

UNIVERSITY OF DA NANG
UNIVERSITY OF SCIENCE AND TECHNOLOGY
FACULTY OF ADVANCED SCIENCE AND TECHNOLOGY



CAPSTONE PROJECT REPORT

M3 REPORT

Topic: Research and integration of PPC (Power Plant Controller) for industrial and commercial (C&I) rooftop solar power plants to meet the requirements of connection to SCADA/EMS system of local power dispatching

Student: Doan Le Xuan An
Class: 20PFIEV2
ID Student: 123200050

Instructor: Doan Ngoc Thanh
TS. Le Quoc Huy

Da Nang,/ 06/2025

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SUMMARY

Project name: Research and integration of controllers for industrial and commercial scale rooftop solar power plants. The PPC-Power Plant Controller for C&I rooftop solar power plant meets the connection requirements of the SCADA/EMS system of the local power dispatcher.

Student: Doan Le Xuan An

Student ID Number: 123200050

Class: 20PFIEV2

Summary of the topic:

- Topic description:
 - The configuration for the controller and use is the central control of PPC connected to Inverter, mesh, other field-level devices.
 - Write the program to control the effective and repulsive power for the PPC and connect it to the dispatching center's SCADA/EMS.
 - Programming can be combined with multi-company Inverter.
- Purpose:
 - Apply modern technology to the solar power network and not be tied to an inverter.
 - Reduce costs, monitor, operate, and manage anytime, anywhere.
- Results:
 - The system operates stably, can operate for a long time.

GRADUATION PROJECT TASKS

TT	Student's Name	SV Card Number	Class	Industry
1	Doan Le Xuan An	123200050	20PFIEV2	Industrial Informatics

1. Project Title:

Research and integration of PPC (Power Plant Controller) for industrial and commercial (C&I) rooftop solar power plants to meet the requirements of connection to the SCADA/EMS system of local power dispatchers.

2. The topic falls into: Having signed an intellectual property agreement on the implementation results ☐

3. Initial figures and data :

.....

.....

.....

.....

4. Contents of explanations and calculations :

a. General part :

TT	Student Name	Content
1	Doan Le Xuan An	- Research on solar power systems. - Research on the process and role of PPC in solar power systems. - Learn how PPCs work. - Research solutions and how to configure and program controls for PPC - Learn about the programming and communication of inverters to connect to PPC - Find directions and come up with solutions to solve the requirements of the topic. - Conduct system testing, calibration, and evaluation of results.

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b. Separate part:

TT	Student's Name	Content
1	Doan Le Xuan An	- Processing data collected from the manuals of the devices used. - Use software to configure and program for PPC - Do HMI to control and display control parameters for PPC and HMI EVN from dispatching power - Summarize content and write reports.

5. Instructor's name:	Part/Content:
TS. Le Quoc Huy	- Monitoring the implementation progress. - Examine and give feedback based on the completed work.
Doan Ngoc Thanh Tran Dang Dat	- Practical knowledge guidance. - Provide references.

6. Date of assignment of project tasks: 18/03/2025

7. Project completion date: 30/06/2025

Da Nang, the day July 2025

**Head of the Department of Industrial
Informatics**

Instructor

PREFACE

After a period of study and research at the University of Science and Technology – University of Da Nang. With the teaching and guidance of teachers, the project team has been fully equipped with the knowledge and qualities of a technician. Finish the theoretical part at the school and implement the graduation project to synthesize knowledge and complete the study program.

In recent years, under the leadership and supervision of Mr. Le Quoc Huy, the team has carried out the graduation project "**Research and integration of PPC (Power Plant Controller) for industrial and commercial (C&I) rooftop solar power plants to meet the requirements of connection to the SCADA/EMS system of the local power dispatcher**".. I have learned more about the solar power system. This is a very valuable opportunity to help us access new knowledge that is a premise to help us understand the project design process for a business or company to supplement our future work.

This graduation project is an important milestone to test students' awareness during their studies and the knowledge that has been taught in the school. At the same time, it also assesses the ability to apply theory to analyze, synthesize and solve problems in practice when doing a large project for the company. Aware of that importance, the team has worked seriously to apply the knowledge learned during their time at school, the contributions of friends and especially the guidance of Mr. Le Quoc Huy to successfully complete the graduation project.

Although, I tried hard to complete the project. However, due to limited qualifications, there are still shortcomings, the project team is looking forward to the guidance and help of the teachers so that this work of the group is more complete.

The team would like to sincerely thank all the teachers of PFIEV in particular and Da Nang University of Science and Technology in general for their dedicated instruction from general subjects to specialized subjects.

The team would like to sincerely thank Vietnam Solar Power EPC Joint Stock Company for facilitating and helping the team during the project. Thank you to the engineers for enthusiastically guiding and answering many questions for the group.

Our project team would like to wish Mr. Le Quoc Huy good health and success in his work and in life in the future to Mr. Le Quoc Huy and all teachers of Da Nang University of Science and Technology

Thank you very much !

Da Nang, ...July, 2025

ASSURE

The project team committed: Graduation project "Research and integration of controllers for industrial and commercial-scale rooftop solar power plants. PPC-Power Plant Controller for C&I rooftop solar power plant meets the requirements of connecting to the SCADA/EMS system of the local power unit dispatcher". Was carried out with the efforts of the team, self-research and experiments under the guidance of Mr. Le Quoc Huy and Mr. Doan Ngoc Thanh.

The data and research results in the project are honest and do not copy or use the results of any similar research topic. If it is found that there is a copy of the research results of another topic, the team would like to take full responsibility

Student group

Doan Le Xuan An

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CHAPTER 1. AN OVERVIEW OF THE TOPIC AND ITS URGENCY

1. Global solar market.

There has been strong growth in recent years, thanks to the increasing demand for clean and sustainable energy sources. Technological developments, supportive government policies, and a sharp decline in the cost of solar panels have fueled the expansion of this industry.

- + **Total installed capacity** (in 2023): about **1.5 TW** (terawatt).

- + **Annual growth rate**: about **20% - 25%**.

- + **Forecast 2030**: expected to reach **5 TW** of installed capacity

- + **Market size**: According to reports from IEA and BloombergNEF, the solar market reached about **239 GW of new capacity** in 2022, and is expected to continue growing at an average annual rate of **10-15%** through 2030.

- + **Proportion in renewable energy** : Solar power currently accounts for about **30% of the total global renewable energy capacity**.

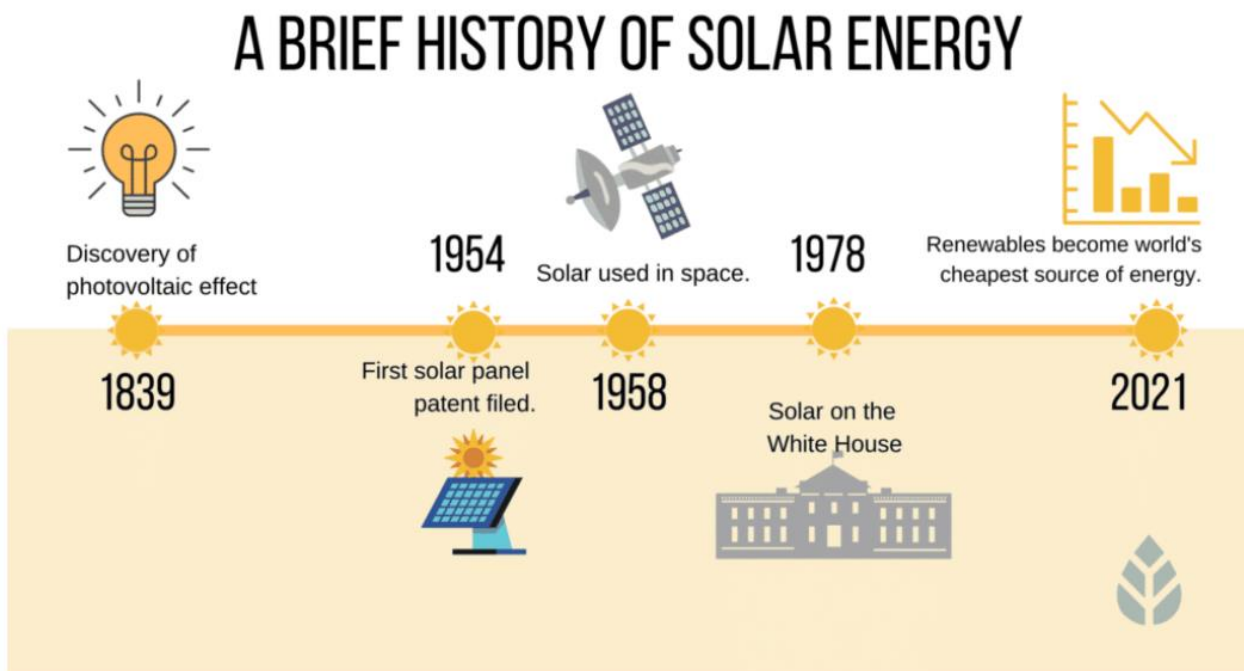


Figure 1: History of the development of the solar industry

2. The main trend of the current market of solar power.

+ Increase installed capacity:

- China, the United States, India, and Europe are the largest markets for solar capacity.
- The trend of distributed solar and utility-scale solar projects is thriving.
- Solar cell capacity is getting higher and higher, with photovoltaic panels with **an efficiency of more than 22%** becoming increasingly popular.

+ Advanced technology:

- **Energy Storage System (BESS):** Combined with a lithium-ion battery system to optimize electricity production and consumption.
- **Perovskite technology and bifacial panels :** Changing the game with higher performance.
- **AI & IoT in Grid Management :** Enhancing the ability to control and optimize solar power systems.

+ Installation and purchase costs are reduced at a more reasonable price than before.

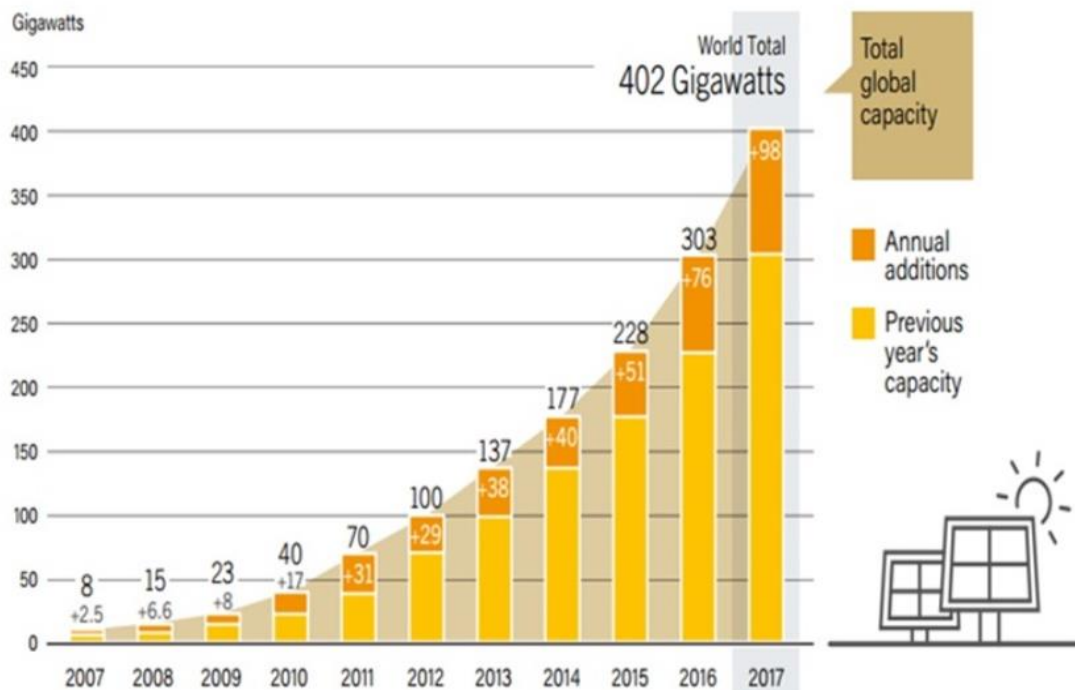


Figure 2 : Solar power output from 2007 to 2017

➔ In the period 2007-2017, the development rate of solar power generation increased very quickly. Currently, an average of 500,000 solar panels are installed every day worldwide.

Market share by region:

- **Asia-Pacific (APAC):** Accounts for **more than 55% of the market share**, with leading countries such as **China, India, Japan, and South Korea**.
- **Europe:** Contributing about **20%**, with Germany, Spain and the Netherlands being key markets.
- **North America:** About **15 percent**, with the U.S. leading the way.
- **Middle East & Africa:** Rapid growth thanks to large-scale projects, especially in the UAE and Saudi Arabia.
- **Latin America:** Emerging with Mexico and Brazil leading the way.

Key Technology Providers:

+ Leading solar panel manufacturer:

- LONGi Solar (China)
- JinkoSolar (China)
- Trina Solar (China)
- Canadian Solar (Canada)
- First Solar (USA)

+ Inverter manufacturer:

- **Huawei (China)** – the leader in the global market.
- **SMA (Germany)** – popular in Europe.
- **Sungrow (China)** – strong growth.
- **Fronius (Austria)** – highly regarded for its quality.
- **SolarEdge (Israel)** – specializing in optimal chain inverters.

3. Vietnam solar energy market.

Vietnam's solar market is estimated to reach 18.4 GigaWatt (GW) by the end of this year and is expected to reach 20.4 GigaWatt (GW) after 5 years, registering a CAGR of over 2.1% during the forecast period.

- In the medium term, increasing investments in the renewable energy sector, increasing demand for electricity in major provinces, and the country's efforts to transition away from fossil fuel-based power generation are expected to drive the market during the forecast period.
- On the other hand, the increasing adoption of alternative clean energy sources and high initial investment costs of solar projects are expected to hinder the growth of the market during the study period.
- However, Vietnam's Power Development Plan VII intends to increase the share of renewable energy to 10% in 8 years. It will also reduce the use of imported coal-fired electricity, which brings great opportunities to the country's solar energy market.



Figure 3: The development history of solar power in Vietnam from 2014 to now

4. Vietnam solar energy market trends.

The solar power (PV) segment is expected to dominate the market

- The solar photovoltaic segment is likely to hold the largest share during the forecast period, owing to the declining cost of solar modules and the versatility of these systems for various applications, such as power generation and water heating.
- According to IRENA Renewable Energy Statistics 2023, the installed capacity of solar power in Vietnam is about 18,474 MW in 2022, up from 16,660 MW in 2021. This growth is a result of the widespread deployment of solar power installations in Vietnam, especially for utility projects. The Ministry of Industry and Trade (MOIT) has more plans to increase the installed capacity of solar power.
- In May 2023, the Vietnamese government launched a \$135 billion energy strategy, in which half of residential rooftops across the country will be equipped with photovoltaic (PV)

systems through a network metering system. The government hopes to become an exporter of electricity in the next 8 years.

