WIN32/INDUSTROYER

A new threat for industrial control systems

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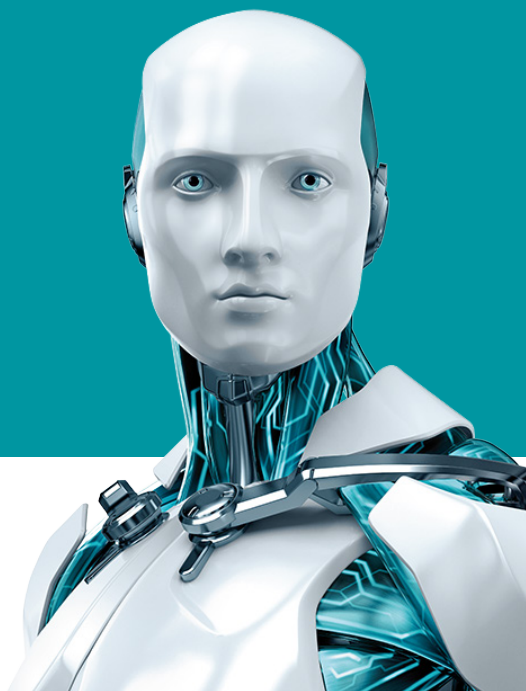

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Contents

Win32/Industroyer: a new threat for industrial control systems

Win32/Industroyer is a sophisticated piece of malware designed to disrupt the working processes of industrial control systems (ICS), specifically industrial control systems used in electrical substations.

Those behind the Win32/Industroyer malware have a deep knowledge and understanding of industrial control systems and, specifically, the industrial protocols used in electric power systems. Moreover, it seems very unlikely anyone could write and test such malware without access to the specialized equipment used in the specific, targeted industrial environment.

Support for four different industrial control protocols, specified in the standards listed below, has been implemented by the malware authors:

- IEC 60870-5-101 (aka IEC 101)
- IEC 60870-5-104 (aka IEC 104)
- IEC 61850
- OLE for Process Control Data Access (OPC DA)

In addition to all that, the malware authors also wrote a tool that implements a denial-of-service (DoS) attack against a particular family of protection relays, specifically the *Siemens SIPROTEC* range.

All this considered, the Win32/Industroyer malware authors show an intensive focus that suggests they are highly specialized in industrial control systems.

The capabilities of this malware are significant. When compared to the toolset used by threat actors in the 2015 attacks against the Ukrainian power grid which culminated in a black out on December 23, 2015 (BlackEnergy, KillDisk, and other components, including legitimate remote access software) the gang behind Industroyer are more advanced, since they went to great lengths to create malware capable of directly controlling switches and circuit breakers. We have seen indications that this malware could have been the tool used by attackers to cause the power outage in Ukraine in December 2016, although at the time of writing, it is not confirmed, and the investigation is still ongoing. The infection vector remains unknown.

The malware contains multiple modules, as analyzed and described in the next sections of this whitepaper. However, before diving into those details, the following simplified schematic shows the connections between the components of the malware.

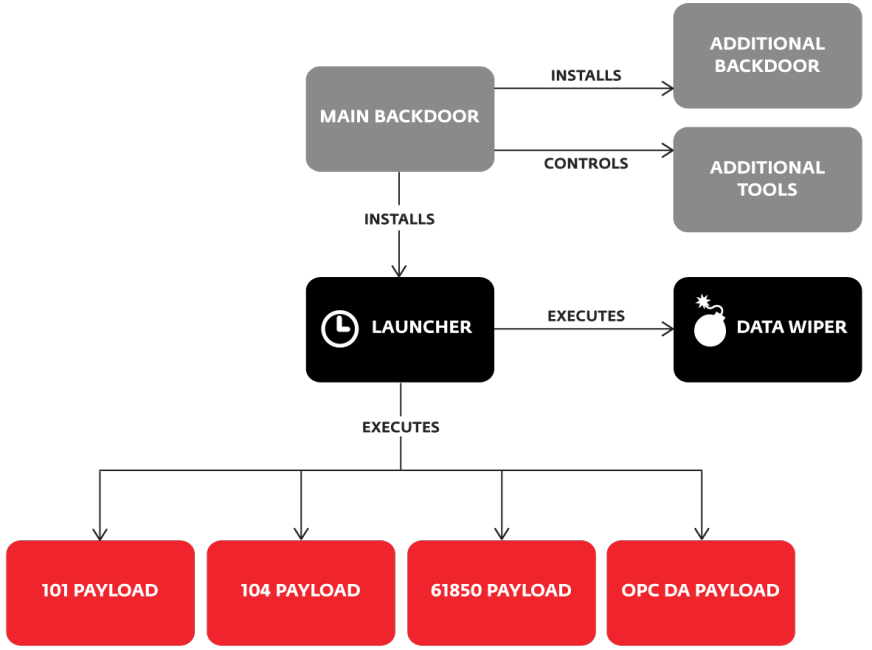


Figure 1. Simplified schematic of Win32/Industroyer components.

While some components (e.g. Wiper) are similar in concept to the *2015 BlackEnergy attacks* against power grid companies in Ukraine, we don't see any link between those attacks and the code in this malware.

Main backdoor

We refer to the core component of Industroyer as the main backdoor. The main backdoor is used by the attackers behind Industroyer to control all other components of the malware.

As backdoors go, this component is pretty straightforward, connecting to its remote C&C server using HTTPS and receiving commands from the attackers. All analyzed samples are hardcoded to use the same proxy address, located in the local network. Thus, the backdoor is clearly designed to work only in one specific organization. It is also worth mentioning that most of the C&C servers used by this backdoor are running Tor software.

Perhaps the most interesting feature of this backdoor is that attackers can define a specific hour of the day when the backdoor will be active. For example, the attackers can modify the backdoor in this way so it will communicate with its C&C server only outside working hours. This can make detection based only on network traffic examination harder. However, all the samples analyzed so far are set to work 24 hours round the clock.

```
int main_loop()
{
  struct _SYSTEMTIME SystemTime; // [esp+0h] [ebp-14h]@4
  DWORD dwMilliseconds; // [esp+10h] [ebp-4h]@2

  SetLastError(0);
  if ( GetLastError() != ERROR_ALREADY_EXISTS )
  {
    dwMilliseconds = 5000;
    SetUnhandledExceptionFilter(TopLevelExceptionFilter);
    if ( !GetSystemMetrics(SM_CLEANBOOT) )
    {
      if ( create_imapi_handle() )
      {
        while ( 1 )
        {
          do
          {
            Sleep(dwMilliseconds);
            GetLocalTime(&SystemTime);
          }
          while ( SystemTime.wHour >= 24u );
          c2_connect_and_execute_cmd(&dwMilliseconds);
        }
      }
    }
  }
  return 0;
}
```

Figure 2. The decompiled main backdoor code has a check for time of the day.

