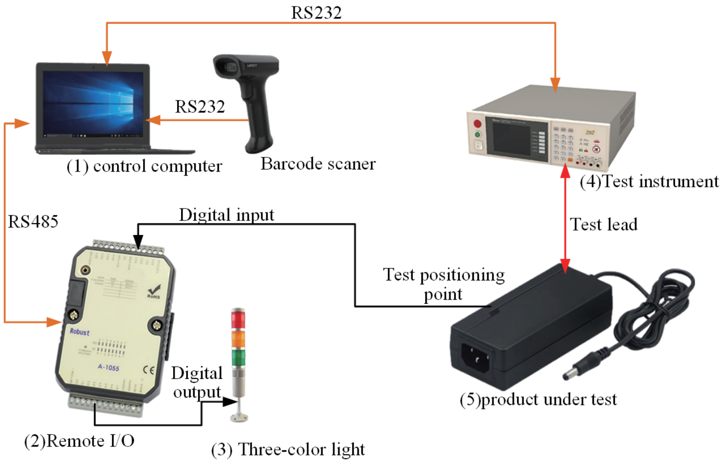


Fig. 1. (Color online) Experimental architecture.

Figure 2 illustrates the planned test process for this program, which is aimed at addressing existing issues and enhancing production efficiency. Several main problems in the original process have been effectively addressed in this optimized version. The proposed testing method offers several advantages, as outlined below. (1) There is no need for personnel to manually select the test method and input the parameter data according to the process card. Instead, the program scans the barcode to retrieve the appropriate test method and parameter data automatically, then sends this information to the instrument. (2) The system now includes a positioning checkpoint detection function to ensure the product has been placed correctly, reducing test failure caused by wiring issues or electric shocks. (3) Test results are automatically uploaded to the database, removing the need for on-site personnel to transfer the data. Managers can directly query the database and retrieve results, eliminating multiple layers of data transfer, thereby reducing response times and improving service quality. The proposed design is explained below.

3.1 Test the object connected to the test lead

Depending on the product, different test leads or fixtures are used to conduct the Hi-Pot test, as shown in Fig. 3. Open-frame products are typically tested with acrylic fixtures and probes. Products with a case will be directly connected to the test lead for testing.

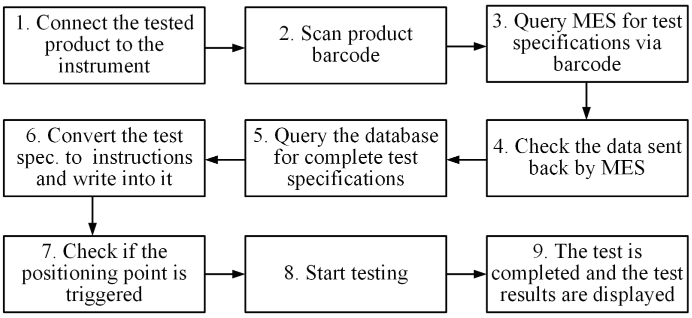


Fig. 2. Flowchart of the proposed testing method.

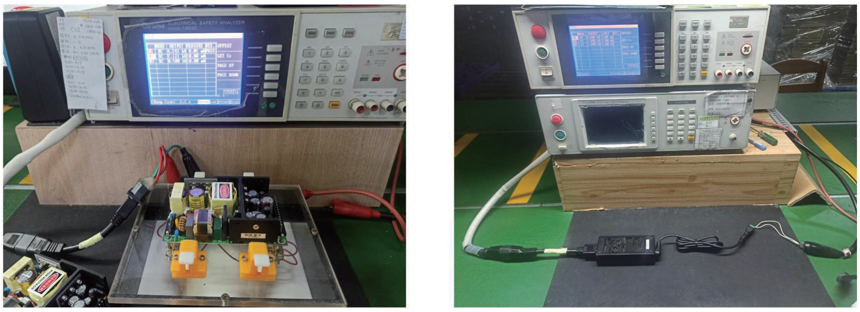

(a) (b)

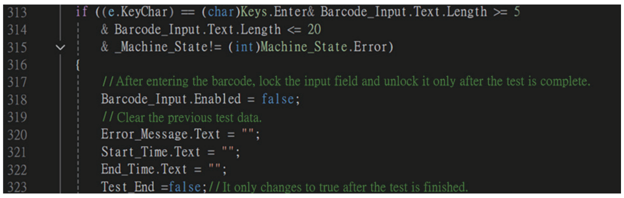
Fig. 3. (Color online) Actual product wiring for testing: (a) open frame product and (b) product with a case.

3.2 Scan the product barcode

Figure 4 shows a program for scanning product barcodes. Lines 313–315 are for first determining whether the user pressed Enter, then verifying that the barcode was read correctly. The standard barcode character count is within 10–20 characters. If the barcode meets the conditions without errors, the next step is enacted. If the system is in Error mode, the human–machine interface (HMI) will display the error code and instructions. Note that lines 318–323 specify the most recent test results to prevent incorrect results from being displayed on the screen.