- Moreover, Vietnam plans to put into operation the Phong Hoa Solar Power Plant with a capacity of 50 MW located in Thua Thien-Hue province by the end of 2023. The project is being developed by STEAG Solar Energy Solutions and Thai Dat Construction.
- Owing to these developments, the solar power segment is expected to have the largest market share in Vietnam during the forecast period

Vietnam Solar Energy Market: Total Solar PV Installed Capacity, in MW, Vietnam, 2017-2022

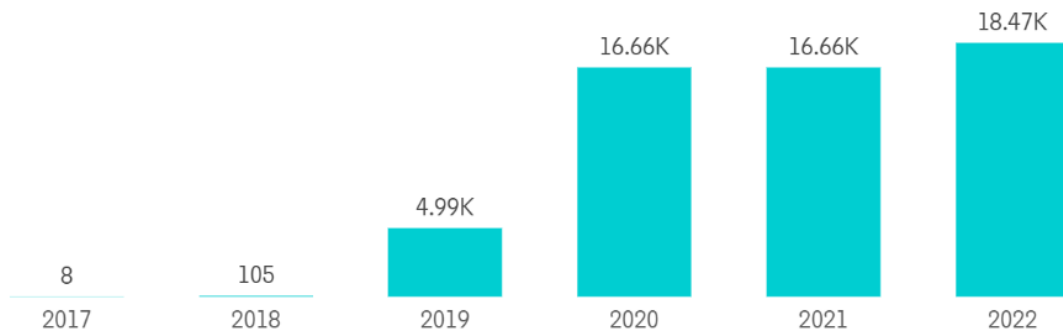
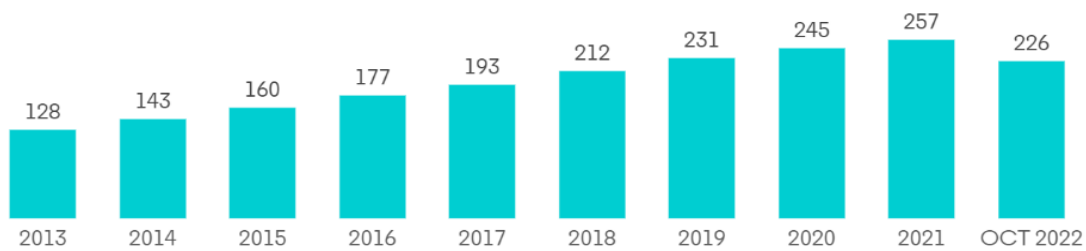


Figure 4: The solar power market in Vietnam has total installations over the years

- Rising Electricity Demand Drives Market Demand
- Vietnam's Ministry of Energy predicts that the country may fall into a shortage of electricity due to the development of new power plants lagging behind the country's rapidly growing energy consumption rate.
- With the increasing pace of industrialization and economic modernization, energy demand is expected to increase by more than 8% per year over the next 7 years.
- In the first 10 months of 2022, Vietnam's total electricity output and demand reached 226 billion Kilowatt hours. Over the past decade, energy demand has increased year by year. Moreover, Vietnam will need 96,500MW of electricity in the next two years and 129,500MW in the next seven years to meet the growing demand.
- To meet the upcoming electricity demand, Vietnam needs about \$10 billion per year until 2030 to keep up with the growing demand. With such high capital requirements, the Government has allowed 100% foreign ownership of Vietnamese companies in the energy sector.
- Thus, Vietnam is focusing on renewable energy sources to meet future electricity demand, which is driving the growth of Vietnam's solar energy market.

Vietnam Solar Energy Market: Energy Production and Demand, in billion KWh, Vietnam, 2013- Oct 2022



Source: Vietnam Power Group EVN



Figure 5: Solar power market in Vietnam total installed capacity over the years

Source: <https://www.mordorintelligence.com/vi/industry-reports/vietnam-solar-energy-market>

Technology suppliers for the Vietnamese market :

+Leading solar panel manufacturer :

- 1) JinkoSolar (China).
- 2) LONGi Solar (China).
- 3) Canadian Solar (Canada).
- 4) Trina Solar (China)

+ Inverter manufacturer :

- 1) SMA (Germany)
- 2) Huawei (China)
- 3) Sungrow (China).
- 3) Fronius (Austria)

+ Solution providers for solar power :

- 1) ATS
- 2) BKAS
- 3) Huawei

5. The urgency of the topic.

On the market today, there are PPC specialized devices/systems or data managers/data loggers such as SMA's SMA Data manager or Huawei's Smart logger 300A to perform the function of data collection, equipment management for the control and monitoring of industrial and commercial solar power plants. However, these devices have the disadvantage that they are only compatible with one inverter manufacturer (such as SMA or Huawei,) and do not have a connectivity feature that is compatible with the new SCADA/EMS requirements of local electricity.

Therefore, the research, design, and integration of PPC that is both capable of connecting to equipment of many different manufacturers and compatible with SCADA/EMS connection of local electricity is an urgent task of this topic to meet the great needs of customers.

➔ Therefore, the urgency of this project is great to solve the problems that investors as well as construction can solve the problem of cost optimization and can be flexible in expanding and integrating more equipment when upgrading the system to better suit the actual situation.

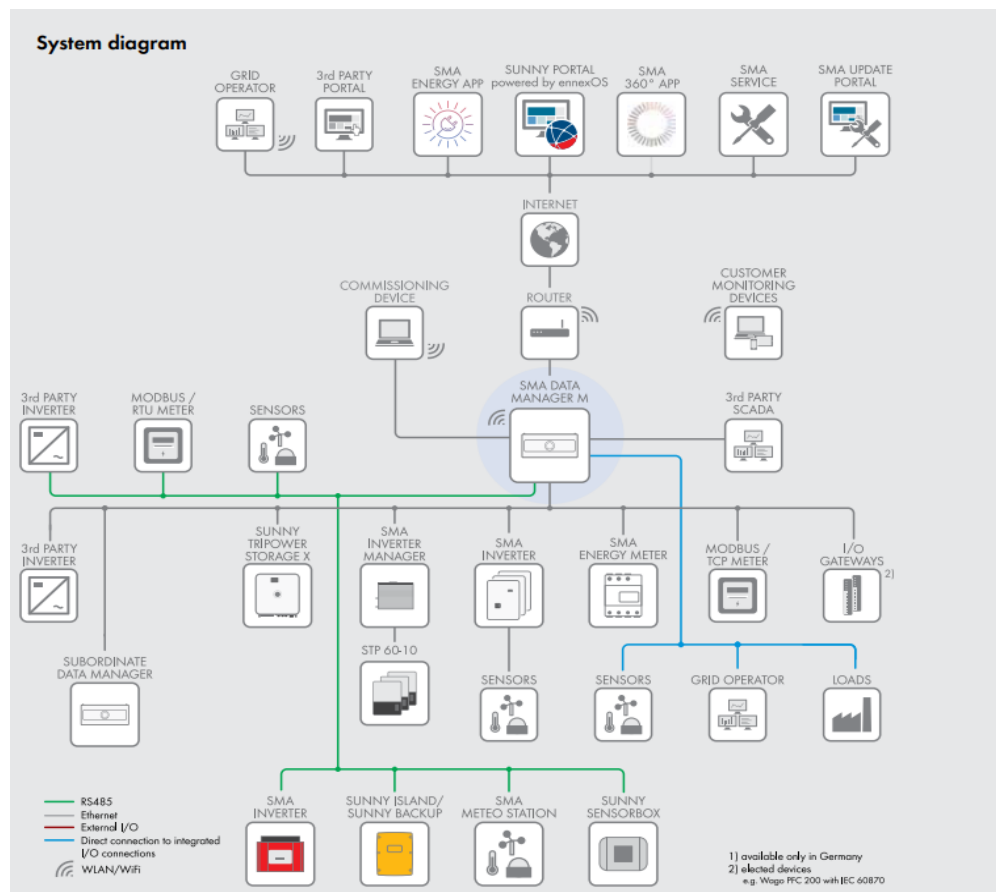


Figure 6: System connection diagram of SMA

Based on the diagram above, we can see that the Inverters connected to SMA DATA MANAGER must be connected to SMA. This makes it difficult to optimize the installation cost for the system. Therefore, being able to integrate a central controller **that can connect to devices from different manufacturers** is essential for the current situation.

*Regarding local electricity regulations for plants with a capacity of 1MW or more, it is required:

- 1) Monitoring and data exchange functions
- 2) Control Functions
- 3) Operational data storage function
- 4) Security functions.

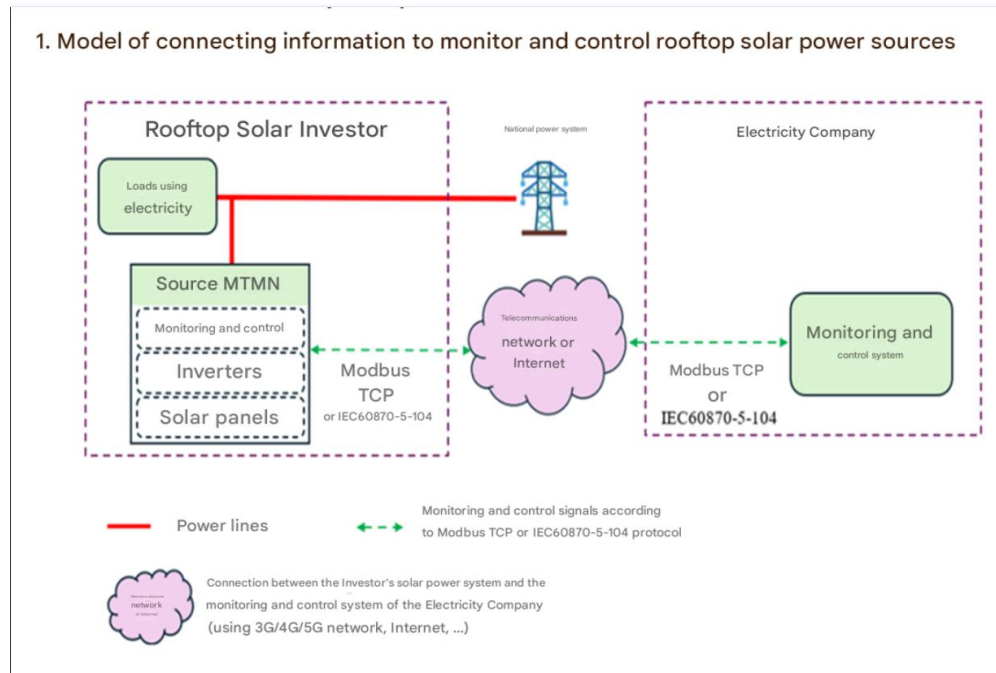


Figure 7: Model of connecting information to monitor and control rooftop solar power

o Required monitoring and control signals					
TT	Parameter	IEC60870-5-104 Protocol		Modbus TCP protocol	
		Data type	Address	Data type	Address
1	Monitoring signal				
	Instantaneous active power delivered to the grid (P-out)	T13	1	T04	1
2	Control signal				
	Enable P-out control	T45	11	T05	11
	SetPoint P-out theo %	T50	12	T06	13

*Signals and parameters need to be controlled according to local electricity requirements

o Recommended monitoring and control signals (if any)

TT	Parameter	IEC60870-5-104 Protocol		Modbus TCP protocol	
		Data type	Address	Data type	Address
I	Monitoring signal				
	Instantaneous reactive power delivered to the grid (kVAr)	T13	2	T04	3
	Instantaneous phase voltage Ua (V)	T13	3	T04	5
	Instantaneous phase voltage Ub (V)	T13	4	T04	7
	Australian instantaneous phase voltage (V)	T13	5	T04	9
	Instantaneous phase current Ia (A)	T13	6	T04	11
	Instantaneous phase current Ib (A)	T13	7	T04	13
	Instantaneous phase current Ic (A)	T13	8	T04	15
	Frequency (Hz)	T13	9	T04	17
	Power factor	T13	1105	T04	1109
II	Control signal				
	Enable Q-out control	T45	12	T05	15
	SetPoint Q-out theo %	T50	13	T06	17

*Signals and parameters need to be monitored and controlled according to local electricity requirements (if we have)

Source : Nghị định số 135/NĐ-CP ngày 22/10/2024 của Chính phủ

CHAPTER 2. DETAILS OF THE TECHNICAL SOLUTION APPLIED TO SOLVE THE PROBLEM

1. General block diagram of the system.

The technical solution is that the PPC unit acts as a gateway and datalogger to connect the inverters of many brands and SCADA Local and Dispatching Centers.

Step 1 : Collect the communication protocol information of the company's Inverter.

Step 2 : Determine the transmission function of the control object and the measurement signal and controller.

Step 3 : After determining the transfer function, find the parameter of the transfer function and put it on Matlab to simulate the stability of the system and calibrate the parameter of the transfer function so that it is most stable with the message time.

Step 4 : Design a local HMI for the controller for PPC to suit the requirements of the topic.

Step 5 : Make a drive containing communication information such as: Register address, Communication protocol, Log data type, Device ID, Units of measurement in the register, Byte type (**Big Endian** or **Little Endian**) for each company you want to connect to. (SMA, Sungrow, Deye)

Step 6 : Write a control algorithm program for the PPC controller to control the control object (Inverter).

Step 7 : To connect to the dispatch center (EMS), you need a separate router and connect according to the IEC 60870-5-104 or Modbus TCP protocol to transmit information to the dispatch center (EMS). From the dispatch center sends control signals and reads data from the system.

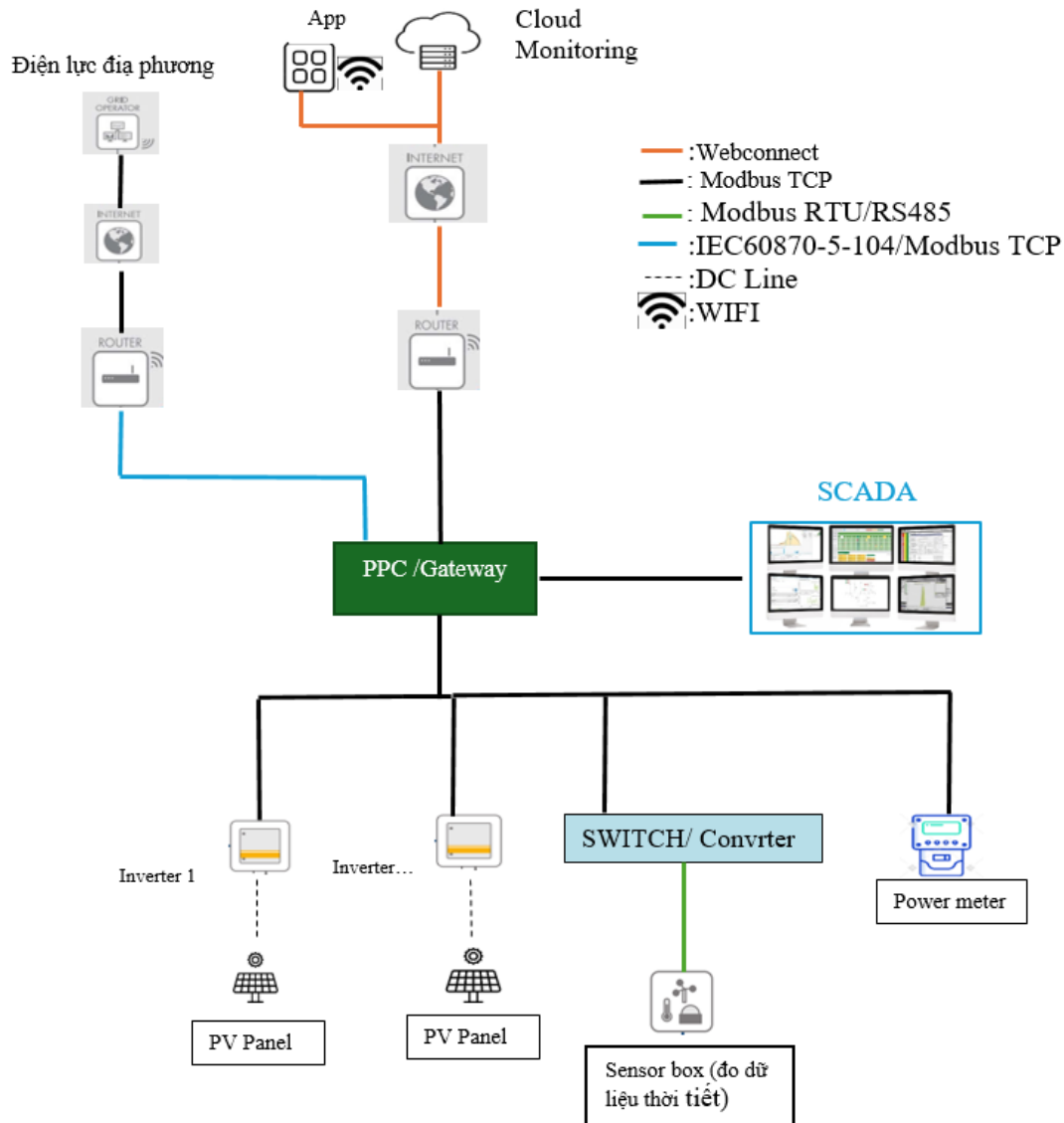


Figure 8: System Block Diagram

2. Inverter Communication Protocol Information Collection

The system is required to be able to connect to many inverters of many different brands, with different connection protocols.