Once connected to its remote C&C server, the main backdoor component sends the following data in a POST-request:

- the globally unique identifier (GUID) string for the current hardware profile retrieved via `GetCurrentHwProfile`
- the version of the malware: 1.1e
- the hardcoded ID of the sample
- the result of any previously-received command

The hardcoded ID is used by the attacker as an identifier for the infected machine. Across all analyzed samples we found the following hardcoded ID values:

- DEF
- DEF-C
- DEF-WS
- DEF-EP
- DC-2-TEMP
- DC-2
- CES-McA-TEMP
- CES
- SRV_WSUS
- SRV_DC-2
- SCE-WSUS01

The main backdoor component supports the following commands:

Command ID	Purpose
0	Execute a process
1	Execute a process under a specific user account. Credentials for the account are supplied by the attacker
2	Download a file from C&C server
3	Copy a file

Command ID	Purpose
4	Execute a shell command
5	Execute a shell command under a specific user account. Credentials for the account are supplied by the attacker
6	Quit
7	Stop a service
8	Stop a service under a specific user account. Credentials for the account are supplied by the attacker
9	Start a service under a specific user account. Credentials for the account are supplied by the attacker
10	Replace "Image path" registry value for a service

Once the attackers obtain administrator privileges, they can upgrade the installed backdoor to a more privileged version that is executed as a *Windows service program*. To do this they have to pick an existing, non-critical Windows service and replace its `Image Path` registry value with the path of the new backdoor's binary.

The functionality of the main backdoor that works as a Windows service is the same as just described. However, there are two small differences: first the backdoor's version is 1.1s, instead of 1.1e, and second, there is code obfuscation. The code of this version of the backdoor is mixed with junk assembly instructions.

```
.text:00403FD2 main_func proc near                     ; CODE XREF: WinMain(x,x,x,x)+14↑p
.text:00403FD2                                         ; .text:004038C4↑p
.text:00403FD2         call    $+5
.text:00403FD7
.text:00403FD7 loc_403FD7:                             ; CODE XREF: main_func+57↓j
.text:00403FD7                                         ; main_func+5F↓j
.text:00403FD7         add     esp, 4
.text:00403FDA         push    ebp                     ; lpOverlapped
.text:00403FDB         mov     ebp, esp
.text:00403FDD         cmp     edx, 142F9F9Ah
.text:00403FE3         jz      short loc_404023
.text:00403FE5         push    ecx
.text:00403FE6         push    ecx
.text:00403FE7         mov     eax, [ebp+10h]
.text:00403FEA         mov     dword_416190, eax
.text:00403FEF         mov     eax, [ebp+8]
.text:00403FF2         mov     dword_416194, eax
.text:00403FF7         mov     eax, [ebp+0Ch]
.text:00403FFA         cmp     edx, 0B5B93EF3h
.text:00404000         jz      short loc_404023
.text:00404002         mov     lpOverlapped, eax
.text:00404007         mov     [ebp-8], eax
.text:0040400A         lea     eax, [ebp-8]
.text:0040400D         push    eax                     ; lpServiceStartTable
.text:0040400E         mov     dword ptr [ebp-4], offset ServiceMain
.text:00404015         call    ds:StartServiceCtrlDispatcherW
.text:0040401B         xor     al, al
.text:0040401D         mov     esp, ebp
.text:0040401F         pop     ebp
.text:00404020         retn
```

Figure 3. The obfuscated assembly code of the main backdoor that works as a Windows service.

Additional backdoor

The additional backdoor provides an alternate persistence mechanism that allows the attackers to regain access to a targeted network in case the main backdoor is detected and/or disabled.

This backdoor is a trojanized version of the Windows Notepad application. This is a fully functional version of the application, but the malware authors have inserted malicious code that is executed each time the application is launched. Once the attackers gain administrator privileges, they are able to replace the legitimate Notepad manually.

The inserted malicious code is heavily obfuscated, but once the code is decrypted it connects to a remote C&C server, which is different to the one linked in the main backdoor, and downloads a payload. This is in the form

of shellcode that is loaded directly into memory and executed. In addition, the inserted code decrypts the original Windows Notepad code, which is stored at the end of the file, and then passes execution to it. Thus, the Notepad application works as expected.

```
.text:01004AD5     lea     eax, [ebp+var_50]
.text:01004AD8     push    eax
.text:01004AD9     lea     eax, [ebp+h]
.text:01004ADC     push    eax
.text:01004ADD     push    0B0h
.text:01004AE2     push    hWnd
.text:01004AE8     mov     stru_100A680.lStructSize, 58h
.text:01004AF2     mov     stru_100A680.hwndOwner, edx
.text:01004AF8     mov     stru_100A680.nMaxFile, 104h
.text:01004B02     mov     stru_100A500.lStructSize, 28h
.text:01004B0C     mov     stru_100A500.hwndOwner, edx
.text:01004B12     call    esi ; SendMessageW
.text:01004B14     push    [ebp+var_50]
.text:01004B17     push    [ebp+h]
.text:01004B1A     push    0B1h
.text:01004B1F     push    hWnd
.text:01004B25     call    esi ; SendMessageW
.text:01004B27     push    ebx
.text:01004B28     push    ebx
.text:01004B29     push    0B7h
.text:01004B2E     push    hWnd
.text:01004B34     call    esi ; SendMessageW
.text:01004B36     push    ebx
.text:01004B37     call    ds:GetKeyboardLayout
.text:01004B3D     and     ax, 3FFh
.text:01004B41     cmp     ax, 11h
.text:01004B45     jnz     short loc_1004B58
.text:01004B47     push    1
.text:01004B49     push    1
.text:01004B4B     push    0D8h
.text:01004B50     push    hWnd
.text:01004B56     call    esi ; SendMessageW
```

```
.text:01004AD5     lea     eax, [ebp+var_50]
.text:01004AD8     push    eax
.text:01004AD9     lea     eax, [ebp+h]
.text:01004ADC     push    eax
.text:01004ADD     push    0B0h
.text:01004AE2     push    hWnd
.text:01004AE8     mov     stru_100A680.lStructSize, 58h
.text:01004AF2     mov     stru_100A680.hwndOwner, edx
.text:01004AF8     mov     stru_100A680.nMaxFile, 104h
.text:01004B02     mov     stru_100A500.lStructSize, 28h
.text:01004B0C     mov     stru_100A500.hwndOwner, edx
.text:01004B12     call    esi ; SendMessageW
.text:01004B14     pusha
.text:01004B15     pushf
.text:01004B16     neg     ebx
.text:01004B18     shr     eax, 1
.text:01004B1B     dec     ebx
.text:01004B1C     mov     eax, 17B200AFh
.text:01004B21     mov     edi, 71CFC28h
.text:01004B26     or      edi, dword_10095C7
.text:01004B2C     xor     esi, 1C779E91h
.text:01004B32     xor     eax, eax
.text:01004B34     dec     edi
.text:01004B35     rol     esi, 5
.text:01004B38     and     esi, edi
.text:01004B3A     and     esi, edi
.text:01004B3C     rol     edx, 6
.text:01004B3F     neg     eax
.text:01004B41     xor     esi, eax
.text:01004B43     neg     ebx
.text:01004B45     shr     ebx, 5
.text:01004B48     mov     ecx, 5E95422h
```

Figure 4. Comparison between original Notepad binary code (at the left) and backdoored binary code.