3.3 Get test specifications

When the program asks the MES which test specification applies to the barcode, the MES first locates the "manufacturing order" associated with the barcode, then returns the test specification to the program based on the test site. This procedure is shown in Fig. 5. Figure 6 shows the product information query program. Lines 1618–1622 are the instructions for establishing API communication. The previous procedure obtained the product barcode, which will be entered into the instruction here. Line 1621 transmits the relevant data to MES through the API_get method. Then, MES will return the appropriate product information.



```
313  if ((e.KeyChar) == (char)Keys.Enter& Barcode_Input.Text.Length >= 5
314      & Barcode_Input.Text.Length <= 20
315      & _Machine_State!= (int)Machine_State.Error)
316  {
317      //After entering the barcode, lock the input field and unlock it only after the test is complete.
318      Barcode_Input.Enabled = false;
319      // Clear the previous test data.
320      Error_Message.Text = "";
321      Start_Time.Text = "";
322      End_Time.Text = "";
323      Test_End =false;//It only changes to true after the test is finished.
```

Fig. 4. (Color online) Barcode detection program

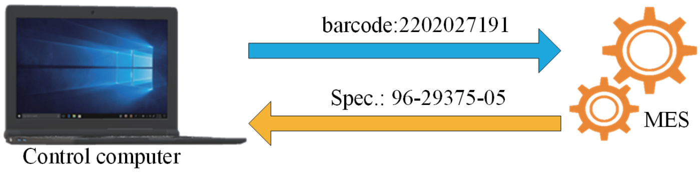
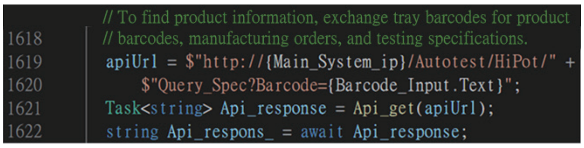


Fig. 5. (Color online) Procedure for the system to get the testing specification for this product.



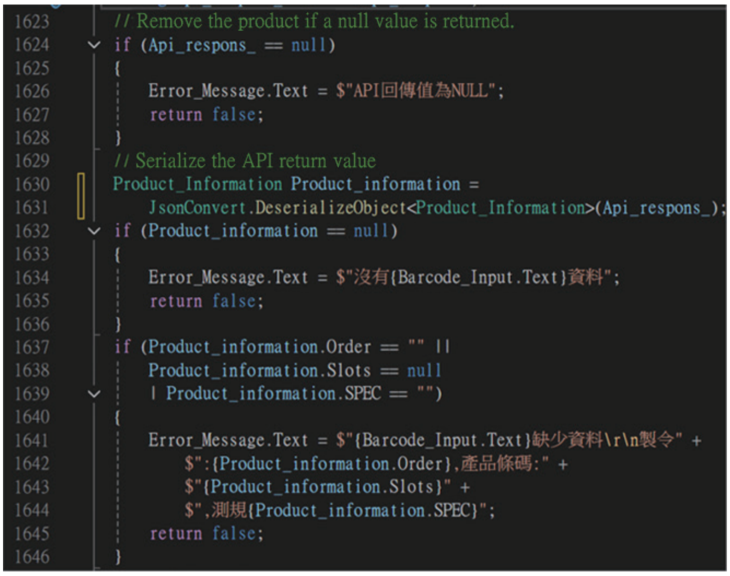
```
      // To find product information, exchange tray barcodes for product
1618  // barcodes, manufacturing orders, and testing specifications.
1619  apiUrl = $"http://{Main_System_ip}/Autotest/HiPot/" +
1620      $"Query_Spec?Barcode={Barcode_Input.Text}";
1621  Task<string> Api_response = Api_get(apiUrl);
1622  string Api_respons_ = await Api_response;
```

Fig. 6. (Color online) Query for the testing specification using the barcode.

Figure 7 illustrates the process for correctly obtaining the testing specification. Unexpected situations, such as packet loss or the MES system failing to locate the data, are inevitable during the communication process. Therefore, when receiving return data from the MES, we must first verify its accuracy and ensure that subsequent program execution is error-free. The program will proceed only if the return value from MES matches the planned return value; otherwise, it will terminate. This will avoid program errors caused by communication problems. Program lines 1624–1628 are used to check for a return value. If the return value is null, the system program displays an error message and the API function exits. Lines 1630–1631 use the JsonConvert. DeserializeObject < T> package to deserialize JSON objects. The serialized format is defined by the class within < >, then populated into the corresponding variables. Lines 1632–1646 check whether each variable has a value. If no value is provided, an error message will be displayed, along with the corresponding action.