Below are some popular inverters in the Vietnamese market today.

SMA Inverter Communication Protocol

- **RS485:** Can be installed to communicate with SMA communication devices or other inverters.
- **Speedwire/Webconnect:** An Ethernet-based communication protocol that enables high-speed data transfer between Speedwire devices in the PV system and the Sunny Explorer software.

- **Bluetooth:** Allows wireless communication between the inverter and other communication devices.



Figure 9: Inverter SMA SUNNY BOY 3000TL

Communication Protocol of Sungrow Inverter

- **RS485:** Used to connect to monitoring devices and transmit operational data.
- **Modbus RTU/Modbus TCP:** Supports communication with remote control and monitoring systems.
- **Wi-Fi/Ethernet/GPRS:** Through the communication accessory port, the inverter can connect to Wi-Fi, Ethernet, or GPRS modules manufactured by Sungrow to transmit data to the iSolarCloud application.



Figure 10: Inverter SUNGROW SH 3.6RS

Communication Protocol of DEYE Hybrid Inverter 12K-SG04LP3-EU



Figure 11: Inverter Deye Hybrid 12K-SG04LP3-EU

Supported Communication Protocols :

- **RS485/RS232:** Use to communicate with monitoring systems, BMS or external devices.
- **CAN:** Used to communicate with battery management systems (BMS), especially with lithium-ion batteries.
- **Modbus RTU / Modbus TCP:** Supports communication with devices such as PLC, SCADA or monitoring software.
- **Wi-Fi/LAN/4G/Bluetooth:** Allows remote monitoring through the app or web gateway.
- **GPRS:** Optional for cellular network connectivity.

Ports and Functions

- **Meter_CON:** The port communicates with the energy meter. **BMS:** The gateway that communicates with the battery management system.
- **Parallel A/B:** Parallel communication port when connecting multiple inverters.
- **CT-L1/CT-L2:** Connects to a current transformer (CT) to measure current and supports "zero export" mode.
- **G-start:** Dry signal to start the diesel generator.
- **RSD_12V_out:** Provides 12V DC power when the inverter is operating.
- **ATS_240V:** 230V AC output port when the inverter is operating.

3. Determine the transmission function of the stage of taking the signal to measure the applied power (P) and the reactive power (Q) and the parameters for the measurement transmission function.

In fact, **both P and Q** are measured through :

- Current Sensor
- Voltage Sensor
- Power Meter

- SCADA/PLC Data Collector

Both are affected by :

- Hardware Latency
- Sampling time
- Signal Processing Speed

Therefore, the measurement transfer functions of P and Q **are usually similar in terms of modeling**, and are represented by **first-order filters**:

$$H_P(s) = \frac{1}{T_m s + 1}$$

$$H_Q(s) = \frac{1}{T_m s + 1}$$

In which:

- $H_P(s)$ is the transmission function that measures the active power
- $H_Q(s)$ is the reactive power transfer function
- T_m is the **measurement time constant** (the same for both P and Q in the majority of systems)

Actual T_m parameter value:

According to international standards (such as ENTSO-E, EVN, IEEE), T_m is also referenced according to the following standards:

Measurement System Level	Recommended Parameter T_m	Remarks
High-speed measurement devices (PMU, Fast Meter)	0.01 ~ 0.05 seconds	Ultra-fast (e.g., 20 ms)
Medium-speed SCADA systems	0.05 ~ 0.2 seconds	Most common (e.g., 100 ms)
Legacy SCADA/PLC systems or slow sampling systems	0.2 ~ 0.5 seconds	Slow systems

In the actual solar power plant, the commonly recommended T_m (time constant) parameter is : $T_m = 0.1$ s (According to the standards of Vietnam Electricity Company EVN), that is, **there is a delay of about 100 ms** in the P and Q measurement signals.

Measured Signal	Transfer Function	Typical Parameter
Active Power (P)	$H_P(s) = \frac{1}{T_m s + 1}$	$T_m = 0.1$ seconds
Reactive Power (Q)	$H_Q(s) = \frac{1}{T_m s + 1}$	$T_m = 0.1$ seconds

4. Define the Inverter's transmission function.

An inverter is a converter of direct current (DC) to alternating current (AC). In system control and simulation (e.g., grid-connected solar power plants), an **inverter is modeled using a transmission function** to:

- Power Response Analysis (P, Q)
- Voltage, frequency, or power controller design

The levels of Inverter modeling include:

a. Switching Model

- Including simulation of each semiconductor device (IGBT, MOSFET), transformer, IC filter **(Inductor + capacitor) ...**
- Complicated, very high simulation time requirements.
- **Do not use simple transfer functions.**

b. Average Model

- Suppose the inverter acts as a **Controlled Voltage** Source.
- It can be modeled using **a first-order or second-order transfer function.**

c. Ultra-Simple Model (High-Level Control Model)

- The inverter is considered a system with a small latency.
- Suitable when designing power, frequency, or voltage control in large systems.

Common Transmission Functions for Inverters in P/Q Power Control

Most commonly, an inverter is modeled with a first-order transmission function as follows:

$$G(s) = \frac{1}{T_{inv}s + 1}$$

Inverter Type	Typical T_{inv} Parameter	Remarks
PV Inverter	0.01 ~ 0.05 seconds	Fast response
BESS Inverter (Battery Energy Storage System)	0.02 ~ 0.1 seconds	Medium response
High-power inverter (wind, grid-forming)	0.05 ~ 0.2 seconds	Slightly slower response

In the actual solar power plant, it is usually chosen: $T_{inv} = 0.02 - 0.05$ s, which means the inverter can respond to the power signal in 20-50 ms.

5. Communication information and connection methods with Inverters of SMA and Sungrow.

Step 1: Prepare information from SMA and Sungrow inverters and standardize communication with inverters via open protocol

- **Communication Type:** Modbus RTU (RS485) or Modbus TCP (Ethernet)
- **Device Address (Slave ID):** SMA slave ID:3 ; Sungrow slave ID: 1
- **The Modbus Register Map document** contains:
 - ✓ Register address (e.g. 40775 – capacity)
 - ✓ Data Type: INT16, UINT32, FLOAT32
 - ✓ Unit: kW, V, Hz, Var
 - ✓ Byte Types: Big Endian and Little Endian
 - ✓ Modern inverters (such as SMA, Sungrow) **all support the Modbus protocol** (RTU or TCP).
 - ✓ Therefore, **PPC can be developed to have a read/write software interface via Modbus**, in accordance with the standard.

Step 2. Connect the hardware and build an "Abstraction Class" – Device Mapper

- **Modbus RTU (RS485):** connects the COM port on the SEL 3505 to the inverter's RS485 port.
- **Modbus TCP:** connects via Ethernet LAN port to the IP address of the inverter.

Because each inverter company:

- **There are** different register address **mappings**.
- Different data formats.

Inverter Company	Protocols	Communication protocols, data types	Regime	Byte Type
SMA	MODBUS	RS485 / Ethernet ; uint16/enum 16/bitfield 16/string/sunssf/acc32	RTU/TCP	Big Endian 32-bit data (e.g. FLOAT32, UINT32) is split into 2 16-bit registers. - High Bytes (MSB) are transmitted first. - Example: - FLOAT32 = 43FA0000 - Modbus Registers: - Reg 30775 = 43FA (MSB) - Reg 30776 = 0000 (LSB)
SUNGROW	MODBUS	RS485 / Ethernet ; int16/U16/U32/S32/S16	RTU/TCP	Little-Endian - With FLOAT32, low bytes (LSB) are transmitted first. - Example: - FLOAT32 = 000043FA - Modbus Registers: - Reg 30012 = 0000 (LSB) - Reg 30013 = 43FA (MSB)
Deye	MODBUS	RS485/Ethernet ; int16/U16/U32/S32/int32 /float32/uint32/uint16	RTU/TCP	Big Endian 32-bit data (e.g. FLOAT32, UINT32) is split into 2 16-bit registers. High Bytes (MSB) are transmitted first. Example: - FLOAT32 = 43FA0000 - Modbus Registers: - Reg 30775 = 43FA (MSB) - Reg 30776 = 0000 (LSB)

No (DEC)	Description/Number code	CNT (WORD)	Type	Access
Header:				
40238	Model ID (ID): 120 = SunSpec Nameplate Model	1	uint16	RO
40239	Number of the following Modbus registers in accordance with the PICS table (L): 26	1	uint16	RO
Fixed Block:				
40240	DER type (DERType), (SMA: Device type): 4 = PV device	1	enum 16	RO
40241	Continuous active power capability (WRtg), in $W \cdot 10^{WRtg_SF}$ (40242), (SMA: Maximum device active power).	1	uint16	RO
40242	Scale factor continuous active power capability (WRtg_SF): 2	1	sunssf	RO

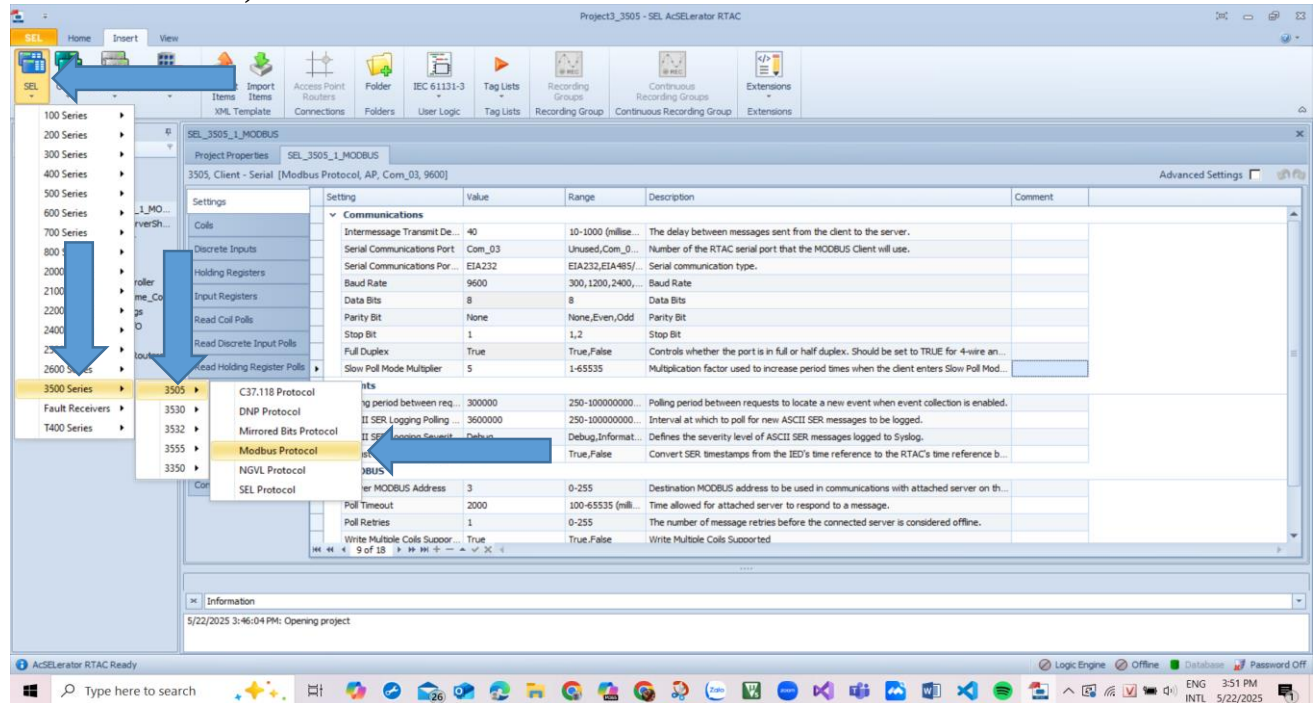
Figure 12: Example of register address and data format of Inverter SMA

No.	Name	Address	Data type	Data range	Unit	Note
1.	Protocol num	4950 - 4951	U32			
2.	Protocol ver	4952 - 4953	U32			
3.	Arm software ver	4954 - 4968	U16			
4.	DSP software ver	4969 - 4983	U16			
5.	Reserved	4984 - 4989	U16			
6.	SN	4990 - 4999	UTF-8			Data type :UTF-8
7.	Device type code	5000	U16			See Appendix 5
8.	Nominal active power	5001	U16		0.1kW	

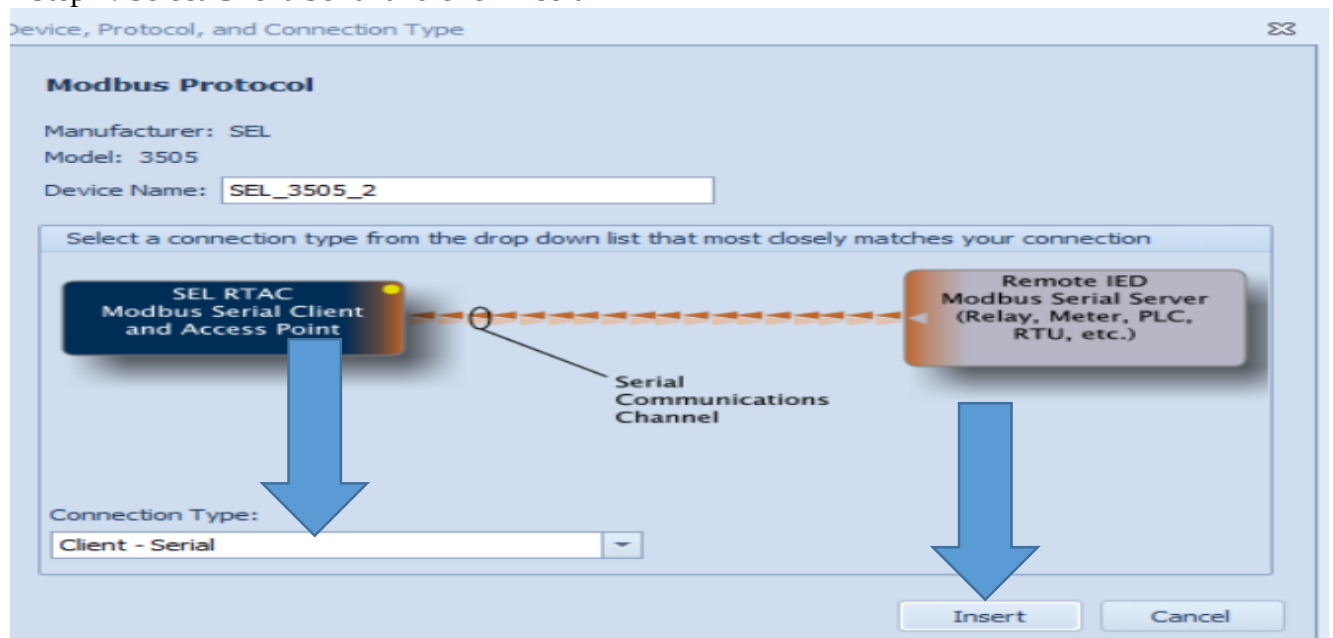
Figure 13: Sungrow Inverter register address and data format example

Step 3. Configuration in SEL 5033 software and "Driver-based" SEL 3505 design.

- Step 1: Modbus RTU Configuration (Modbus/RTU configuration, you can choose other protocols such as Ethernet...)