Launcher component

This component is a separate executable responsible for launching the payloads and the wiper component.

The Launcher component contains a specific time and date. Analyzed samples contained two dates, 17th December 2016 and 20th December 2016. Once one of these dates is reached the component creates two threads. The first thread makes attempts to load a payload DLL, while the second thread waits one or two hours (it depends on the Launcher component version) and then attempts to load the Wiper component. The priority for both threads is set to `THREAD_PRIORITY_HIGHEST`, which means that these two threads receive a higher than normal share of CPU resources from the operating system.

The name of the payload DLL is supplied by the attackers via a command line parameter supplied in one of the main backdoor's "execute a shell command" commands. The Wiper component is always named `haslo.dat`. The expected command lines are of the form:

```
%LAUNCHER%.exe %WORKING_DIRECTORY% %PAYLOAD%.dll
%CONFIGURATION%.ini
```

Each argument on the command line represents the following:

- `%LAUNCHER%.exe` is the filename of the Launcher component
- `%WORKING_DIRECTORY%` is the directory where the payload DLL and configuration is stored
- `%PAYLOAD%.dll` is the filename of the payload DLL
- `%CONFIGURATION%.ini` is the file that stores configuration data for the specified payload. The path to this file is supplied to the payload DLL by the Launcher component

The payload and wiper components are standard Windows DLL files. In order to be loaded by the Launcher component they must export a function named `Crash` as seen in Figure 5.

```
;
; Export directory for Crash101.dll
;
                dd 0                    ; Characteristics
                dd 5855F8EDh            ; TimeDateStamp: Sun Dec 18 02:48:13 2016
                dw 0                    ; MajorVersion
                dw 0                    ; MinorVersion
                dd rva aCrash101_dll    ; Name
                dd 1                    ; Base
                dd 1                    ; NumberOfFunctions
                dd 1                    ; NumberOfNames
                dd rva off_100355F8     ; AddressOfFunctions
                dd rva off_100355FC     ; AddressOfNames
                dd rva word_10035600    ; AddressOfNameOrdinals
;
; Export Address Table for Crash101.dll
;
off_100355F8    dd rva Crash            ; DATA XREF: .rdata:100355EC↑o
;
; Export Names Table for Crash101.dll
;
off_100355FC    dd rva aCrash           ; DATA XREF: .rdata:100355F0↑o
                                        ; "Crash"
;
; Export Ordinals Table for Crash101.dll
;
word_10035600   dw 0                    ; DATA XREF: .rdata:100355F4↑o
aCrash101_dll   db 'Crash101.dll',0     ; DATA XREF: .rdata:100355DC↑o
aCrash          db 'Crash',0            ; DATA XREF: .rdata:off_100355FC↑o
```

Figure 5. Example payload DLL that has internal name `Crash101.dll` and `Crash` export function.

101 payload component

This payload DLL has the filename `101.dll` and is named after IEC 101 (aka *IEC 60870-5-101*), an international standard that describes a protocol for monitoring and controlling electric power systems. The protocol is used for communication between industrial control systems and Remote Terminal Units (RTUs). The actual communication is transmitted through a serial connection.

The 101 payload component partly implements the protocol described in the IEC 101 standard and is able to communicate with an RTU or any other device with support for that protocol.

Once executed, the 101 payload component parses the configuration stored in its INI file. The configuration may contain several entries: process name, Windows device names (usually COM ports), number of ranges, and Information Object Address (IOA) range values. IOA is a number that identifies a particular data element in the device. Figure 6 illustrates a 101 payload configuration file with two defined IOA ranges, 10-15 and 20-25.

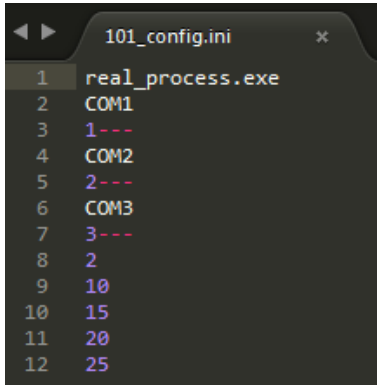


Figure 6. An example of a 101 payload DLL configuration.

The name of the process specified in the configuration belongs to an application the attackers suspect is running on the victim machine. It should be the application the victim machine uses to communicate through serial connection with the RTU. The 101 payload attempts to terminate the specified process and starts to communicate with the specified device, using the `CreateFile`, `WriteFile` and `ReadFile` Windows API functions. The first COM port from the configuration file is used for the actual communication and the two other COM ports are just opened to prevent other processes accessing them. Thus, the 101 payload component is able to take over control of the RTU device.

This component iterates through all defined IOA ranges. For each such IOA it constructs "select and execute" packets with a single command (`C_SC_NA_1`) and double command (`C_DC_NA_1`) and sends it to the RTU device. The main goal of the component is to change the On/Off state of single command type IOA and double command type IOA. Specifically, the 101 payload has three stages: in the first stage this component attempts

to switch IOAs to their Off state, in the second stage it attempts to invert IOA states to On, and in the final stage the component switches IOA states to Off again.