3.4 Obtain the full set of test specifications from the database system

In the previous step, we obtained only the test specification name, which is insufficient to generate test data that the instrument can process directly. After receiving the specification name, it is necessary to retrieve its detailed content from the database before converting it into a specific instrument command for actual testing. Before executing the process, the program will first retrieve the latest version number and then use it to query the complete test specification. Figure 8 shows the test specification data query program. Lines 499 to 525 are responsible for querying the latest version of the test specification. Structured query language (SQL) commands are used to sort by edit date as well as to obtain the newest test version number, and then the



```
1623  // Remove the product if a null value is returned.
1624  if (Api_respons_ == null)
1625  {
1626      Error_Message.Text = $"API回傳值為NULL";
1627      return false;
1628  }
1629  // Serialize the API return value
1630  Product_Information Product_information =
1631      JsonConvert.DeserializeObject<Product_Information>(Api_respons_);
1632  if (Product_information == null)
1633  {
1634      Error_Message.Text = $"沒有{Barcode_Input.Text}資料";
1635      return false;
1636  }
1637  if (Product_information.Order == "" ||
1638      Product_information.Slots == null
1639      | Product_information.SPEC == "")
1640  {
1641      Error_Message.Text = $"{Barcode_Input.Text}缺少資料\r\n製令" +
1642          $":{Product_information.Order},產品條碼:" +
1643          $"{Product_information.Slots}" +
1644          $",測規{Product_information.SPEC}";
1645      return false;
1646  }
```

Fig. 7. (Color online) Obtaining the return serialization format from MES.

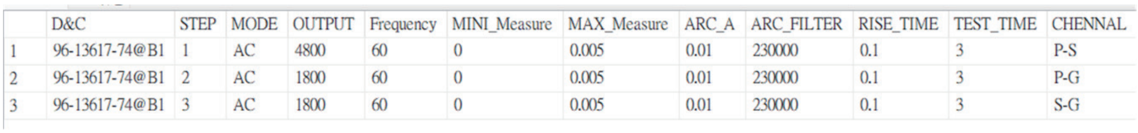
```
498  // Search the latest test specification version number
499  string sqlQuery = $"SELECT  TOP (1) [D&C] FROM " +
500      $"HIPOT_TEST_SPECIFICATION_TITLE WHERE " +
501      $"[D&C] LIKE  '{SPEC_Serial_Number}%' ORDER BY  EDIT_DATE desc";
502  using (SqlConnection connection =
503      new SqlConnection(Main_Menu.SQL_CONNECTION_STRING)){
504      try{
505          connection.Open();
506          using (SqlCommand command =
507              new SqlCommand(sqlQuery, connection)){
508              // Execute the query and retrieve the latest results.
509              SqlDataReader reader = command.ExecuteReader();
510              if (reader.Read()){ // If there are results
511                  result = reader["D&C"].ToString();// Read the values from the
512                  Spec_Number = result;             // [D & C] fields
513              }
514              else{
515                  Error_Message.Text = $"查無{SPEC_Serial_Number}的資料";
516                  return -1;
517              }
518              reader.Close();
519          }
520      }
521      catch (Exception ex){
522          //Error handling
523          MessageBox.Show(ex.Message, "查詢錯誤",
524              MessageBoxButtons.OK, MessageBoxIcon.Error);
525      }
526  }
527  // Query test specification content
528  sqlQuery = $"SELECT STEP,MODE,OUTPUT,Frequency,MINI_Measure" +
529      $",MAX_Measure,ARC_A,ARC_FILTER,RISE_TIME,TEST_TIME,CHENNAL," +
530      $"PA_TIME FROM HIPOT_TEST_SPECIFICATION WHERE [D&C] LIKE '{result}%'";
531  // Query content from the database
532  SqlDataAdapter da =
533      new SqlDataAdapter(sqlQuery, Main_Menu.SQL_CONNECTION_STRING);
534  SPEC_SQLData.Clear();
535  da.Fill(SPEC_SQLData);//Insert the STEP data into SPEC_Data(Datatable).
```

Fig. 8. (Color online) Query for the latest version number and content of the test specification.

query results are stored in the variable ‘result’. If no data is found, the query function will terminate. Next, lines 528 to 535 execute another SQL query using the previously obtained test version number to retrieve the complete test content and populate the SPEC_SQLData object for subsequent use. When the query is completed, the program creates a table to store the testing specification contents, as shown in Fig. 9. The table fields are described in Table 1. Items 1 and 2 constitute the primary key of the entire specification. Its function is similar to that of an ID number, providing a unique identifier for each specification. Items 3 to 13 are the relevant parameter values for each test item. Engineers will fill in these parameters in accordance with the test specifications and upload them to the database. This design ensures that the test specifications across all test stations are consistent, thereby improving data management accuracy and operational efficiency.