- Step 2: Select Client-Serial and click Insert



- Step 3 : Modbus configuration interface of SEL-5033

Intermessage Transmit De...	40	10-1000 (millise...	The delay between messages sent from the client to the server.
Serial Communications Port	Com_03	Unused,Com_0...	Number of the RTAC serial port that the MODBUS Client will use.
Serial Communications Por...	EIA232	EIA232,EIA485/...	Serial communication type.
Baud Rate	9600	300,1200,2400,...	Baud Rate
Data Bits	8	8	Data Bits
Parity Bit	None	None,Even,Odd	Parity Bit
Stop Bit	1	1,2	Stop Bit
Full Duplex	True	True,False	Controls whether the port is in full or half duplex. Should be set to TRUE for 4-wire an...
Slow Poll Mode Multiplier	5	1-65535	Multiplication factor used to increase period times when the client enters Slow Poll Mod...
Events			
Polling period between req...	300000	250-100000000...	Polling period between requests to locate a new event when event collection is enabled.
ASCII SER Logging Polling ...	3600000	250-100000000...	Interval at which to poll for new ASCII SER messages to be logged.
ASCII SER Logging Severit...	Debug	Debug,Informat...	Defines the severity level of ASCII SER messages logged to Syslog.
Adjust ASCII SER Logging ...	True	True,False	Convert SER timestamps from the IED's time reference to the RTAC's time reference b...
MODBUS			
Server MODBUS Address	3	0-255	Destination MODBUS address to be used in communications with attached server on th...
Poll Timeout	2000	100-65535 (milli...	Time allowed for attached server to respond to a message.
Poll Retries	1	0-255	The number of message retries before the connected server is considered offline.
Write Multiple Coils Suppor...	True	True,False	Write Multiple Coils Supported
Write Multiple Holding Regi...	True	True,False	Write Multiple Holding Registers Supported

1. **Select the COM port** in use (e.g. COM3)
2. The configuration of communication parameters (baudrate, parity...) matches the inverter is EIA232 or EIA485,422
3. Baud Rate :9600 (Adjust according to Inverter)
4. Data Bits :8(Adjustable according to Inverter)
5. Parity bit :1(Adjusts according to Inverter)

This can help us connect to many Inverters of different brands by adjusting the configuration of each port according to each Inverter. The communication protocol on the software can be adjusted depending on how the system is installed.

Step 4. Use of data

Enter the registers to be read of the Inverter type e.g. SMA (400001), SUNGROW (4500-5999)

- Assign variables to **the control logic**
- Send data to **SCADA, HMI, Cloud**

6. Steps to proceed in practice

Steps	Job Description
1	Research on Modbus RTU and TCP protocols
2	Collecting Modbus Map of SMA inverter, Sungrow
3	Building software for the SEL 3505 as a multi-driver, multi-protocol
4	SEL 3505 modular software design (can add/remove drivers)
5	Actual testing with at least 2 inverter companies to validate multi-connectivity

7. Simulation method.

Basic diagram of the system and simulation on Matlab Simulink:

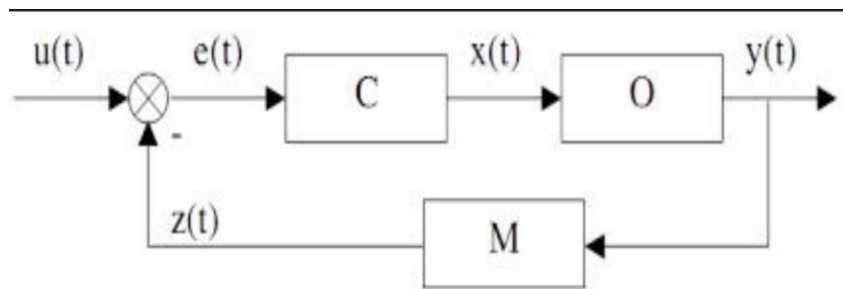


Figure 14: Basic diagram of the system

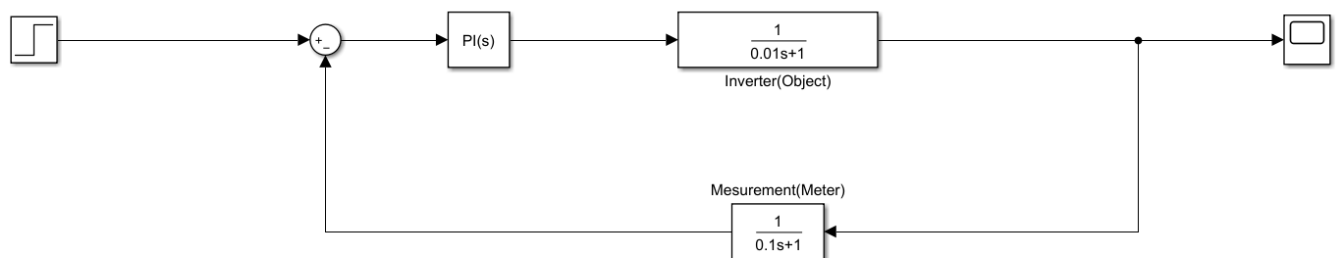
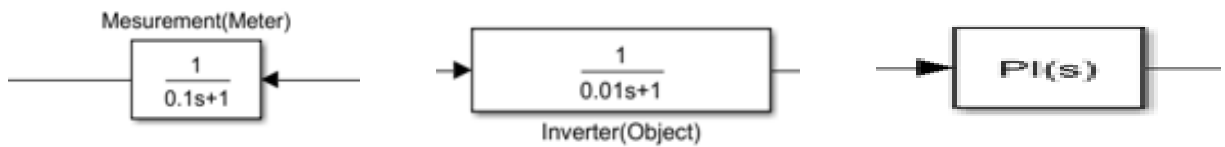


Figure 15: Simulation on Matlab

- The task is to find the transfer function parameter of the blocks as follows so that the system is stable for a period of 0.1 seconds.



It is necessary to stabilize the system for 0.1 seconds because :

Because the inverter is a fast dynamic control object including :

- Inverters have the ability to change the transmitting power (P/Q) very quickly, usually responding in a few tens of ms.
- So the **PI controller** used to regulate the output power (or voltage, current, frequency) also needs to be fast enough not to cause control delays.

To ensure the stable control of the system :

- When there is a deflation, inflator or Q adjustment order from the PPC → Inverter, the system needs a fast and stable response to avoid :
 - **Power Fluctuation**
 - **Prolonged transients**, causing voltage/frequency fluctuations
 - **Incorrect grip controls**

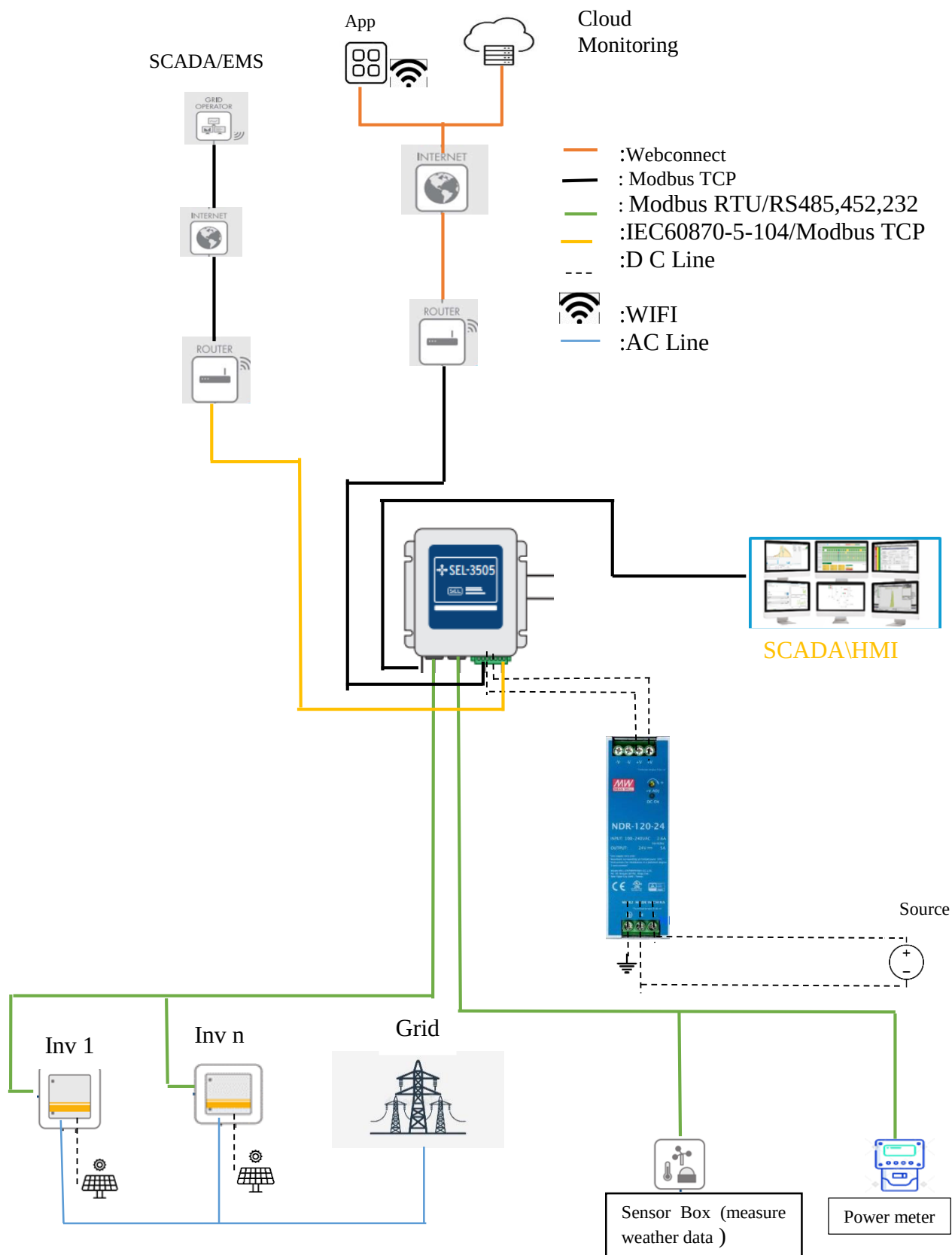
Because the requirements of grid connection standards (grid codes) :

- According to technical requirements such as EVN, **National Grid Code, IEC 61727, IEEE 1547**, commands from dispatching centers such as **Setpoint P/Q** need to be responded to in a short time (≤ 100 ms).
- Some systems also require the inverter **to meet the power control command for 50~100 ms**.

For Responding to PPC (Plant Power Controller) Requirements :

- PPC sends commands to set power (P_ref, Q_ref) every 100 ms ~ 1 second.
- If the PI ring responds too slowly (e.g. >300 ms), then it is impossible to stick to the PPC command → the control is unstable.

8. Connection diagram of the system and Modbus protocol



Modbus Protocol

MODBUS is an **industrial communication protocol standard** released and developed by MODICON in 1979, and officially belonged to Schneider Electric in 1996. MODBUS has quickly become the communication standard in the automation industries because of its stability, ease, convenience and more specifically FREE and is now maintained by the "modbus.org" organization.

MODBUS Operating Principle : MODBUS operates on the principle of "Master – Slave" or "Master – Servant". A Master can connect to one or more "Slaves". The "master" is usually a PLC, PC, DCS, RTU or SCADA. "Slaves" are usually field-level devices. In simple terms, it is a method used to transmit information over a serial line between electronic devices. The device that requests information is called Modbus Master, and the device that provides information is Modbus Slaves. In a standard Modbus network, there is one Master and a maximum of 247 Slaves, each with a unique Slave address from 1 to 247. The Master can also write information to the Slaves.

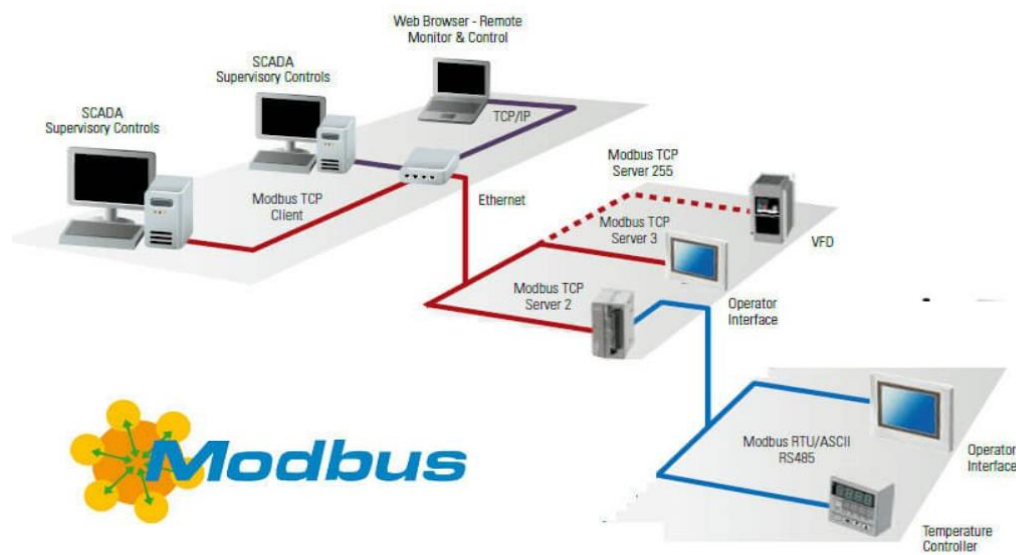


Figure 16: MODBUS Operation Process

Variant	Physical Layer Protocol	Characteristics
Modbus RTU	RS-485 / RS-232	Binary data, fast speed, most commonly used
Modbus ASCII	RS-232 / RS-485	Text-based data, easier to read but slower
Modbus TCP/IP	Ethernet	Based on TCP/IP, used in industrial LAN networks

9. Hardware and software used in the project

a) Hardware used in the project :

- SEL 3505 : acts as a controller and data collection in PPC.
- Inverters need to be connected to PPC (SMA, Sungrow, DEYE).



Figure 17: The inverter needs to be connected to PPC(SMA, Sungrow, DEYE)



Figure 18: Inverter Deye Hybrid 12K-SG04LP3-EU

❖ Main Specifications of SEL-3505 :

- **Dimensions** : 176.8 mm x 140.7 mm x 57.2 mm (6.96" x 5.54" x 2.25") – suitable for DIN bar or cabinet mounting

Communication Interface :

- 2 rear Ethernet ports (RJ45 or LC Fiber, 10/100 Mbps).
- SEL-3505 : 4 serial ports (2 ports EIA-232/EIA-485 selectable by software, 2 ports EIA-232).
- SEL-3505-3 : 3 serial EIA-232/EIA-485 ports selectable by software.
- 1 USB Type B port

I/O port number :

- SEL-3505-3 : 8 digital inputs, 3 digital outputs in Form C format.
- SEL-3505 : 1 digital input, 1 digital output.
- **Power supply** : 12–24 VDC or 24–48 VDC (optional).
- **Operating temperature** : –40°C to +85°C.
- **Processor** : 333 MHz, 512 MB DDR2 ECC RAM, 2 GB storage.

Supported Protocols :

- DNP3 (Serial, LAN/WAN), Modbus RTU/TCP, IEC 60870-5-101/104, IEC 61850 GOOSE, IEEE C37.118 (synchrophasor), SEL Fast Messaging, SEL Mirrored Bits

Outstanding features

- **IEC 61131-3 Logic Processor** : Supports programming using Ladder Diagram, Structured Text, Function Block, and Continuous Function Chart.