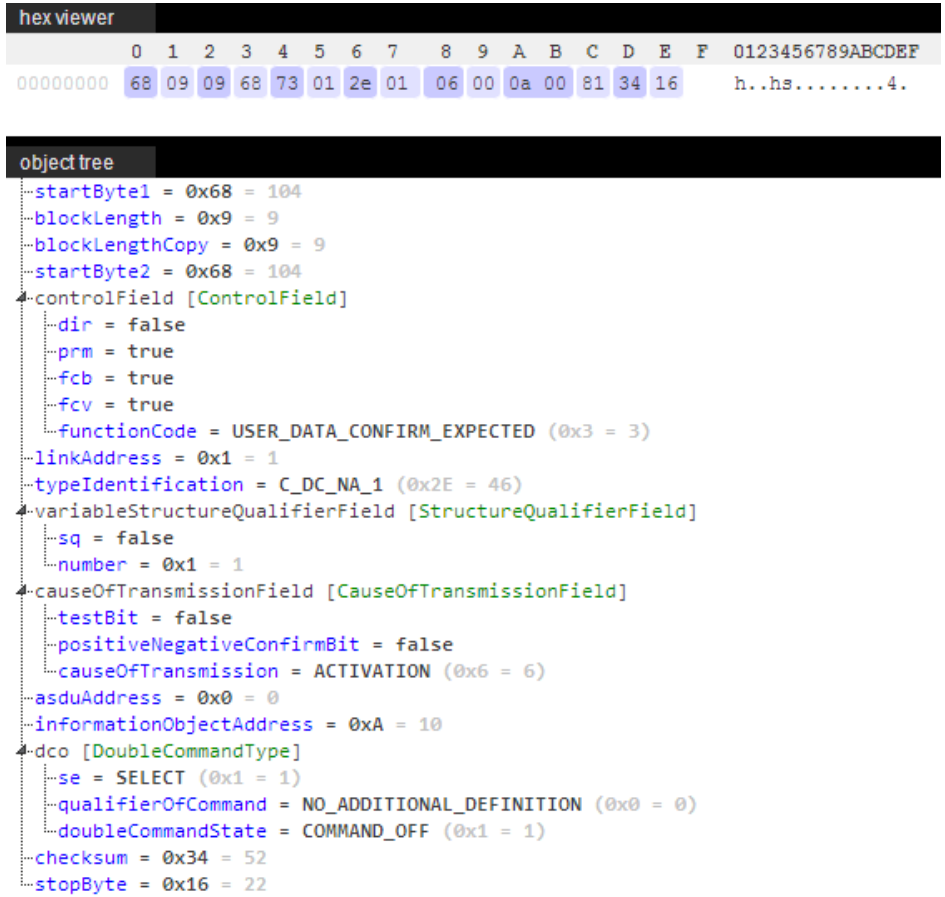


Figure 7. An example of a dissected 101 payload packet in Kaitai Struct WebIDE.

104 payload component

This payload DLL has the filename 104.dll and is named after IEC 104 (aka *IEC 60870-5-104*), an international standard. The IEC 104 protocol extends IEC 101, so the protocol can be transmitted over a TCP/IP network.

Due to its highly configurable nature, this payload can be customized by the attackers for different infrastructures. Figure 8 shows what a configuration file may look like.

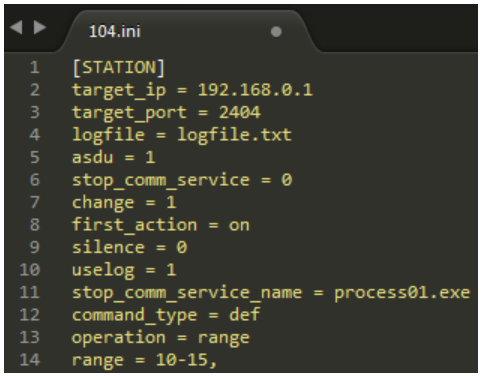


Figure 8. An example of 104 payload DLL configuration.

Once executed, the 104 payload DLL attempts to read the configuration file. As described above, the path for the configuration file is supplied by the Launcher component.

The configuration contains a `STATION` section followed by properties that configure how 104 would work. The configuration may contain multiple `STATION` entries.

Our analysis of this component reveals the following possible configuration properties:

Property	Expected value	Purpose
target_ip	IP address	The IP address that will be used for the communication using IEC 104 protocol standard
target_port	Port number	Self-explanatory
uselog	1 or 0	Enables or disables logging to a file
logfile	Filename	Specifies the filename for the log, if enabled
stop_comm_service	1 or 0	Enables or disables termination of the process
stop_comm_service_name	Process name	Specifies the process name that will be terminated
timeout	Timeout in milliseconds	Specifies timeout between send and recv calls. Default value: 15000
socket_timeout	Timeout in milliseconds	Specify the receiving timeout. Default value: 15000
silence	1 or 0	Enables or disables console output
asdu	Integer	Specifies ASDU (Application Service Data Unit) address also known as sector
first_action	on or off	Specifies the Switch value in ASDU packet for first iteration
change	1 or 0	Specifies that the Switch value in ASDU packet should be inverted during iterations
command_type	def or short or long	Specifies command pulse duration for qualifier of command (QOC)
operation	range or sequence or shift	Specifies iteration type for Information Object Addresses (IOA)
range	Specific format of IOAs	Specifies range of Information Object Addresses (IOA)
sequence	Specific format of IOAs	Specifies sequence of Information Object Addresses (IOA)
shift	Specific format of IOAs	Specifies shift of Information Object Addresses (IOA)

Once the configuration file is read, the 104 payload creates a thread for each STATION section defined in the configuration file, one per thread. In each such thread, the 104 payload will attempt to communicate with the specified IP address using the protocol described in the IEC 104 standard. Before the connection is made, the 104 payload attempts to terminate the legitimate process that is normally responsible for IEC 104 communication with the device. It does so only if the `stop_comm_service` property is specified in its configuration. By default, the 104 payload terminates the process named `D2MultiCommService.exe`, or the process name specified in its configuration.

The main idea behind the 104 payload is relatively simple. It connects to the specified IP address and starts to send packets with the ASDU address that was defined in its configuration. The goal of this communication is to interact with an IOA of a single command type.

In the configuration file, the attacker can define the `operation` property to specify exactly how single command type IOAs will be iterated.

The first such `operation` mode is the `range` mode. The attackers use this mode in order to discover possible IOAs in the targeted device. The attackers have to take this approach because the protocol described in the IEC 104 standard does not provide a specific method to obtain such information.

The `range` mode has two stages. During the first stage, once the range of IOAs is obtained from the configuration file, the 104 payload connects to

the target IP address and starts to iterate through the specified IOAs. To each such IOA the 104 payload sends "select and execute" packets in order to switch the state and to confirm whether the IOA belongs to the single command type.

```
▷ Internet Protocol Version 4, Src: 192.168.0.1, Dst: 192.168.0.2
▷ Transmission Control Protocol, Src Port: 2404, Dst Port: 49168, Seq: 39, Ack: 45, Len: 16
▷ IEC 60870-5-104-Apci: -> I (2,2)
◢ IEC 60870-5-104-Asdu: ASDU=1 C_SC_NA_1 ActTerm IOA=10 'single command'
    TypeId: C_SC_NA_1 (45)
    0... .... = SQ: False
    .000 0001 = NumIx: 1
    ..00 1010 = CauseTx: ActTerm (10)
    .0.. .... = Negative: False
    0... .... = Test: False
    OA: 0
    Addr: 1
  ◢ IOA: 10
      IOA: 10
    ◢ SCO: 0x01
        .... ...1 = ON/OFF: On
        .000 00.. = QU: No pulse defined (0)
        0... .... = S/E: Execute
```

Figure 9. An example of a dissected 104 payload packet in Wireshark.