3.5 Convert the test specification and write the command into the instrument

Even after obtaining the testing specification, it cannot be entered directly into the instrument. The specification content must be converted into instruction sets before it can be written into the instrument. If it is a test program for a specific instrument model, the instructions are already hard-coded in the instrument. You only need to enter or write the parameters directly into the instrument. However, to make this program usable across different instrument platforms, the instrument commands are stored in a database. The commands for



	D&C	STEP	MODE	OUTPUT	Frequency	MINI_Measure	MAX_Measure	ARC_A	ARC_FILTER	RISE_TIME	TEST_TIME	CHENNAL
1	96-13617-74@B1	1	AC	4800	60	0	0.005	0.01	230000	0.1	3	P-S
2	96-13617-74@B1	2	AC	1800	60	0	0.005	0.01	230000	0.1	3	P-G
3	96-13617-74@B1	3	AC	1800	60	0	0.005	0.01	230000	0.1	3	S-G

Fig. 9. Complete content of test specification.

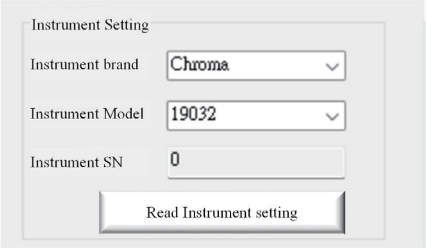
Table 1
Description of each field in Fig. 8.

Item	Field name	Description
1	D&C	Specific number and version (Primary key)
2	STEP	Test steps (Primary key)
3	MODE	Test mode
4	OUTPUT	Test voltage
5	Frequency	Frequency
6	MINI_MEASURE	Minimum measurement value
7	MAX_MEASURE	Maximum measured value
8	ARC_A	Test arc current
9	ARC_FILTER	Arc current bandwidth
10	RISE_TIME	Voltage rise time
11	TEST_TIME	Testing time
12	CHANNEL	Test channel
13	PA_TIME	Standing time

other models are selected in accordance with the instrument settings. After finding the corresponding command in the database, the parameters are entered into the command and then written into the instrument. Before the test begins, the user must set the instrument brand and model on the test platform, as shown in Fig. 10. Figure 11 illustrates the partial program for querying the instrument's test command. Note that lines 697 to 703 incorporate the instrument's brand, model, mode, and item information into the SQL query statement and use this information as a condition to retrieve the corresponding instrument instructions from the database. Next, Fig. 12 illustrates the partial program for writing each command into the instrument. Figure 13 shows the final results after all testing commands have been written into the instrument.

3.6 Complete the testing procedure in accordance with the trigger

When all instructions are written into the instrument, the program will be ready to start testing. However, before testing, the program first checks whether the positioning point is closed, as shown in Fig. 14. Testing can begin only when the positioning point is closed. This procedure is essential to ensure that the product has reached the positioning point before the test starts. This may protect operators from safety risks such as electric shock. Additionally, this prevents the instrument from producing erroneous test results, thereby affecting the accuracy of product quality judgments. After completing the above steps, the program, as shown in Fig. 15,



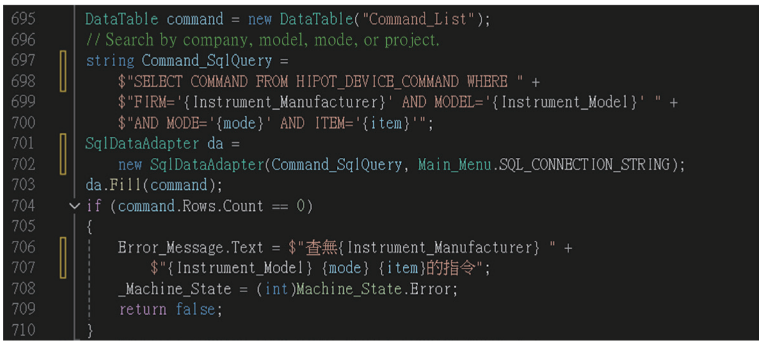
Instrument Setting

Instrument brand: Chroma

Instrument Model: 19032

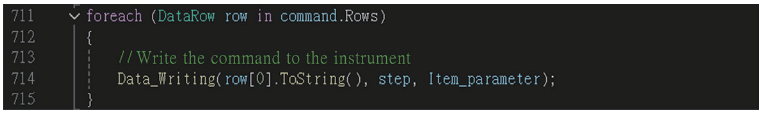
Instrument SN: 0

Fig. 10. Setting up the testing instrument.



```
DataTable command = new DataTable("Command_List");
// Search by company, model, mode, or project.
string Command_SqlQuery =
    $"SELECT COMMAND FROM HIPOT_DEVICE_COMMAND WHERE " +
    $"FIRM='{Instrument_Manufacturer}' AND MODEL='{Instrument_Model}' " +
    $"AND MODE='{mode}' AND ITEM='{item}'";
SqlDataAdapter da =
    new SqlDataAdapter(Command_SqlQuery, Main_Menu.SQL_CONNECTION_STRING);
da.Fill(command);
if (command.Rows.Count == 0)
{
    Error_Message.Text = $"查無{Instrument_Manufacturer} " +
        $"{Instrument_Model} {mode} {item}的指令";
    _Machine_State = (int)Machine_State.Error;
    return false;
}
```

Fig. 11. (Color online) Program for querying the instrument command.