- **Synchrophasor Integration** : Supports the IEEE C37.118 protocol, which allows the integration of synchrophasor data into SCADA systems through protocols such as DNP3 or Modbus.
- **Playing the role of Cyber Security and EMS connection of EVN:**
 - Centralized user authentication via LDAP or RADIUS.
 - Access logging, gate control, and intrusion detection with accelerometers and optical sensors.
 - Supports SSL/TLS and SSH encryption.
- **Configuration Software** : Use the free ACSELERATOR RTAC® SEL-5033 software to configure and program the device

❖ Pv-met Weather Station 500



Figure 19: Pv-met 500 Weather Station

Specs and Sensors

Standard sensors (in the basic module) :

- **Ambient temperature** : AT-02 sensor, measurement range from -40°C to +80°C, accuracy $\pm 0.3^{\circ}\text{C}$.
- **Relative humidity** : Built-in AT-02 sensor.
- **Atmospheric Pressure** : Built-in AT-02 Sensor

Optional Sensors :

- **Solar Radiation Intensity (Irradiance)** :
 - Supports up to 3 sensors, including thermopile types (Class A, B, C) and silicon diodes.
 - Parameters such as Global Horizontal Irradiance (GHI), Plane of Array (POA), Albedo (for bifacial systems) and diffuse radiation can be measured.

- **Back-of-Module Temperature :**
 - Supports up to 3 BPT-01 sensors, measurement range from -40°C to +80°C, accuracy $\pm 0.3^\circ\text{C}$.
- **Wind speed and direction :**
 - Mini-Aervane sensor or CV7-V ultrasonic sensor.
- **Rainfall :**
 - Tipping bucket rain sensor, available in PVC or aluminum versions.

Communication and Power Supply :

- **Communication Protocol :** Modbus RTU (RS-485) or Modbus TCP (Ethernet).
- **Power supply :** 10–30 VDC, current consumption is about 50mA.
- **Data transfer rate :** 9600 baud, 2-wire half duplex.
- **Protection Rating :** IP65, operating in a temperature range from -40°C to +60°C.

Installation and integration :

- **Installation :** The PVmet 500 station is delivered as pre-assembled and factory calibrated, which saves installation time.
- **Interface :** Compatible with popular data loggers and SCADA systems such as Acquisuite A8810/A8820, FlexOM Gateway, VSN700, Data Manager M and Huawei Smartloggers.
- Must Comply with SunSpec and IEC 61724-1 standards, ensuring accuracy and reliability in PV system performance monitoring

❖ Solar panels, or photovoltaic (PV) modules



Figure 20: Jinko Solar Panel

A solar panel, or photovoltaic (PV) module, is a set of photovoltaic cells mounted on a frame for installation, which is used to convert light from the sun, including particles. The energy is called a "photon", an electric wall that can be used to power electric loads.

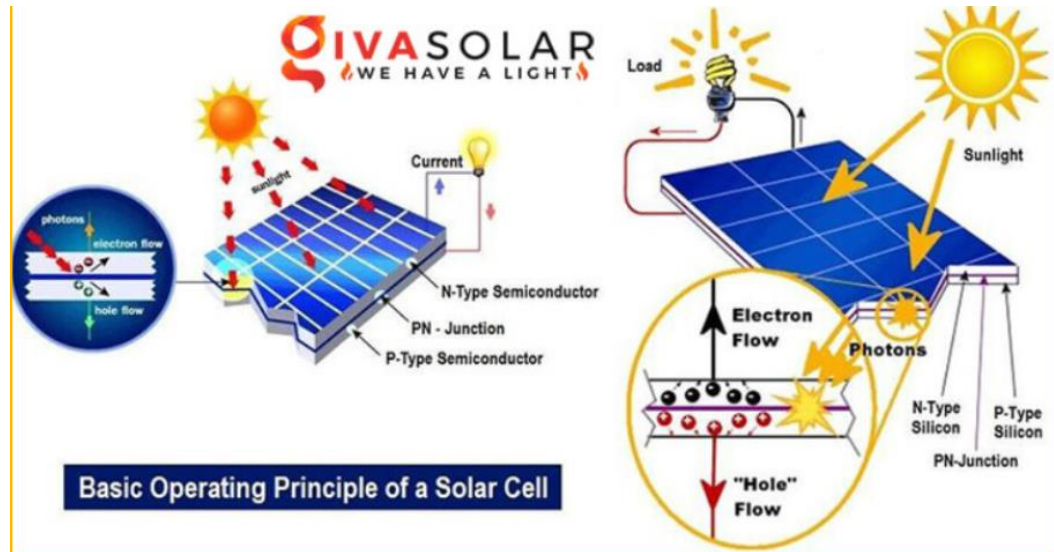


Figure 21: Solar Panel Structure

b) Software used in the project :

❖ SEL's SEL 5033 Software :

- Used to configure the SEL 3505 controller, collect and store real-time data
- The purpose is to configure the registers and communication protocols to be used to read data from control objects such as Inverter, Meter, PV panel, comparator.....
- Programmable according to IEC 61131-3 and loaded control program

❖ Software for writing and loading control programs for ADAM 3600 (optional)

❖ Using Labview as an HMI for the SEL 3505

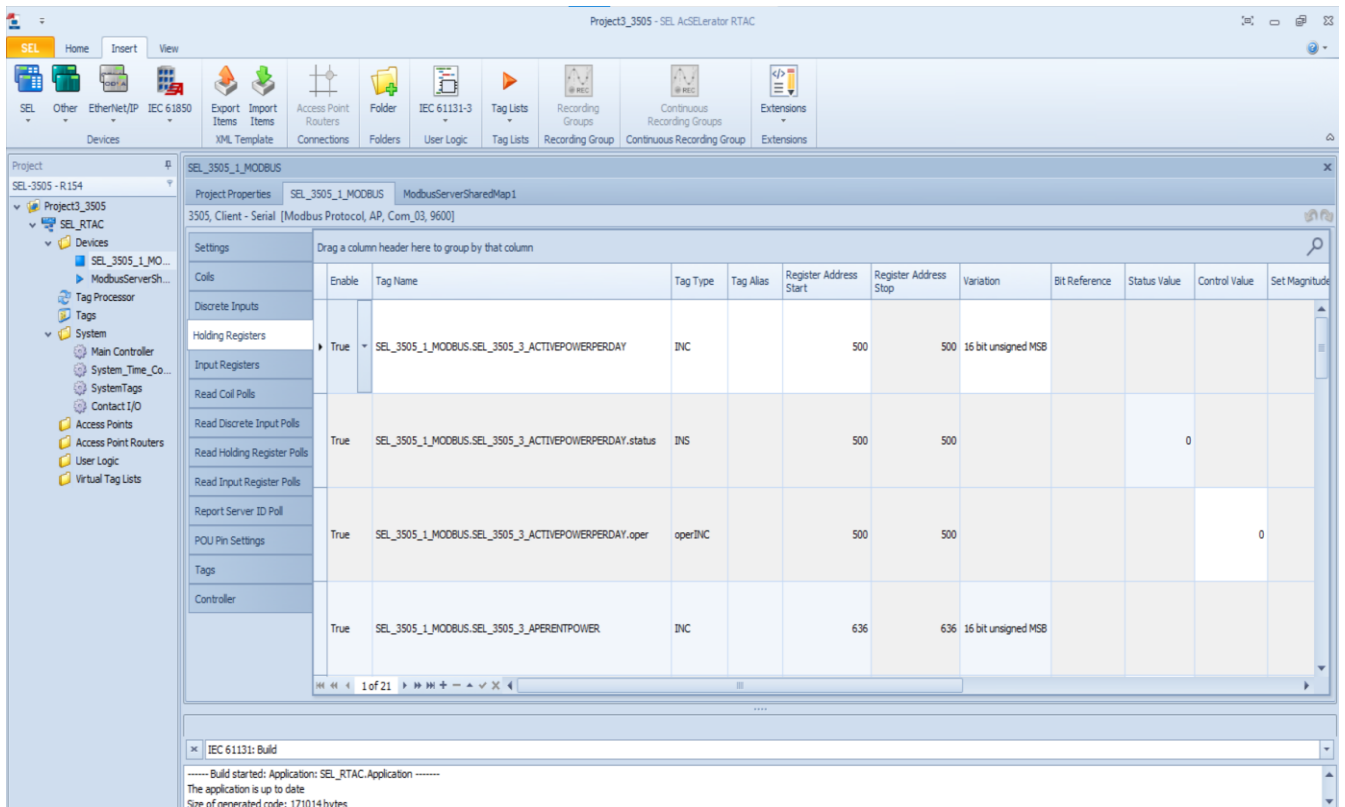


Figure 22: SEL 5033 Software

❖ Codesys Software :

1. Supports multiple programming languages

According to IEC 61131-3 :

- **Ladder Diagram (LD)** – similar to a traditional ladder circuit.
- **Structured Text (ST)** – like programming languages such as C/C++, Python
- **Function Block Diagram (FBD)** – programming functional blocks.
- **Instruction List (IL)** – giống Assembly
- **Sequential Function Chart (SFC)** – state-based programming.
- **Continuous Function Chart (CFC)** – a free-drag and drop form.

2. Simulation

It is possible to run program simulations without hardware, which is useful for development and testing.

3. Communicate and connect devices

- Supports standard protocols such as **Modbus (RTU/TCP), EtherCAT, CANopen, OPC UA, PROFINET, Ethernet/IP**, etc.
- It is possible to make **the gateway switch protocol**.

4. Web Programming & HMI

- CODESYS supports embedded HMI (WebVisu) interface design.
- Can be accessed via a browser to control and monitor the system.

5. Runtime on multiple platforms

- Can run CODESYS Runtime on devices such as Raspberry Pi, industrial PCs, Beckhoff PLCs, Wago, IFM, Bosch Rexroth, etc.
- There is a paid runtime for custom installations.

6. CODESYS Store

- A place to offer libraries, extensions, plugins (both free and paid) from the community and third parties.

7. Safety and security

- There are versions that support **CODESYS Safety** (for SIL applications), **CODESYS Security** (authentication, encryption, access decentralization).
- ❖ Visual studio software :

The purpose is to create a test run program for ADAM 3600 and build a database for the Server so that it can be accessed remotely.

Main Functions of Visual Studio

1. Drafting and compiling the source code

- Supports many languages such as: **C#, C++, Visual Basic, Python, JavaScript, TypeScript**, HTML/CSS...
- There is **an IntelliSense feature**: smart code suggestions, quick lookup of functions/variables/classes.

2. Powerful debug

- Step-by-step debugging, variable value tracking, call stack, breakpoints, watch variables...
- Hỗ trợ **remote debugging, multithread debugging, memory analysis**...

3. Project development and translation

- Automated project structure management (.sln, .csproj).
- There is **an MSBuild tool** that helps build projects independently or in a CI/CD series.
- Supports creating **Windows Forms, WPF, Console App, ASP.NET Web App**, etc.

4. Web & Cloud Development

- Tích hợp với **ASP.NET, Blazor, Azure SDF, Docker, Kubernetes**.
- Có sẵn mẫu project cho web API, web frontend (Angular/React/Vue), cloud app.

5. Cross-platform application development (Mobile/Desktop)

- Supports **.NET MAUI** or **Xamarin** to make the app run on **Android, iOS, Windows, macOS**.
- There is a mobile device simulation and a drag-and-drop GUI design.

6. Manage packages and libraries

- Integration with **NuGet** (like pip, npm), allows for quick installation of third-party libraries.

7. DevOps & Testing Tools

- **Git/GitHub** integration, Azure DevOps.
- Support writing **unit tests, integration tests, load tests**.
- There are test runners for MSTest, xUnit, NUnit...

8. GUI Design

- Drag-and-Drop interface for **Windows Forms, WPF**, visual design.

Visual studio can use the Python language for embedded programming for ADAM 3600 and a variety of text languages for writing drivers and creating databases for servers.

❖ Labview Software:

LabVIEW (short for **Laboratory Virtual Instrument Engineering Workbench**) is a **graphical programming environment** developed by **National Instruments (NI)** to:

- **Development of measurement, control, automation applications**
- HMI/SCADA Interface **Design**
- Digital **signal data processing (DAQ, sensor)**
- Communicate with peripherals via **RS232, RS485, Modbus, TCP/IP, GPIB, OPC UA...**

The biggest difference: LabVIEW doesn't program with command-line code, but with **block diagrams** – intuitive and easy to visualize.

LABVIEW APPLICATION ARCHITECTURE

1. **Front Panel** – user interface (UI/HMI)
2. **Block Diagram** – back-end control diagram (signal processing logic)
3. **Controls & Indicators** – push buttons, indicators, clocks, graphs, sliders, etc.

Applications of Labview in the following areas:

Field	Application
Industrial Automation	Monitoring & control of machines, motors, robots
Electricity – energy	HMI interface for inverter, PLC, relay (such as SEL, Siemens), power control
Measurement – Sensors	Acquisition of data from DAQ, ADC, sensor (temperature, pressure, force, etc.)
Academic – research	Simulation of control systems, oscillation measurement, chemical reactions, mechatronics
Embedded/IoT	Communicate with microcontrollers (Arduino, Raspberry Pi), create dashboards, collect data

Supported Media Communication:

Protocol	Supported?	Library
Modbus TCP/RTU	✔ Yes	NI Modbus Library
OPC UA/DA	✔ Yes	OPC Toolkit
DNP3	✔ Yes (paid)	NI Industrial Protocols
RS232/RS485	✔ Yes	VISA Communication
CAN, GPIB, Ethernet	✔ Yes	NI Drivers
MQTT/HTTP	✔ Yes (customizable)	Open source toolkit

✅ ADVANTAGES OF LABVIEW

Advantage	Description
Visual programming	No need to write traditional code, easy for students and new engineers to learn.
Powerful data processing	Integrated graphing, statistics, FFT, signal filtering, and logging.
Strong communication support	Easily connects with industrial devices, sensors, and PLCs.
Rich function library	Over 1000+ drag-and-drop processing blocks available.
Fast HMI interface	Allows easy creation of real-time control and monitoring screens.

⚠️ DISADVANTAGES

Disadvantage	Details	
High licensing cost	LabVIEW is not free, except for trial or academic versions.	
Requires NI hardware for advanced use	For advanced control (DAQ, cRIO), NI-specific hardware is required.	
Not optimized for large-scale projects	Not suitable for large, complex industrial software systems like SCADA.	

- ❖ Conclusion: using SEL 5033 software to load the driver program for the SEL 3505 because Codesys and Visual Studio cannot load the program directly for the SEL 3505. The purpose of using Codesys and Visual Studio software is to compile and test the program before inserting it into the SEL 5033 software to load the program.

CHAPTER 3. FINAL PRODUCT AND TEST RESULTS

The product testing model of the project is based on the requirements of Decision 378/QĐ-EVN dated March 12, 2025 on Technical requirements for connecting self-produced and self-consumed rooftop solar power with the Collection, Monitoring and Control System (SCADA/EMS) and the Metering Data System of the Electricity of Vietnam according to Decree No. 58/ND-CP dated March 3, 2025 of the Government. In particular, the project uses SEL3505 as a PCC controller, which acts as both a gateway for protocol management, data collection and control functions. Because there are no conditions for testing the direct connection with SCADA/EMS of local electricity, the project assumes that the EVN end model is a computer with HMI for remote control monitoring of plant parameters, a Local HMI interface for on-site communication with PPC representative for on-site monitoring communication on the factory side. Communication protocols use MODBUS/TCP. The following is a detailed description of the actual system tested and the results during actual operation.