Once all possible IOAs from the specified range are iterated, the 104 payload switches to the second stage of `range` mode. If logging is enabled, the payload writes `Starting only success` to the log. The rest of this second stage is an infinite loop that uses the previously discovered IOAs of single command type. In the loop the payload constantly sends "select and execute" packets. In addition, if the option change is defined, the payload flips the On/Off state between loop steps.

Figure 10 demonstrates the log file that was produced by the 104 payload during our analysis. It shows the payload iterated IOAs from 10 to 15, and once IOAs of the single command type were discovered, the payload started to use them in the loop. The configuration had the `change` option enabled, so between loop iterations the payload flipped the switch value from On to Off and wrote it to the log.

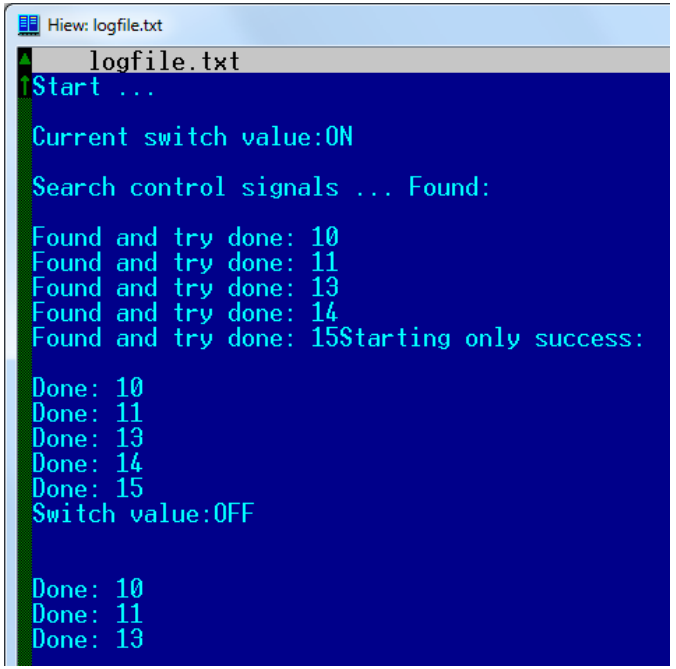


Figure 10. Example log file produced by the 104 payload

The second `operation` mode is the `shift` mode. This is very similar to the range mode. The attacker defines, in the configuration file, a range of IOAs and shift values. Once the 104 payload is activated it does everything the same way as in `range` mode; however, once all IOAs in the defined range are iterated, it starts to iterate over the new range. The new range is calculated by adding the shift values to the default range values.

The third `operation` mode is the `sequence` mode. It can be used by attackers once they know the values of all IOAs of the single command type that are supported by the connected device. This payload immediately executes an infinite loop, sending "select and execute" packets to the IOAs defined in the configuration file.

Aside from its logging capability, the 104 payload can output debug information to the console, as seen in Figure 11.

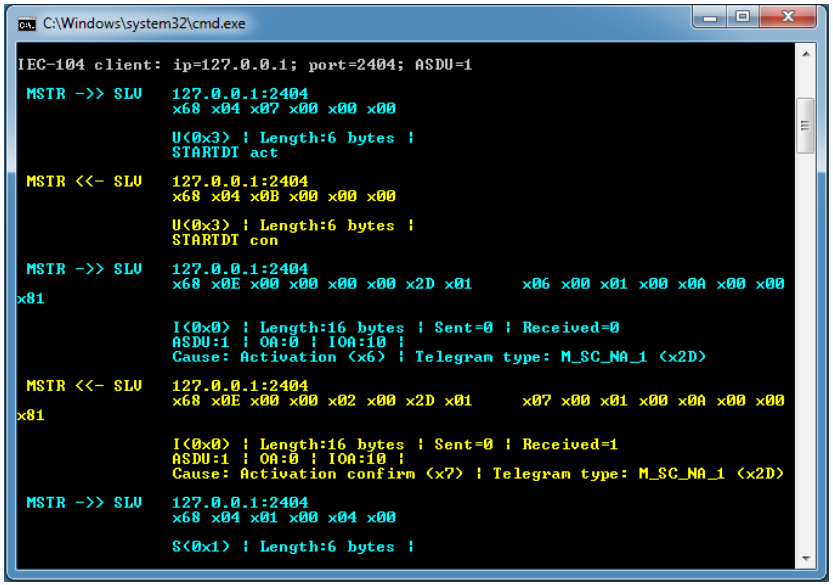


Figure 11. The console output of the 104 payload.

61850 payload component

Unlike the 101 and 104 payloads, this payload component exists as a standalone malicious tool comprising an executable named `61850.exe` and the `DLL 61850.dll`. It is named after the *IEC 61850* standard. This standard describes a protocol used for multivendor communication among devices that perform protection, automation, metering, monitoring, and control of electrical substation automation systems. The protocol is very complex and robust, but the 61850 payload uses only a small subset of the protocol to produce its disruptive effect.

Once executed, the 61850 payload DLL attempts to read the configuration file, the path to which is supplied by the Launcher component. The standalone version defaults to reading its configuration from `i.ini`. The configuration file is expected to contain a list of IP addresses of devices capable of communicating via the protocol described in the IEC 61850 standard.

If the configuration file is not present, then this component enumerates all connected network adaptors to determine their TCP/IP subnet masks. The 61850 payload then enumerates all possible IP addresses for each of these subnet masks, and tries to connect to port 102 on each of those addresses. Therefore, this component has the ability to discover relevant devices in the network automatically.

Otherwise, if a configuration file is present and it contains target IP addresses, this component connects to port 102 on those IP addresses and on IP addresses that were discovered automatically.

Once this component connects to a target host, it sends a Connection Request packet using the Connection Oriented Transport Protocol, as seen in Figure 12.