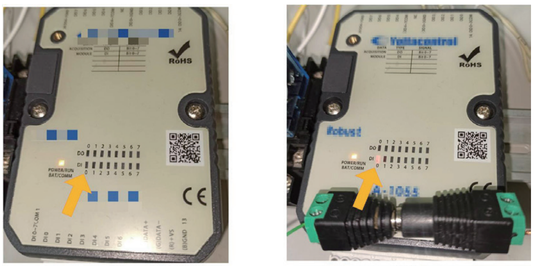
```
foreach (DataRow row in command.Rows)
{
    // Write the command to the instrument
    Data_Writing(row[0].ToString(), step, Item_parameter);
}
```

Fig. 12. (Color online) Partial program for writing each command into the instrument.

TEST

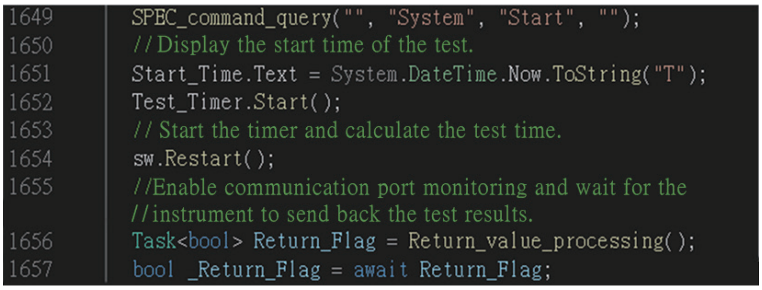
	MODE	SOURCE	LIMIT	RES.
01	AC	4.800 kV	5.00 mA	
02	AC	1.800 kV	5.00 mA	
03	AC	1.800 kV	5.00 mA	

Fig. 13. (Color online) Final testing setting in the instrument.



(a) (b)

Fig. 14. (Color online) Positioning checkpoint status indication: (a) testing product is not in position and (b) testing product is in position.



```
1649    SPEC_command_query("", "System", "Start", "");
1650    //Display the start time of the test.
1651    Start_Time.Text = System.DateTime.Now.ToString("T");
1652    Test_Timer.Start();
1653    // Start the timer and calculate the test time.
1654    sw.Restart();
1655    //Enable communication port monitoring and wait for the
        //instrument to send back the test results.
1656    Task<bool> Return_Flag = Return_value_processing();
1657    bool _Return_Flag = await Return_Flag;
```

Fig. 15. (Color online) Send the start test command.

will send a start-test command, and the instrument will begin testing. Line 1649 sends the start-test command; lines 1651–1654 calculate the test time; and lines 1656–1657 are instructions to start the monitoring thread and wait for the instrument to return the test results. After the test is complete, the program, as shown in Fig. 16, will upload the current test results to the database for easy access. In addition, Line 1124 will write the test results into a local text file if the database connection fails. The position-check mechanism is used solely to determine whether the testing process should begin. False triggering should therefore be prevented at the hardware level of the position-check system to prevent unintended activation.

4. Experimental Results

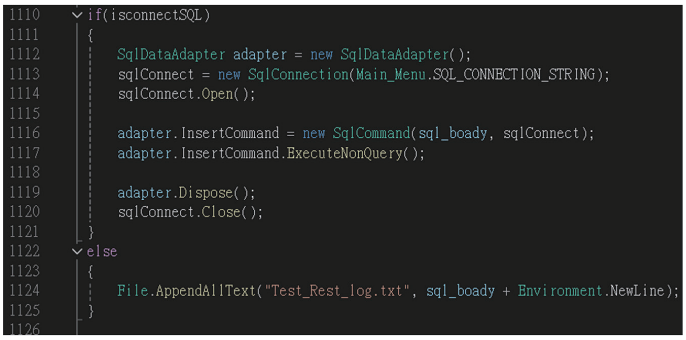
Figure 17 shows the practical architecture of the proposed UHPTS for AC/DC power supplies in automated manufacturing environments. Experimental testing will be carried out as follows.

4.1 UHPTS and Chroma 19032

Figure 18 illustrates the instrument settings, including the communication port and remote digital input and output devices. It is worth noting that the settings are based on the selected method, which can reduce input errors. Once all previous steps are complete, the program will begin testing by scanning the barcode. No human intervention is required during the process, as shown in Fig. 19. After the test is completed, the current test results and measurement values will be displayed on the HMI. Figure 20 shows the actual test process. The total test time is 12 s, and the test result is PASS. Figure 21 shows that the instrument's test results are consistent with those displayed by the HMI.