1. Software products:

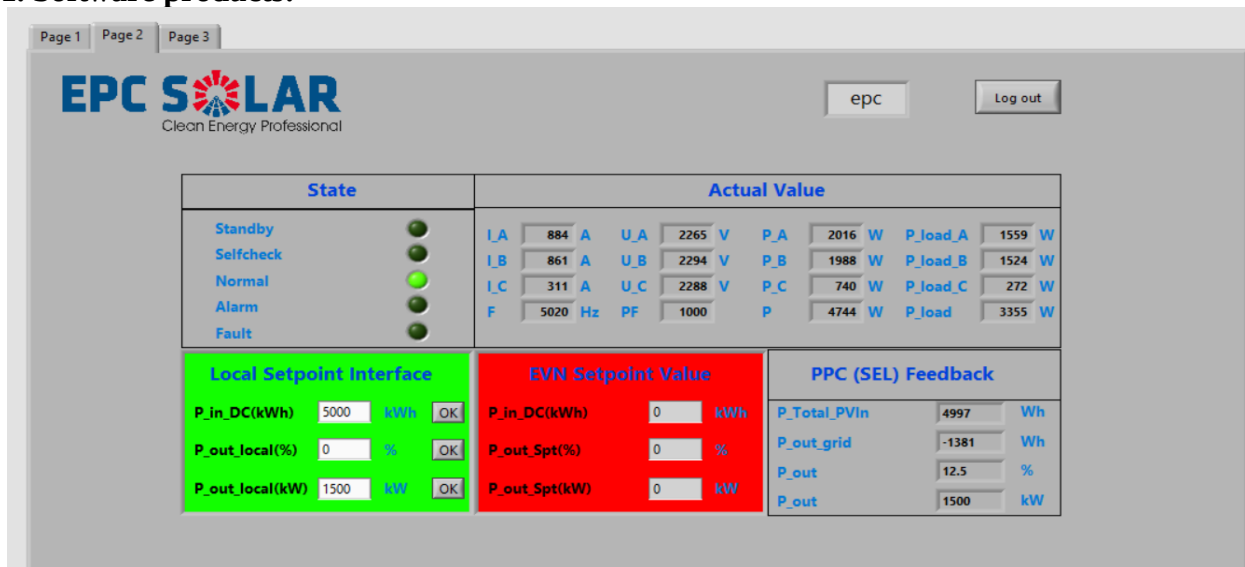


Figure 23: Local control HMI of SEL 3505

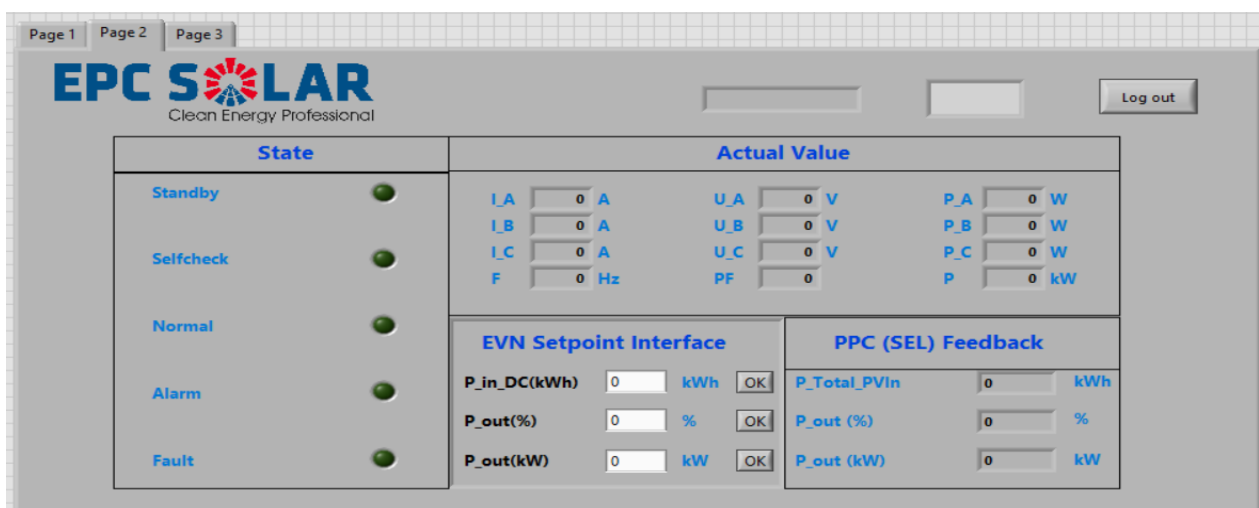


Figure 24: EVN's HMI

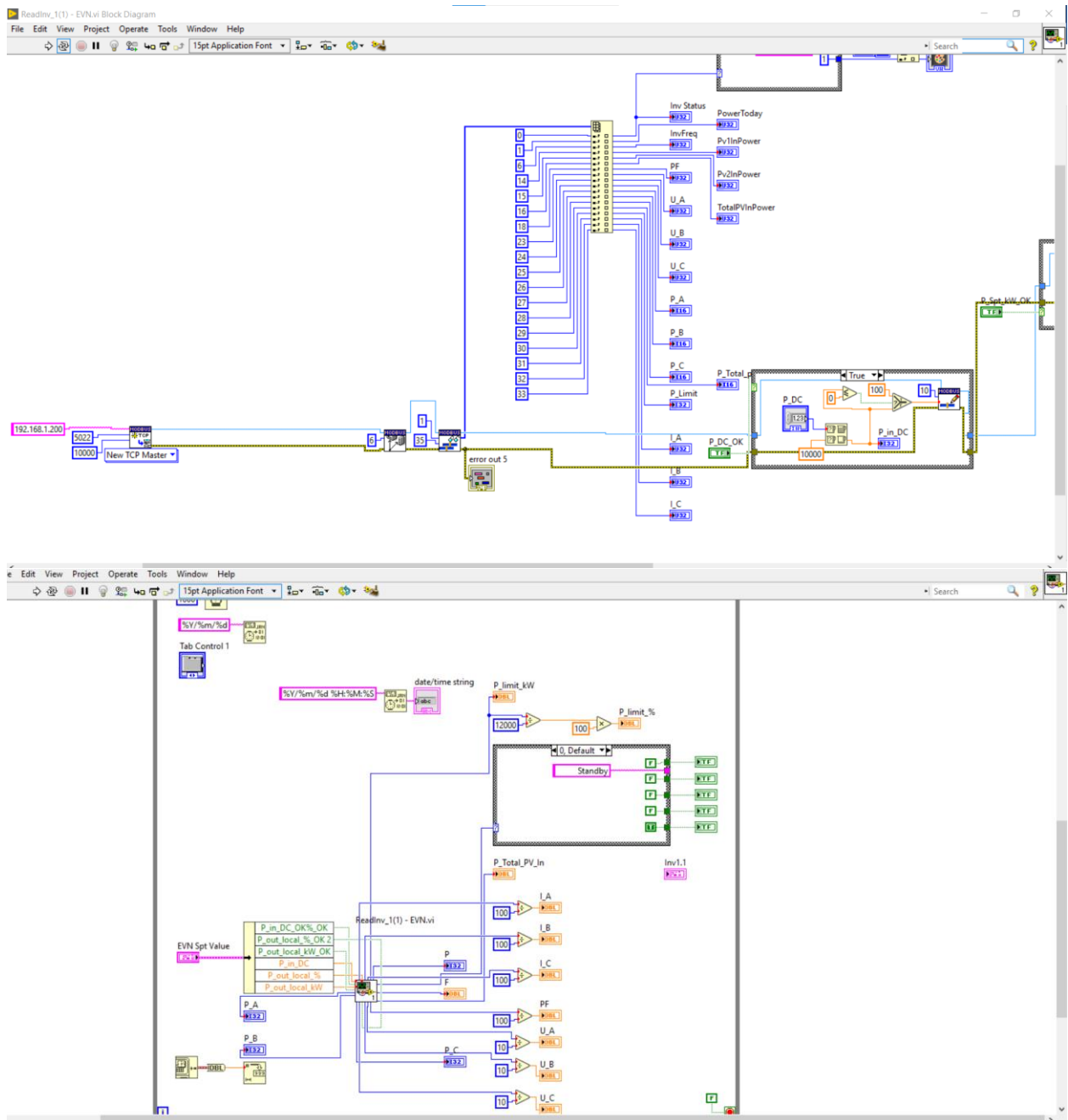


Figure 25: HMI Local and HMI EVN programs

*HMI Description:

HMI consists of 5 parts:

1. The area showing control rights includes Local HMI and EVN HMI:

- The purpose of this zone is to grant control rights to one of the two Local HMI and EVN HMI
- Granting control permissions will ensure that only 1 of the 2 can control PPC not to both control simultaneously.
- The granting of control permissions will be done on the HMI Local

Local Setpoint Interface				EVN Setpoint Value			
P_in_DC(kWh)	5000	kWh	OK	P_in_DC(kWh)	0	kWh	
P_out_local(%)	0	%	OK	P_out_Spt(%)	0	%	
P_out_local(kW)	1500	kW	OK	P_out_Spt(kW)	0	kW	

2. The area represents the parameter setpoints of the Local HMI

- This zone represents the control parameter that can input the desired parameter to control the power for the Inverter

Local Setpoint Interface			
P_in_DC(kWh)	5000	kWh	OK
P_out_local(%)	0	%	OK
P_out_local(kW)	1500	kW	OK

3. EVN HMI's setpoint display area

- This area represents the control parameter that can input the desired parameter of EVN (Dispatching Electricity) to control the power for the Inverter

EVN Setpoint Interface			
P_in_DC(kWh)	0	kWh	OK
P_out(%)	0	%	OK
P_out(kW)	0	kW	OK

4. Actual Value Area.

- It is the Meter area that responds to the parameters to be measured. This area only shows the measured parameter
- This area is also to test the power control ability of the setpoint of HMI Local and EVN HMI

Actual Value											
I_A	884	A	U_A	2265	V	P_A	2016	W	P_load_A	1559	W
I_B	861	A	U_B	2294	V	P_B	1988	W	P_load_B	1524	W
I_C	311	A	U_C	2288	V	P_C	740	W	P_load_C	272	W
F	5020	Hz	PF	1000		P	4744	W	P_load	3355	W

5. PPC feedback

- This area displays the setpoint parameters from HMI Local and EVN Local
- This area is used to compare the setpoint power and the actual power measured from the Meter

PPC (SEL) Feedback		
P_Total_PVIn	4997	Wh
P_out_grid	-1381	Wh
P_out	12.5	%
P_out	1500	kW

2. Hardware Products:



Figure 26: Product Photos

*Hardware Product Description:

- In the figure, the SEL 3505 has the role of data collection and power control (depending on the control parameters).
- The product can connect inverters and other field-level devices and configure for ports such as: Com 1,2,3,4..... Ethernet for project purposes.
- The above image is connected to the Inverter Deye for parameter monitoring and control. The connection diagram is in the big 3 section of the report.
- The hardware product also shows that this is the PPC that the project needs.