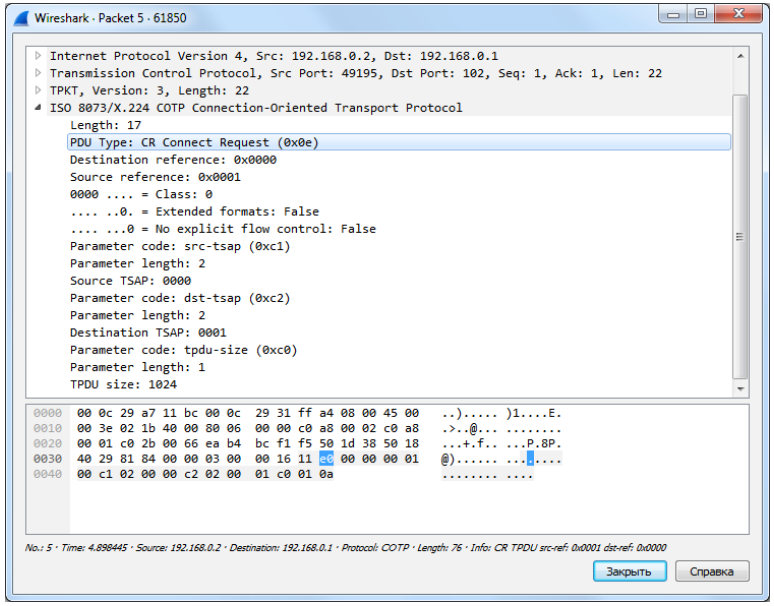


Figure 12. A dissected Connection Request packet in Wireshark

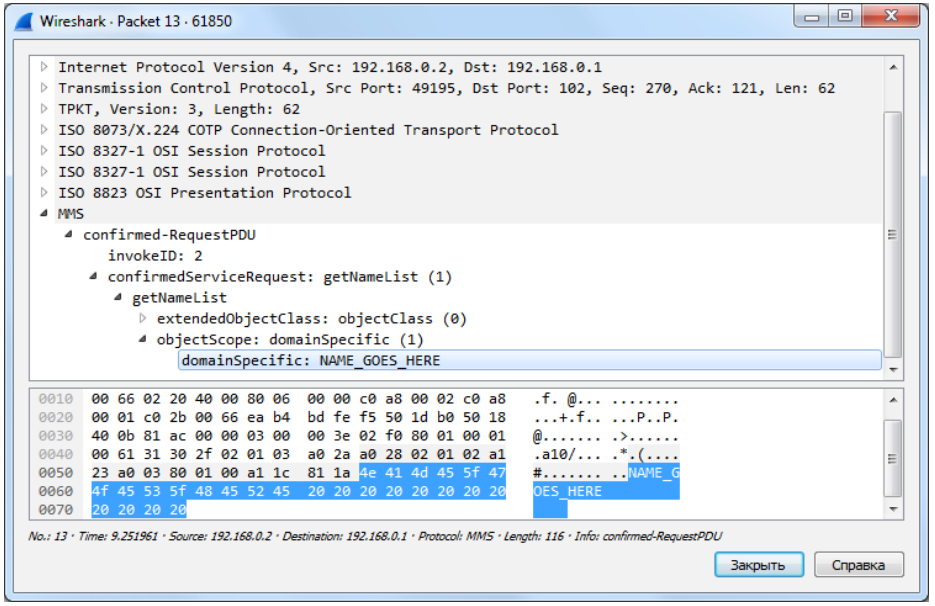


Figure 13. The dissected MMS `getNameList` request in Wireshark.

If the target device responds appropriately, the 61850 payload then sends an `InitiateRequest` packet using the *Manufacturing Message Specification* (MMS). If the expected answer is received, it continues, sending an MMS `getNameList` request. Thereby, the component compiles a list of object names in a Virtual Manufacturing Device (VMD).

Next, this component enumerates the objects discovered in the previous step and sends the device domain-specific `getNameList` requests with each object name. This enumerates named variables in a specific domain.

Afterwards, the 61850 payload parses data received in response to these requests, searching for variables that contain following strings:

- **CSW, CF, Pos,** and **Model**
- **CSW, ST, Pos,** and **stVal**
- **CSW, CO, Pos, Oper,** but not **$T**
- **CSW, CO, Pos, SBO,** but not **$T**

The string CSW is a name for logical nodes, which are used to control circuit breakers and switches.

For variables that contain the Model or stVal string the 61850 payload sends an additional MMS `Read` request. For some of the variables this component may also issue an MMS `Write` request that will change its state.

The 61850 payload produces a log file of its operations that contains the IP addresses, MMS domains, named variables and the node states (open or closed) of its targets.

OPC DA payload component

The OPC DA payload component implements a client for the protocol described in the *OPC Data Access* specification. *OPC (OLE for Process Control)* is a software standard and specification that is based on Microsoft technologies such as OLE, COM, and DCOM. The Data Access (DA) part of the OPC specification allows real-time data exchange between distributed components, based on a client–server model.

This component exists as a standalone malicious tool with the filename `OPC.exe` and a DLL, which implement both 61850 and OPC DA payload functionalities. This DLL is named, internally in PE export table, `OPCClientDemo.dll`, suggesting that the code of this component may be based on the open source project *OPC Client*.

```
;
; Export Address Table for OPCClientDemo.dll
;
off_10039678    dd rva Crash            ; DATA XREF: .rdata:1003966C↑o
;
; Export Names Table for OPCClientDemo.dll
;
off_1003967C    dd rva aCrash           ; DATA XREF: .rdata:10039670↑o
                                        ; "Crash"
```

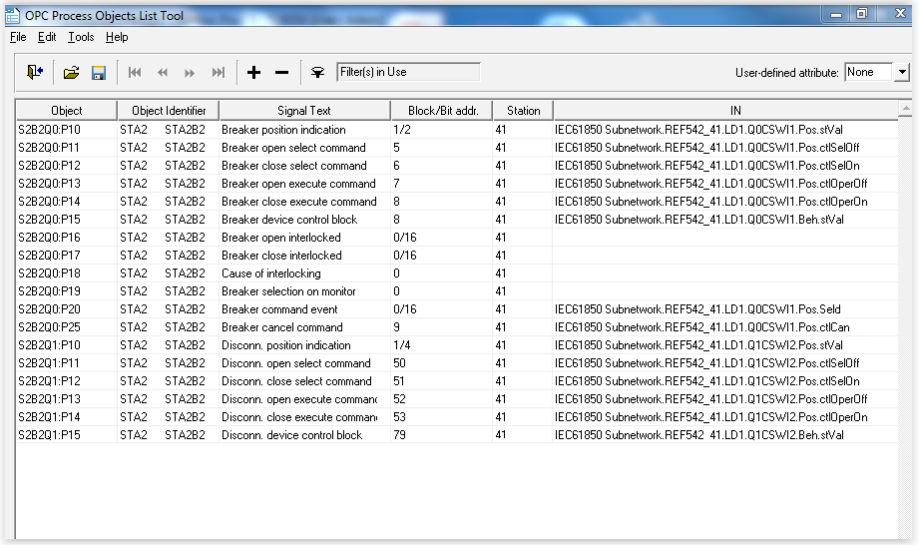
Figure 14. The PE export reveals the internal DLL name of the OPC DA payload.

The OPC DA payload does not require any kind of configuration file. Once executed by the attacker, it enumerates all OPC servers using the `ICatInformation::EnumClassesOfCategories` method with `CATID_OPCDAServer20` category identifier and `IOPCServer::GetStatus` to identify the ones running.

Next the component uses the `IOPCBrowseServerAddressSpace` interface to enumerate all OPC items on the server. Specifically, it looks for items that contain the following strings in their name:

- ctlSelOn
- ctlOperOn
- ctlSelOff
- ctlOperOff
- \Pos and stVal

The names of these items may suggest that attackers are interested in OPC items provided by OPC servers that belong to solutions from *ABB*, such as their *MicroSCADA range*. Figure 15 demonstrates an example list of OPC items that contain names with similar strings. This list of OPC items is received by the OPC Process Objects List Tool from ABB.