4.2 Experimental results and discussion

Table 2 shows the results of the original and the UHPTS. Note that the testing specifications have been changed 10 times. The data clearly shows that after using the UHPTS, the time required for operators to change specifications was significantly reduced, demonstrating the



```
if(isconnectSQL)
{
    SqlDataAdapter adapter = new SqlDataAdapter();
    sqlConnect = new SqlConnection(Main_Menu.SQL_CONNECTION_STRING);
    sqlConnect.Open();

    adapter.InsertCommand = new SqlCommand(sql_boady, sqlConnect);
    adapter.InsertCommand.ExecuteNonQuery();

    adapter.Dispose();
    sqlConnect.Close();
}
else
{
    File.AppendAllText("Test_Rest_log.txt", sql_boady + Environment.NewLine);
}
```

Fig. 16. (Color online) Upload test data to the database.

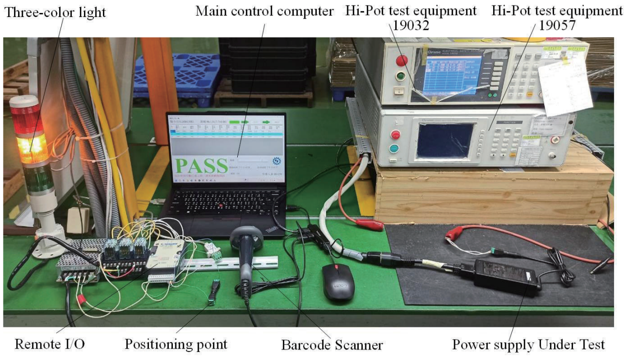
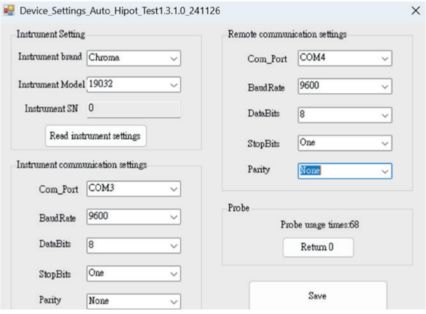


Fig. 17. (Color online) Practical architecture of the UHPTS.



Device_Settings_Auto_Hipot_Test1.3.1.0_241126

Instrument Setting

Instrument brand: Chroma
Instrument Model: 19032
Instrument SN: 0

Instrument communication settings

Com_Port: COM3
BaudRate: 9600
DataBits: 8
StopBits: One
Parity: None

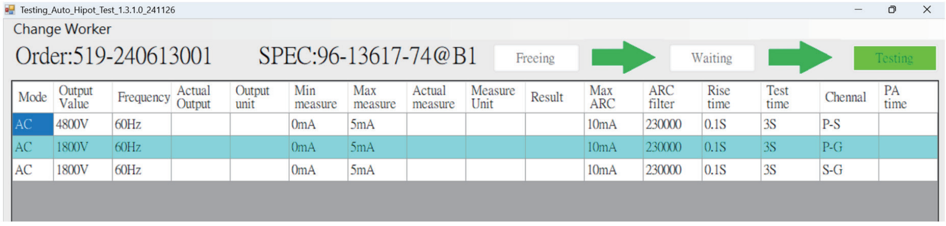
Remote communication settings

Com_Port: COM4
BaudRate: 9600
DataBits: 8
StopBits: One
Parity: None

Probe

Probe usage times:68

Fig. 18. (Color online) Instruments and communication settings in the UHPTS.