3. Test run results

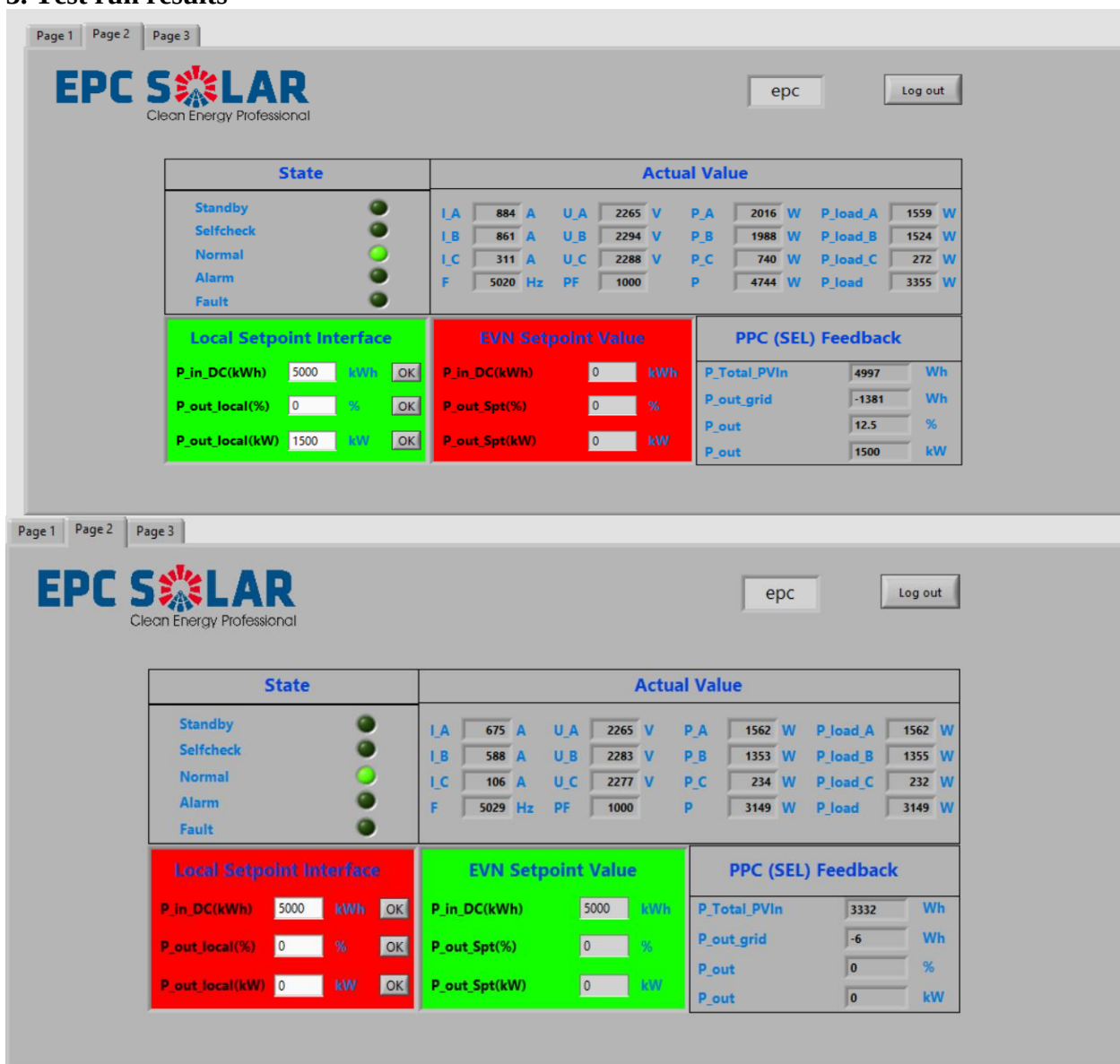


Figure 27: HMI EVN Setpoint and HMI Local

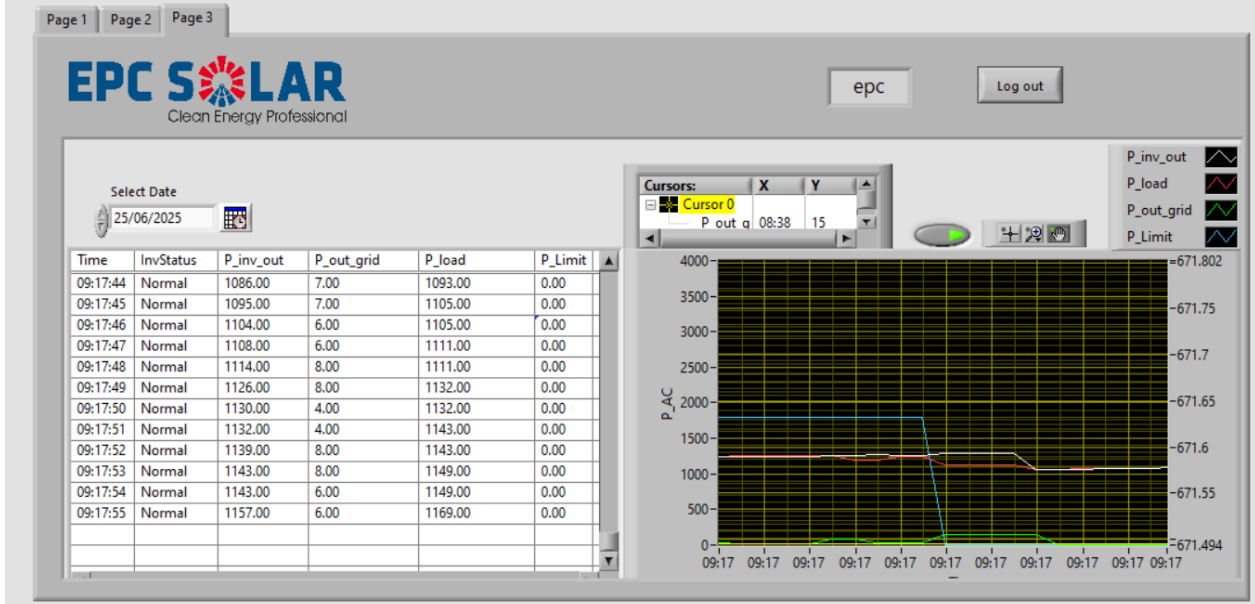
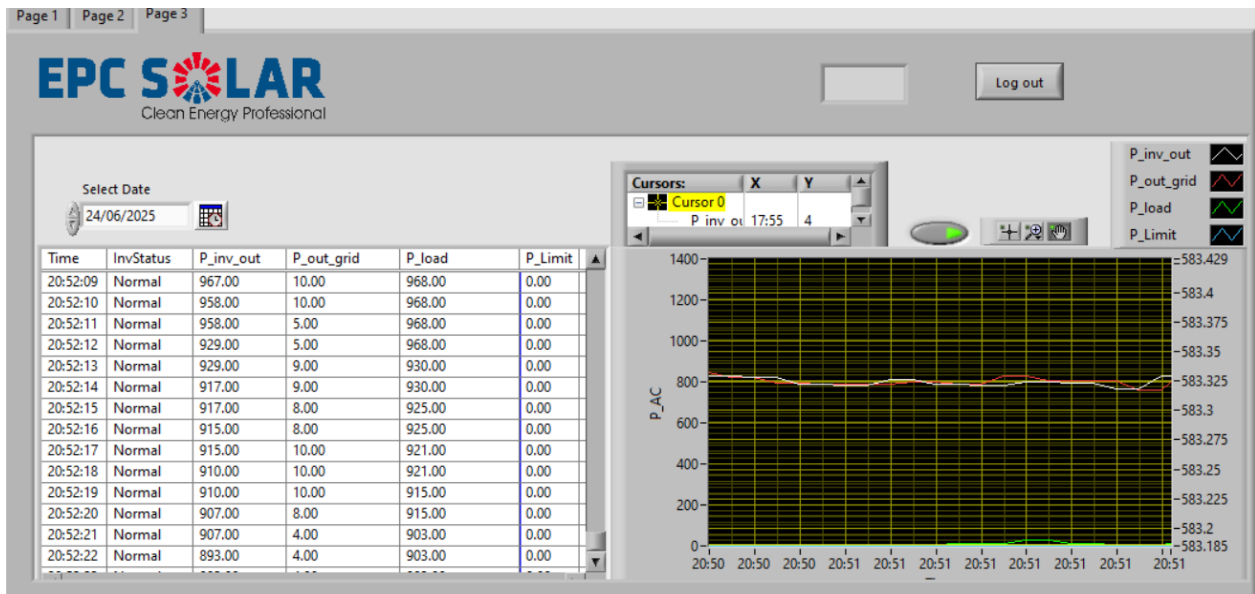


Figure 28: The graph shows the change in the parameter to be measured

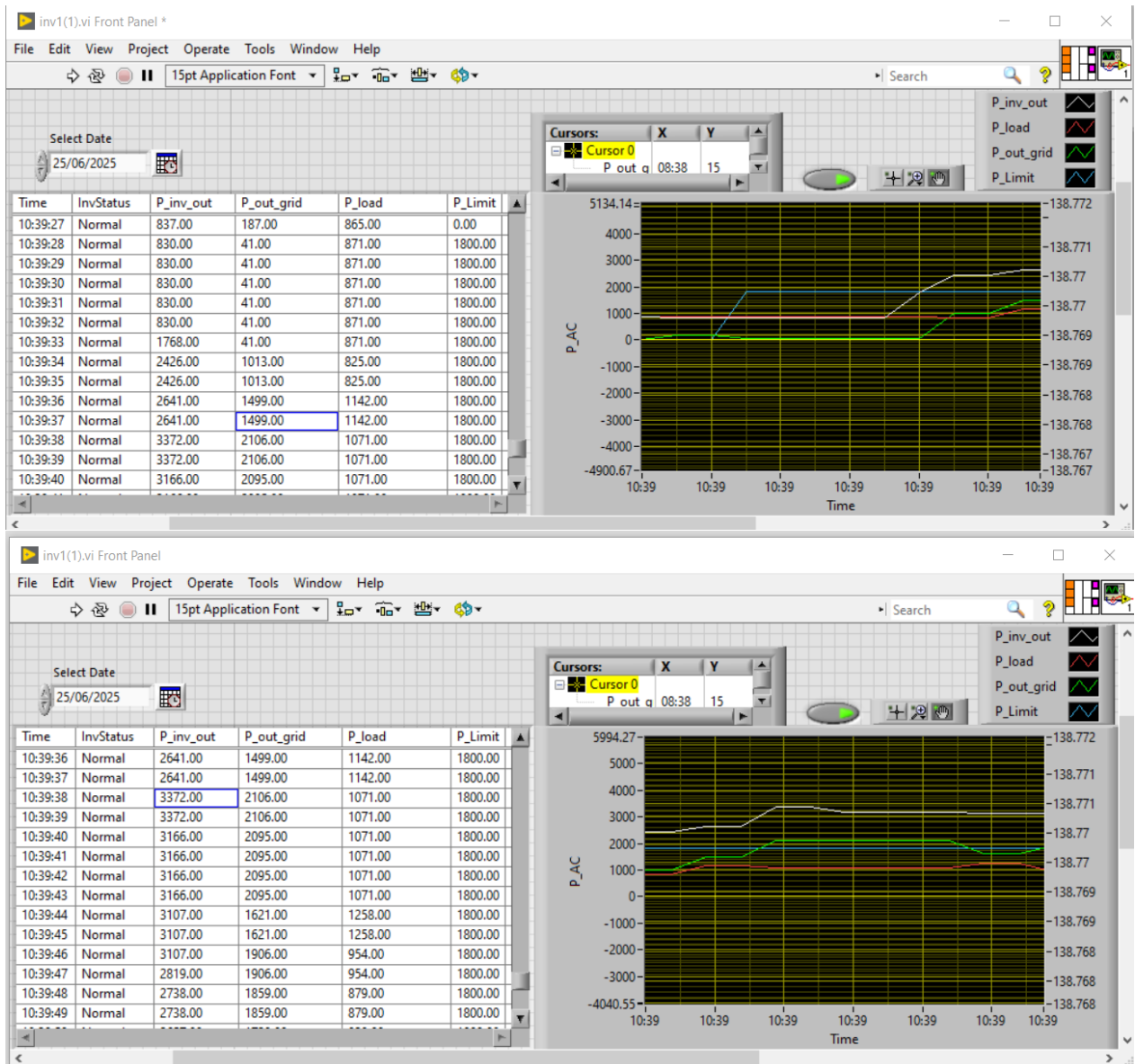


Figure 29 : The graph shows the change in the parameter to be measured

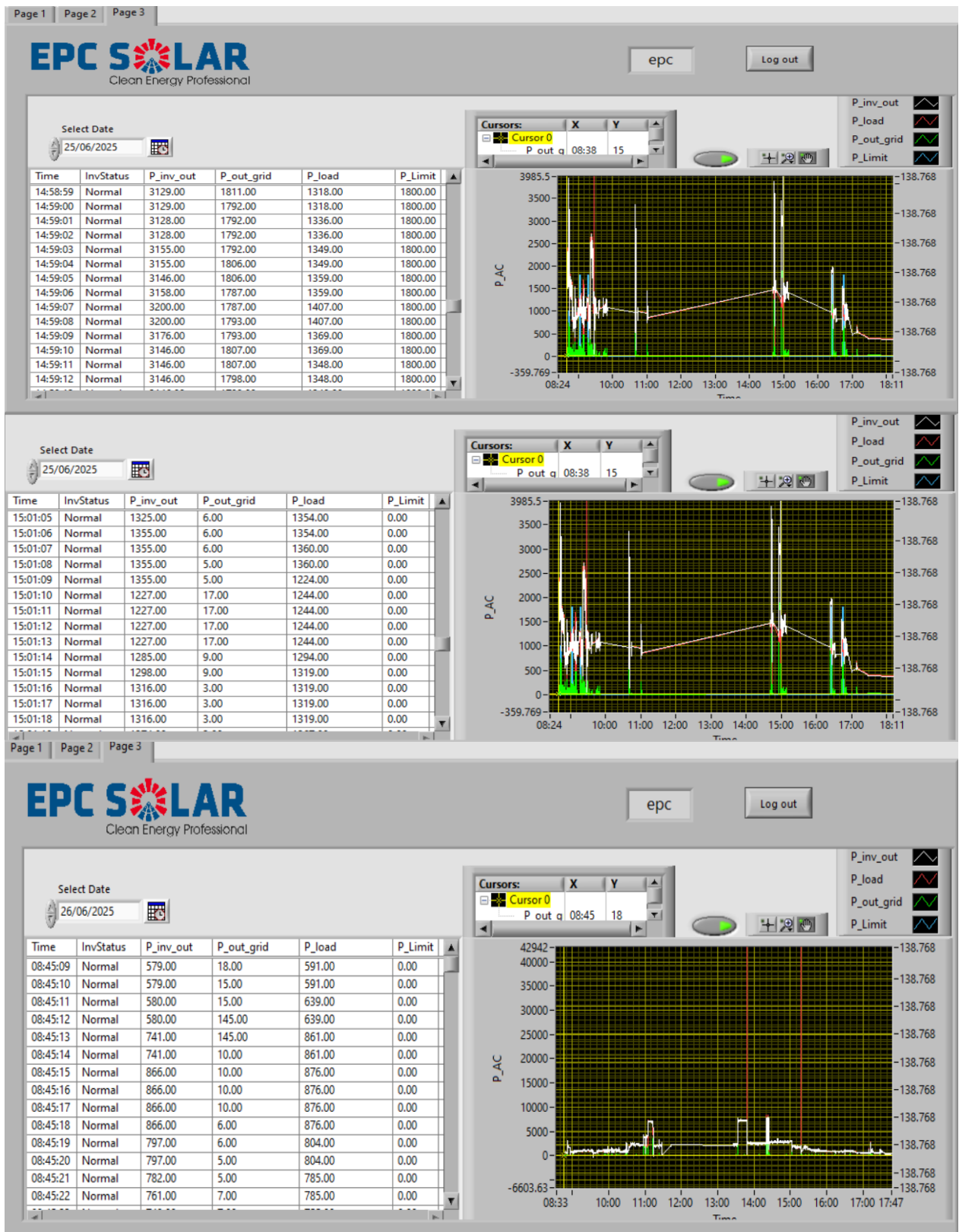


Figure 30 : The graph shows the change in the parameter to be measured

4. Conclusion: Criteria to be achieved and results achieved

❖ Criteria to be achieved:

1) Multi-brand inverter compatibility:

Supports popular protocols such as:

- **Modbus TCP/RTU** (commonly used by inverters such as SMA, Huawei, Sungrow, ABB, etc.)
- **IEC 61850** (if large-scale factory, many high-end companies support)
- **Proprietary API** or OPC UA (depending on the specific inverter)
- **Driver-based architecture:** PPC needs to be able to quickly add drivers to communicate with new inverters.
- **Parallel and asynchronous communication:** Ensure PPC can get data/control many different inverters at the same time.

2) Comply with legal and technical regulations from the dispatching center

According to Decree 58/2020/ND-CP and related documents:

- **Compliance with the requirements of Power System Dispatching (NLDC/A0 or A1/A2):**
 - Communication via **SCADA or IEC 60870-5-104/101, DNP3, or IEC 61850 MMS**
 - Capable of controlling/automatically reducing capacity according to grid requirements
- **Control and monitoring functions are required:**
 - Transmitter power control (active/reactive)
 - Power Factor Adjustment ($\cos \varphi$)
 - AGC/AVC function if required (frequency/voltage control)
 - Inverter system status and alarm monitoring
- **Time synchronization system (GPS or NTP)** accurate to the second
- **Ability to store data for a minimum of 30 days** and transmit real-time data to the dispatch center

3) Extensibility (can be further developed)

- The system has an **open, modular**, and easily scalable architecture with new inverters
- There is a Web interface or application to configure, track, update
- Capable of remote maintenance, remote firmware update
- User Authorization System and Access Security

4) Reliability and safety

- **Short response time (< 1 second)** for dispatch commands
- Resistant to industrial environments (temperature, humidity, EMC...)

- Cybersecurity protection (firewall, SSL, user authentication)

5) There is HMI monitor and control.

- Has an HMI monitor that complies with basic standards
 - The screen has an easy-to-see interface that is not too bad.
 - The display must show the parameters to be monitored and controlled.
- ❖ Results achieved: The project has built a system to ensure that the basic criteria are achieved:
1. Multi-brand inverter compatibility
 2. There is an HMI monitor and parameter control
 3. Comply with legal and technical regulations from the dispatching center
 4. Extensibility (can be further developed)
 5. Reliability and safety

6) What has been achieved and what has not been achieved:

- What has been achieved:

- Can connect to another Inverter manufacturers
- Can connect HMI EVN with Modbus TCP/IP protocol
- Full range of HMI local and HMI EVN
- The system can collect data continuously and can also view data from the past.

- What has not been achieved:

- The system has no controller yet.
- Cannot connect HMI Local with HMI EVN directly to the system via IEC 60870-5-104 protocol
- The security of the system's information has not yet been verified
- Unable to retrieve remote data.