Object	Object Identifier		Signal Text	Block/Bit addr.	Station	IN
S2B2Q0:P10	STA2	STA2B2	Breaker position indication	1/2	41	IEC61850 Subnetwork.REF542_41.LD1.Q0CSWI1.Pos.stVal
S2B2Q0:P11	STA2	STA2B2	Breaker open select command	5	41	IEC61850 Subnetwork.REF542_41.LD1.Q0CSWI1.Pos.ctlSelOff
S2B2Q0:P12	STA2	STA2B2	Breaker close select command	6	41	IEC61850 Subnetwork.REF542_41.LD1.Q0CSWI1.Pos.ctlSelOn
S2B2Q0:P13	STA2	STA2B2	Breaker open execute command	7	41	IEC61850 Subnetwork.REF542_41.LD1.Q0CSWI1.Pos.ctlOperOff
S2B2Q0:P14	STA2	STA2B2	Breaker close execute command	8	41	IEC61850 Subnetwork.REF542_41.LD1.Q0CSWI1.Pos.ctlOperOn
S2B2Q0:P15	STA2	STA2B2	Breaker device control block	8	41	IEC61850 Subnetwork.REF542_41.LD1.Q0CSWI1.Beh.stVal
S2B2Q0:P16	STA2	STA2B2	Breaker open interlocked	0/16	41	
S2B2Q0:P17	STA2	STA2B2	Breaker close interlocked	0/16	41	
S2B2Q0:P18	STA2	STA2B2	Cause of interlocking	0	41	
S2B2Q0:P19	STA2	STA2B2	Breaker selection on monitor	0	41	
S2B2Q0:P20	STA2	STA2B2	Breaker command event	0/16	41	IEC61850 Subnetwork.REF542_41.LD1.Q0CSWI1.Pos.SelId
S2B2Q0:P25	STA2	STA2B2	Breaker cancel command	9	41	IEC61850 Subnetwork.REF542_41.LD1.Q0CSWI1.Pos.ctlCan
S2B2Q1:P10	STA2	STA2B2	Disconn. position indication	1/4	41	IEC61850 Subnetwork.REF542_41.LD1.Q1CSWI2.Pos.stVal
S2B2Q1:P11	STA2	STA2B2	Disconn. open select command	50	41	IEC61850 Subnetwork.REF542_41.LD1.Q1CSWI2.Pos.ctlSelOff
S2B2Q1:P12	STA2	STA2B2	Disconn. close select command	51	41	IEC61850 Subnetwork.REF542_41.LD1.Q1CSWI2.Pos.ctlSelOn
S2B2Q1:P13	STA2	STA2B2	Disconn. open execute comman	52	41	IEC61850 Subnetwork.REF542_41.LD1.Q1CSWI2.Pos.ctlOperOff
S2B2Q1:P14	STA2	STA2B2	Disconn. close execute comman	53	41	IEC61850 Subnetwork.REF542_41.LD1.Q1CSWI2.Pos.ctlOperOn
S2B2Q1:P15	STA2	STA2B2	Disconn. device control block	79	41	IEC61850 Subnetwork.REF542_41.LD1.Q1CSWI2.Beh.stVal

Figure 15. An example of OPC items names in IN field received using OPC Process Objects List Tool.

The attackers use the string `Abdul` when they add a new OPC group. Possibly this string is used by the attackers as a slang term when referring to the ABB solutions.

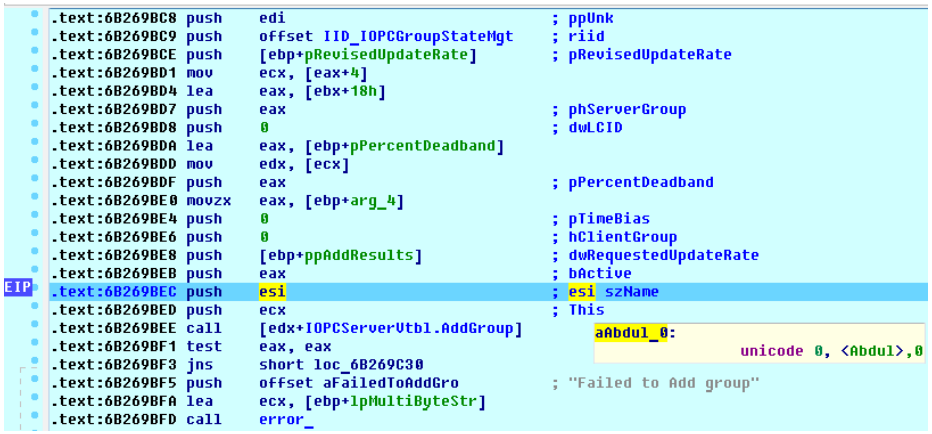


Figure 16. The disassembled code of the OPC DA component that uses the `Abdul` string.

On the final step, the OPC DA payload attempts to change the state of discovered OPC items using the `IOPCSyncIO` interface by writing the 0x01 value twice.

```
.text:004034FE          mov     eax, VT_I2
.text:00403503          mov     word ptr [ebp+pItemValues.anonymous_0], ax
.text:0040350A          mov     eax, 1
.text:0040350F          mov     word ptr [ebp+pItemValues.anonymous_0+8], ax
.text:00403516          lea     eax, [ebp+pItemValues]
.text:0040351C          push    eax                             ; pItemValues
.text:0040351D          mov     eax, [ebp+OPC_items]
.text:00403523          mov     ecx, [eax+esi*4]
.text:00403526          call    IOPCSyncIO_Write
.text:0040352B          cmp     esi, edi
.text:0040352D          jb      short loc_403539
.text:0040352F          push    80070057h
.text:00403534          call    throw_exception
```

Figure 17. Disassembled code of OPC DA payload that uses `IOPCSyncIO` interface.

The component writes the OPC server name, OPC item name state, quality code and value to the log file. The logged values are separated with the following headers:

- [*ServerName: %SERVERNAME%] [State: Before]
- [*ServerName: %SERVERNAME%] [State: After ON]
- [*ServerName: %SERVERNAME%] [State: After OFF]

Data wiper component

The data wiper component is a destructive module that is used in the final stage of an attack. The attackers are using this component to hide their tracks and to make recovery difficult.

This component has the filename `haslo.dat` or `haslo.exe` and can be executed by the Launcher component or used as a standalone malicious tool.

Once executed it attempts to enumerate all keys in the registry that list Windows services:

- HKEY_LOCAL_MACHINE\SYSTEM\CurrentControlSet\Services

It attempts to set the registry value `ImagePath` with an empty string in each of the entries found. This operation will make the operating system unbootable.