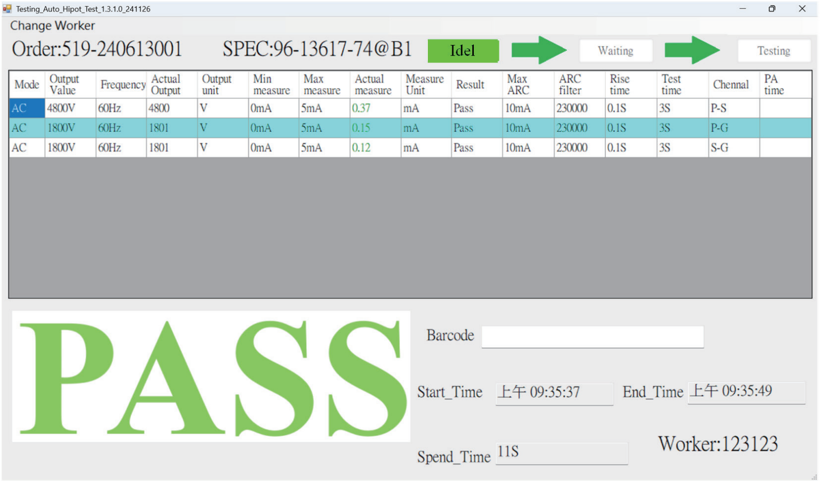
Testing_Auto_Hipot_Test_1.3.1.0_241126

Change Worker

Order:519-240613001 SPEC:96-13617-74@B1

Mode	Output Value	Frequency	Actual Output	Output unit	Min measure	Max measure	Actual measure	Measure Unit	Result	Max ARC	ARC filter	Rise time	Test time	Chennal	PA time
AC	4800V	60Hz			0mA	5mA				10mA	230000	0.1S	3S	P-S	
AC	1800V	60Hz			0mA	5mA				10mA	230000	0.1S	3S	P-G	
AC	1800V	60Hz			0mA	5mA				10mA	230000	0.1S	3S	S-G	

Fig. 19. (Color online) Screenshot of the UHPTS data during testing.



Order:519-240613001 SPEC:96-13617-74@B1

Mode	Output Value	Frequency	Actual Output	Output unit	Min measure	Max measure	Actual measure	Measure Unit	Result	Max ARC	ARC filter	Rise time	Test time	Chennal	PA time
AC	4800V	60Hz	4800	V	0mA	5mA	0.37	mA	Pass	10mA	230000	0.1S	3S	P-S	
AC	1800V	60Hz	1801	V	0mA	5mA	0.15	mA	Pass	10mA	230000	0.1S	3S	P-G	
AC	1800V	60Hz	1801	V	0mA	5mA	0.12	mA	Pass	10mA	230000	0.1S	3S	S-G	

Barcode

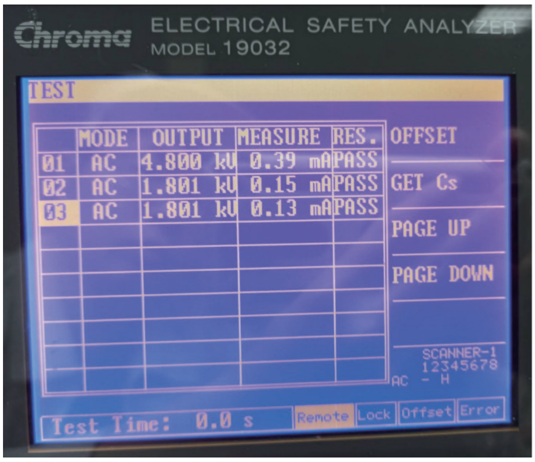
Start_Time 上午 09:35:37

End_Time 上午 09:35:49

Spend_Time 11S

Worker:123123

Fig. 20. (Color online) Final result output by the UHPTS.



	MODE	OUTPUT	MEASURE	RES.
01	AC	4.800 kV	0.39 mA	PASS
02	AC	1.801 kV	0.15 mA	PASS
03	AC	1.801 kV	0.13 mA	PASS

Fig. 21. (Color online) Test results in the instrument.

Table 2
Time required to change the specification in Chroma 19032.

Item	Original testing system (s)	UHPTS (s)	Instruction number (No.)
1	15	2	21
2	11	2	21
3	13	1	10
4	8	2	17
5	9	2	17
6	11	2	21
7	17	1	10
8	12	1	10
9	18	1	10
10	13	3	32

substantial benefits of this system in improving work efficiency. Since the traditional method requires manual specification replacement, the actual time required can vary significantly depending on factors such as the order of menu items and the operator's familiarity with the system. For example, in Table 2, the specification for the 4th test is listed earlier in the menu, allowing the operator to locate and load it quickly. In contrast, the specification for the 9th test is located in the middle of the menu, requiring the operator to browse through the options several times before finding the corresponding specification, thereby prolonging the operation time. Additionally, external factors such as fatigue and screen reflection may lead to the incorrect specification being selected.

5. Conclusions

We proposed a UHPTS for AC/DC power supplies in an automated manufacturing environment that supports multiple instrument brands. The use of traditional automated test software is typically limited to instruments of a specific brand or model. Once the instrument is damaged or discontinued, the software becomes ineffective, rendering the entire test system inoperable. However, the proposed universal architecture enables the control of instruments from different brands through a single software. Even if the equipment is replaced, there is no need to redevelop the test program, maintaining high scalability and sustainability. The proposed system, based on the database as its core, builds an instruction correspondence and management mechanism. It automatically queries the corresponding communication instruction template in accordance with the instrument brand. It dynamically fills in the required test parameters and sends them to the instrument, enabling cross-brand and cross-model instrument control.

Additionally, this system can be integrated with the MES, enabling relevant personnel to track the production progress and test status in real time. When an abnormality occurs during production, the system can provide immediate feedback, thereby helping to identify and resolve the problem. In the future, the MES system will also be able to query the historical records of the machine, including key data such as machine utilization rate, test yield rate of each site, and average test time, which will serve as an essential basis for optimizing the test process and improving production line efficiency. The research method proposed in this paper significantly enhances the system's flexibility and scalability. In the future, new instruments can be quickly integrated by simply updating the database. There is no need to modify the original code unless test results are affected, thereby significantly reducing maintenance costs and enhancing the application's practical value.

References

1 Y.-C. Chuang and Y.-L. Ke: IEEE Trans. Ind. Electron. **55** (2008) 3030. https://doi.org/10.1109/TIE.2008.921218
2 M. Brown: Power Supply Cookbook (Newnes, Oxford, 2001) 2nd ed., Chap. 3. https://doi.org/10.1016/B978-075067329-7/50004-0
3 B. G. Armăşelu and M. Frunzete: Proc. 2022 14th Int. Conf. Electronics, Computers and Artificial Intelligence (IEEE, 2022) 1–5. https://doi.org/10.1109/ECAI54874.2022.9847473
4 M. Jiang, H. H. Goh, J. Yi, S. Li, D. Zhang, and T. Wu: Energy Rep. **8** (2022) 332. https://doi.org/10.1016/j.egyr.2022.09.158E.

5 Bushra, K. Zeb, I. Ahmad, and M. Khalid: Results Eng. **22** (2024) 102213. https://doi.org/10.1016/j.rineng.2024.102213

6 S. Winder: Power Supplies for LED Driving (Newnes, London, 2017) 2nd ed. Chap. 13. https://doi.org/10.1016/B978-0-08-100925-3.00013-6

7 Y. Sha, W. Chen, Z. Zhao, F. Zhang, C. Pei, and Z. Chen: Proc. 2018 IEEE Applied Power Electronics Conf. and Exposition (APEC, 2018) 611–614. https://doi.org/10.1016/B978-0-12-386533-5.00016-4

8 M. Chen, G. Li, Y. Li, and L. Li: Proc. 2021 IEEE 4th Int. Electrical and Energy Conf. (CIEEC, 2021) 1–5. https://doi.org/10.1109/CIEEC50170.2021.9510735

9 H. Ma and Q. Guo: Proc. 2013 1st Int. Future Energy Electronics Conf. (IFEEC, 2013) 839–843. https://doi.org/10.1109/IFEEC.2013.6687618

10 P. Narayanan and V. P. Mini: Proc. 2014 Int. Conf. Advances in Green Energy (ICAGE, 2014) 204–209. https://doi.org/10.1109/ICAGE.2014.7050166

11 Keysight Technologies: https://www.keysight.com/tw/zh/assets/7122-1097/white-papers/Three-Ways-to-Boost-ATE-Power-Supply-Throughput.pdf (accessed April 2025).

12 A. M. Gole, A. Keri, C. Kwankpa, E. W. Gunther, H. W. Dommel, and I. Hassan: IEEE Trans. Power Del. **12** (1997) 505. https://doi.org/10.1109/61.568278

13 J. Hu and S. Gude: Proc. 2020 IEEE Energy Conversion Congr. and Exposition (ECCE, 2020) 2521–2528. https://doi.org/10.1109/ECCE44975.2020.9235752

14 B. K. Gupta, H. G. Sedding, G. C. Stone, and J. Stein: Proc. 2010 IEEE Int. Symp. Electrical Insulation (IEEE, 2010) 1–4. https://doi.org/10.1109/ELINSL.2010.5549759

15 B. K. Gupta, G. C. Stone, and J. Stein: Proc. Electrical Insulation Conf. and Electrical Manufacturing and Coil Winding Conf. (IEEE, 2001) 323–326. https://doi.org/10.1109/EEIC.2001.965645

16 B. K. Gupta, G. C. Stone, and J. Stein: Proc. 2009 IEEE Electrical Insulation Conf. (IEEE, 2009) 409–413. https://doi.org/10.1109/EIC.2009.5166381

17 M. Ashiquzzaman, S. Mitra, N. M. Molla, T. Chakma, and K. F. Nasrin: Proc. 2020 IEEE Region 10 Symp. (TENSYMP, 2020) 1026–1029. https://doi.org/10.1109/TENSYMP50017.2020.9230655

18 Chroma Germany GMBH, Electrical Safety Analyzer Model 19032/19032-P Technology Specification: https://www.chromaate.com/downloads/catalogue/Safety/19032-19032-P-EN.pdf (Accessed June 2025).

19 P. Zhang, Z. Wei, G. Shi, and J. Tan: Proc. 2024 6th Int. Conf. Artificial Intelligence and Computer Applications (ICAICA, 2024) 225–228. https://doi.org/10.1109/ICAICA63239.2024.10823050

20 Y. Yan and N. Han: Proc. 2011 Int. Conf. Management and Service Science (IEEE, 2011) 1–4. https://doi.org/10.1109/ICMSS.2011.5998200