The next step is actual deletion of file contents. The component enumerates files with specific file extensions on all drives connected to computer, from C:\ to Z:\. It should be noted that during enumeration the component skips files that are located in subdirectory that contains `Windows` in its name.

The component rewrites file content with meaningless data obtained from newly allocated memory. In order to perform this operation thoroughly the component attempts to rewrite files twice. The first attempt happens once the file is found on a drive. If the first attempt is unsuccessful then the wiper malware makes a second attempt, but before that the malware terminates all processes except those included in a list of critical system processes. The list of these processes is displayed in Figure 18.

To speed up the wiping operation this component rewrites only partial file content at the beginning of the file. The amount of data to be rewritten depends on file size: the smallest amount of data will be rewritten for files less than or equal to 1Mb (4096 bytes); the largest amount of data will be rewritten for files less than or equal to 10Mb (32768 bytes).

Finally, this component attempts to terminate all processes (including system processes) except its own. This will result in the system becoming unresponsive and eventually crashing.

```
off_10010E88    dd offset aAudiodg_exe  ; DATA XREF: _terminate_processes:loc_10001470↑r
                                        ; "audiodg.exe"
                dd offset aConhost_exe  ; "conhost.exe"
                dd offset aCsrss_exe    ; "csrss.exe"
                dd offset aDwm_exe      ; "dwm.exe"
                dd offset aExplorer_exe ; "explorer.exe"
                dd offset aLsass_exe    ; "lsass.exe"
                dd offset aLsm_exe      ; "lsm.exe"
                dd offset aServices_exe ; "services.exe"
                dd offset aShutdown_exe ; "shutdown.exe"
                dd offset aSmss_exe     ; "smss.exe"
                dd offset aSpoolss_exe  ; "spoolss.exe"
                dd offset aSpoolsv_exe  ; "spoolsv.exe"
                dd offset aSvchost_exe  ; "svchost.exe"
                dd offset aTaskhost_exe ; "taskhost.exe"
                dd offset aWininit_exe  ; "wininit.exe"
                dd offset aWinlogon_exe ; "winlogon.exe"
                dd offset aWuauclt_exe  ; "wuauclt.exe"
```

Figure 18. List of processes that are not terminated on second rewriting attempt.

The filename masks targeted by the data wiper component to be overwritten are:

SYS_BASCON.COM	*.pcmi	*.bak
*.v	*.pcmt	*.bk
*.PL	*.ini	*.bkp
*.paf	*.xml	*.log
*.v	*.CIN	*.zip
*.XRF	*.ini	*.rar
*.trc	*.prj	*.tar
*.SCL	*.cxm	*.7z
*.bak	*.elb	*.exe
*.cid	*.epl	*.dll
*.scd	*.mdf	
*.pcmp	*.ldf	

This list contains filename extensions that are used in a standard environment, such as Windows binaries (.exe/.dll), archives (.7z /.tar/.rar/.zip), backup files (.bak/.bk/.bkp), Microsoft SQL server files (.mdf/.ldf), and various configuration files (.ini/.xml). In addition, the component also wipes files that may be used in industrial control systems, such as files written using *Substation Configuration description Language* (.scl/.cid/.scd) and there many files and file extensions that are used by various products from ABB. For example, a file named `SYS_BASCON.COM` is used by ABB solutions for storing configuration data, and files with the `.paf (Product Authorization File)` filename extension are used to store license data for ABB MicroSCADA products.

Additional tools: port scanner tool

The attackers' arsenal includes a port scanner that can be used to map the network and to find computers relevant to their attack. Interestingly, instead of using software already existing, the attackers built their own custom-made port scanner. As is evident from Figure 19, the attacker can define a range of IP addresses and a range of network ports that are to be scanned by this tool.

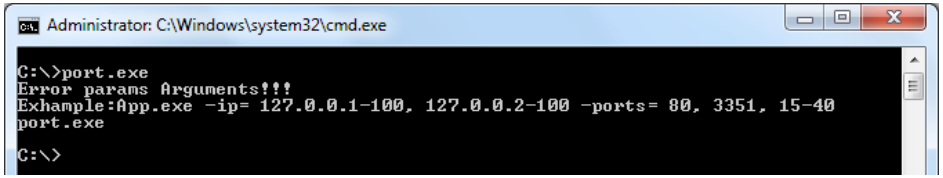


Figure 19. The port scanner tool usage example.

Additional tools: DoS Tool

Another tool from the attackers' arsenal is a Denial-of-Service (DoS) tool that can be used against Siemens SIPROTEC devices. This tool leverages the *CVE-2015-5374* vulnerability in order to make a device unresponsive. Once this vulnerability is successfully exploited, the device stops responding to any commands until the device is rebooted manually.

To exploit this vulnerability the attackers hardcoded the device IP addresses into this tool. Once the tool is executed it sends specifically crafted packets to port 50,000 of the target IP addresses using UDP. The UDP packet contains only 18 bytes.

Figure 20. Content of UDP packet used during exploitation of CVE-2015-5374.

Conclusion

The investigation behind the Ukrainian power outage last December is still ongoing and it is currently not confirmed that the malware analyzed here was the direct cause. Nevertheless, we believe that to be a very probable explanation, as the malware is able to directly control switches and circuit breakers at power grid substations using four ICS protocols and contains an activation timestamp for December 17, 2016, the day of the power outage.

We can definitely say that the Win32/Industroyer malware family is an advanced and sophisticated piece of malware that is used against industrial control systems. However, it should be noted that the malware itself is just a tool in hands of an even more advanced and very capable malicious actor. Using logs produced by the toolset and highly configurable payloads, the attackers could adapt the malware to any comparable environment.

The commonly-used industrial control protocols used in this malware were designed decades ago without taking security into consideration. Therefore, any intrusion into an industrial network with systems using these protocols should be considered as “game over”.

Indicators of Compromise (IoC)

SHA-1 hashes:

```
F6C21F8189CED6AE150F9EF2E82A3A57843B587D
CCCCE62996D578B984984426A024D9B250237533
8E39ECA1E48240C01EE570631AE8F0C9A9637187
2CB8230281B86FA944D3043AE906016C8B5984D9
79CA89711CDAEDB16B0CCCCFDCFBD6AA7E57120A
94488F214B165512D2FC0438A581F5C9E3BD4D4C
5A5FAFBC3FEC8D36FD57B075EBF34119BA3BFF04
B92149F046F00BB69DE329B8457D32C24726EE00
B335163E6EB854DF5E08E85026B2C3518891EDA8
```

IP addresses of C&C servers:

```
195.16.88[.]6
46.28.200[.]132
188.42.253[.]43
5.39.218[.]152
93.115.27[.]57
```

Warning! Most of the servers with these IP addresses were part of Tor network which means that the use of these indicators could result in a false positive match.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