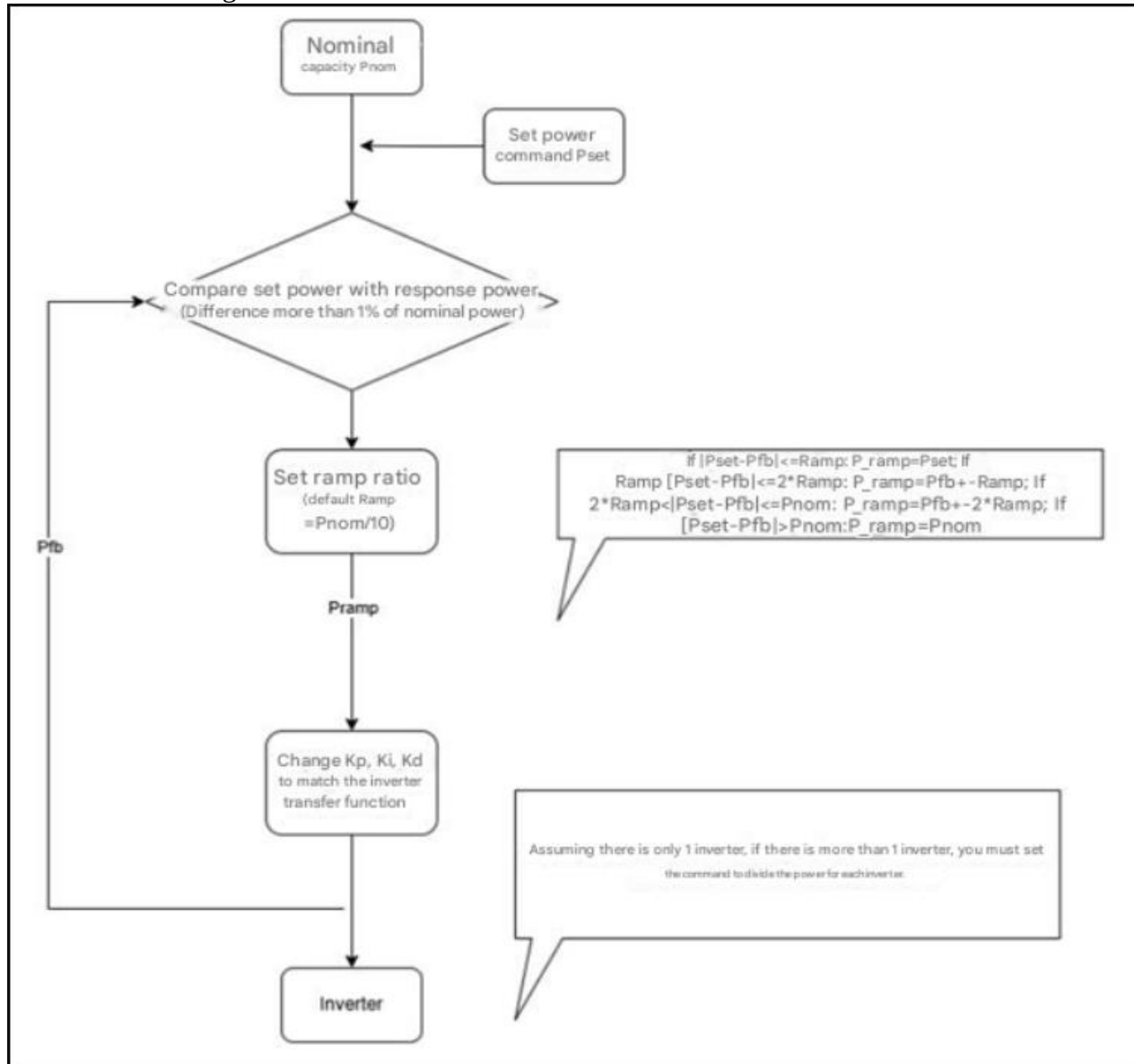
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ADDENDUM

1. Control Program

*Recommended algorithm flow chart :



*Python Program

```
import matplotlib.pyplot as plt
```

```
class PController:
```

```
    def __init__(self, Kp, Ki, dt):
```

```
        self.Kp = Kp
```

```
        self.Ki = Ki
```

```
        self.T = T
```

```
        self.integral = 0.0
```

```
    def compute(self, setpoint, measured):
```

```

    error = setpoint - measured
    self.integral += error * self.dt
    return self. Kp * error + self. Ki * self.integral

class Inverter:
    def __init__(self):
        self. P_output = 0.0
        self. Q_output = 0.0

    def receive_commands(self, P_cmd, Q_cmd):
        self. P_output = P_cmd
        self. Q_output = Q_cmd
    def __init__(self, name, protocol, slave_id, byte_order, data_type):
        self.name = name
        self.protocol = protocol # "Modbus TCP" or "Modbus RTU"
        self.slave_id = slave_id # Typically an integer
        self.byte_order = byte_order # "big-endian" or "little-endian"
        self.data_type = data_type # E.g., "FLOAT32", "UINT16", etc.

    @abstractmethod
    def get_modbus_map(self):
        pass

    def __str__(self):
        return f'{self.name}: Protocol={self.protocol}, Slave ID={self.slave_id}, Byte Order={self.byte_order}, Data Type={self.data_type}'

class SMAInverter(Inverter):
    def __init__(self):
        super().__init__(
            name="SMA",
            protocol="Modbus TCP",
            slave_id=3,
            byte_order="little-endian",
            data_type="FLOAT32"
        )

    def get_modbus_map(self):
        return {
            "AC Power": {"address": 40775, "length": 2, "unit": "W"},
            "DC Voltage": {"address": 40771, "length": 2, "unit": "V"},
            "DC Current": {"address": 40769, "length": 2, "unit": "A"},
        }

class SungrowInverter(Inverter):
    def __init__(self):
        super().__init__(
            name="Sungrow",
            protocol="Modbus RTU",
            slave_id=1,
            byte_order="big-endian",
            data_type="INT16"
        )

    def get_modbus_map(self):
        return {

```

```

        "AC Power": {"address": 5016, "length": 2, "unit": "W"},
        "DC Voltage": {"address": 5031, "length": 2, "unit": "V"},
        "DC Current": {"address": 5033, "length": 2, "unit": "A"},
    }
}

class DeyeInverter(Inverter):
    def __init__(self):
        super().__init__(
            name="Deye",
            protocol="Modbus RTU",
            slave_id=3,
            byte_order="Big Endian",
            data_type="FLOAT32"
        )

    def get_modbus_map(self):
        return {
            "AC Power": {"address": 76, "length": 2, "unit": "W"},
            "DC Voltage": {"address": 676, "length": 2, "unit": "V"},
            "DC Current": {"address": 108, "length": 2, "unit": "A"},
        }

class Meter:
    def __init__(self):
        self. P_meas = 0.0
        self. Q_meas = 0.0

    def update(self, inverter):
        # Simulation of measuring power from inverter
        self. P_meas = inverter. P_output
        self. Q_meas = inverter. Q_output
        return self. P_meas, self. Q_meas

class PPC:
    def dispatch(self, P_tot, Q_tot):
        # Simulate power distribution to inverter (only 1 inverter here)
        alpha = P_tot
        beta = Q_tot
        return alpha, beta

# Parameter
T = 0.1
steps = 100
P_set = 1000 # kW
Q_set = 2#kVar

# Initialization
pi_P = PIController(Kp=1, Ki=50, T=T)
pi_Q = PIController(Kp=0.88, Ki=48.9, T=T)
inverter = Inverter()
meter = Meter()
ppc = PPC()

# Save history
P_log = []
Q_log = []
time_log = []

```

```

# Simulation
for t in range(steps):
    P_mes, Q_mes = meter.update(inverter)
    P_tot = pi_P.compute(P_set, P_mes)
    Q_tot = pi_Q.compute(Q_set, Q_mes)

    alpha, beta = ppc.dispatch(P_tot, Q_tot)
    inverter.receive_commands(alpha, beta)

# Data Logging
time_log.append(t * dt)
P_log.append(P_mes)
Q_log.append(Q_mes)

# Draw the result
plt.figure(figsize=(10, 5))
plt.subplot(2, 1, 1)
plt.plot(time_log, P_log, label="P_meas")
plt.axhline(P_set, color='r', linestyle='--', label="P_set")
plt.ylabel("P (kW)")
plt.legend()
plt.grid(True)

plt.subplot(2, 1, 2)
plt.plot(time_log, Q_log, label="Q_meas")
plt.axhline(Q_set, color='r', linestyle='--', label="Q_set")
plt.ylabel("Q (kVar)")
plt.xlabel("Time (s)")
plt.legend()
plt.grid(True)

plt.tight_layout()
plt.show()

_Struct Test code on SEL 5033 to configure for SEL 3505.
VAR_INPUT
    P_set   : REAL;    // Lệnh đặt công suất tác dụng (W)
    Q_set   : REAL;    // Lệnh đặt công suất phản kháng (Var)
    P_meas  : REAL;    // Công suất tác dụng đo được
    Q_meas  : REAL;    // Công suất phản kháng đo được
    T_s     : REAL;    // Chu kỳ lấy mẫu (giây)
END_VAR

VAR_OUTPUT
    P_ctrl_cmd : REAL; // Lệnh điều khiển công suất tác dụng gửi về inverter
    Q_ctrl_cmd : REAL; // Lệnh điều khiển công suất phản kháng gửi về inverter
END_VAR

VAR
    // Sai số
    error_P   : REAL := 0.0;
    error_Q   : REAL := 0.0;

```

```

// Tích phân sai số
int_P    : REAL := 0.0;
int_Q    : REAL := 0.0;

// Tham số bộ điều khiển PI(D)
Kp_P     : REAL := 1; // Tỷ lệ công suất tác dụng
Ki_P     : REAL := 48.89; // Tích phân công suất tác dụng

Kp_Q     : REAL := 0.889; // Tỷ lệ công suất phản kháng
Ki_Q     : REAL := 50; // Tích phân công suất phản kháng

// Giới hạn tích phân
int_P_max : REAL := 10000.0;
int_P_min : REAL := -10000.0;
int_Q_max : REAL := 10000.0;
int_Q_min : REAL := -10000.0;
END_VAR
// Tính sai số
error_P := P_set - P_meas;
error_Q := Q_set - Q_meas;

// Tích phân sai số
int_P := int_P + error_P * T_s;
int_Q := int_Q + error_Q * T_s;

// Chống tích phân bão hòa
IF int_P > int_P_max THEN
    int_P := int_P_max;
ELSIF int_P < int_P_min THEN
    int_P := int_P_min;
END_IF;

IF int_Q > int_Q_max THEN
    int_Q := int_Q_max;
ELSIF int_Q < int_Q_min THEN
    int_Q := int_Q_min;
END_IF;

// Bộ điều khiển PI
P_ctrl_cmd := Kp_P * error_P + Ki_P * int_P;
Q_ctrl_cmd := Kp_Q * error_Q + Ki_Q * int_Q;

// Giới hạn đầu ra (tuỳ theo khả năng inverter)
IF P_ctrl_cmd > 10000 THEN
    P_ctrl_cmd := 10000;
ELSIF P_ctrl_cmd < -10000 THEN

```

```

    P_ctrl_cmd := -10000;
END_IF;
IF Q_ctrl_cmd > 10000 THEN
    Q_ctrl_cmd := 10000;
ELSIF Q_ctrl_cmd < -10000 THEN
    Q_ctrl_cmd := -10000;
END_IF;
VAR
    HMI_Local_Request : BOOL; // Yêu cầu điều khiển từ HMI Local
    HMI_EVN_Request   : BOOL; // Yêu cầu điều khiển từ HMI EVN
    Local_Enable      : BOOL; // Đang cho phép HMI Local điều khiển
    EVN_Enable        : BOOL; // Đang cho phép HMI EVN điều khiển
END_VAR
// Logic cấp quyền điều khiển độc quyền
IF NOT Local_Enable AND NOT EVN_Enable THEN
    // Nếu chưa có ai điều khiển, cấp quyền cho người đầu tiên gửi yêu cầu
    IF HMI_EVN_Request THEN
        EVN_Enable := TRUE;
        Local_Enable := FALSE;
    ELSIF HMI_Local_Request THEN
        Local_Enable := TRUE;
        EVN_Enable := FALSE;
    END_IF;
ELSIF EVN_Enable THEN
    // Nếu EVN đang điều khiển
    IF NOT HMI_EVN_Request THEN
        EVN_Enable := FALSE; // EVN nhả quyền => reset
    END_IF;
    Local_Enable := FALSE;
ELSIF Local_Enable THEN
    // Nếu Local đang điều khiển
    IF NOT HMI_Local_Request THEN
        Local_Enable := FALSE; // Local nhả quyền => reset
    END_IF;
    EVN_Enable := FALSE;
END_IF;
VAR
    Force_Release : BOOL; // Tín hiệu buộc nhả điều khiển từ SCADA
END_VAR

IF Force_Release THEN
    Local_Enable := FALSE;
    EVN_Enable := FALSE;
END_IF;

```

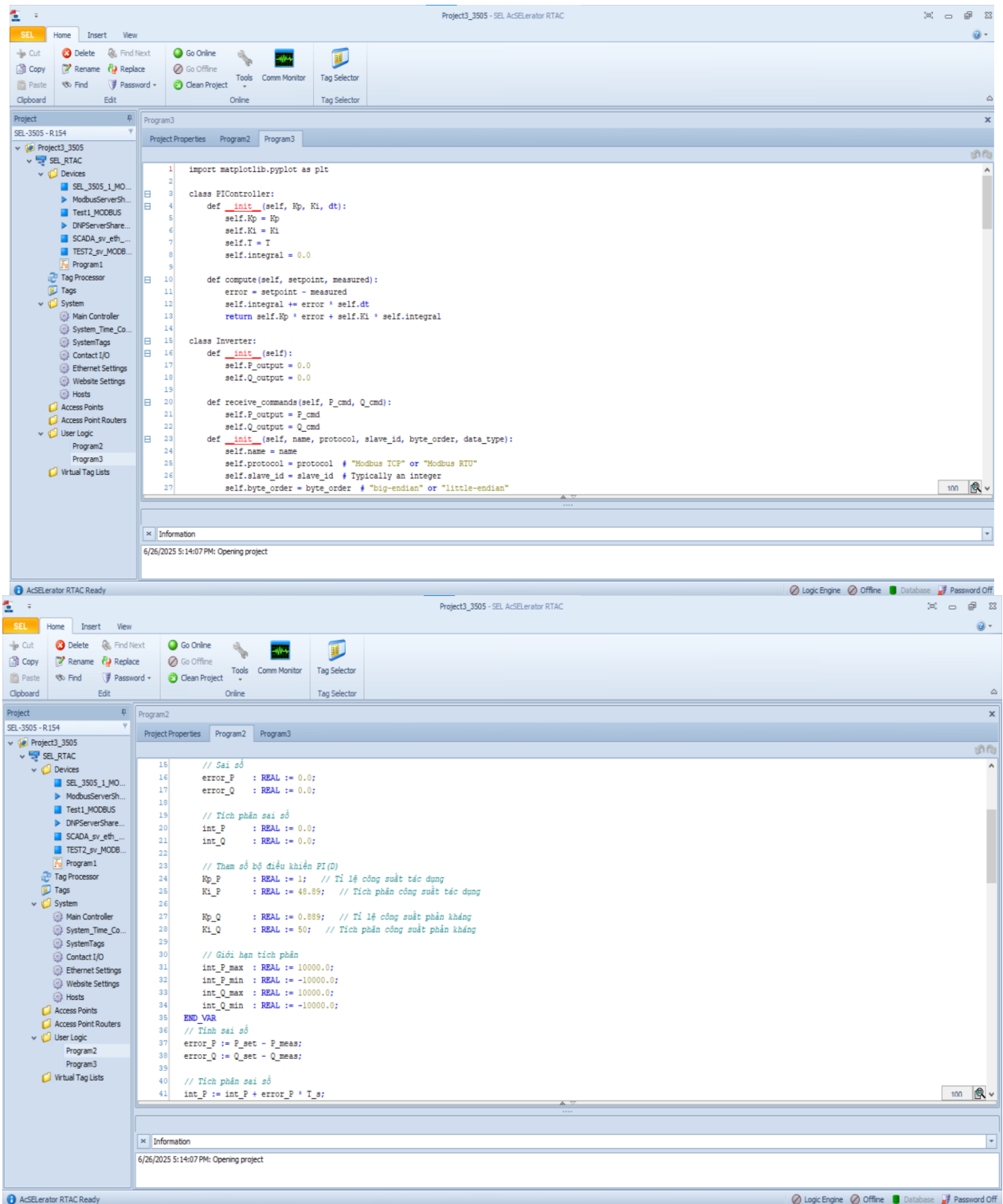


Figure 31 : System control program in SEL 5033

2. Development direction and Simulation Proposal with MATLAB Simulink(Proposal to complete the topic).

Inverters connected to the grid usually have an IC (Inductor + Capacitor) filter (Inductor + capacitor). The transmission function of the output current (i_{out}) according to the control voltage ($v_{control}$) will be the **quadratic transmission function**:

$$G(s) = \frac{\omega_c^2}{s^2 + 2\xi\omega_c s + \omega_c^2}$$

With :

ω (**omega**) is the cut-off frequency (rad/s)

ξ (**xi**) is damping ratio

➔ Inverters with IC filters are common in today's industry.

Model	Inverter Transfer Function	Notes
No Filter(IC)	$G(s) = \frac{1}{T_{inv}s + 1}$	With $T_{inv} = 0.02 \Rightarrow 0.05s$
With IC filter	$G(s) = \frac{\omega_c^2}{s^2 + 2\xi\omega_c s + \omega_c^2}$	ω_c is the cutoff frequency (rad/s) ξ is the damping ratio

***Why use a PI controller:**

According to the request from EVN (local electricity), there are requirements to: Monitor and send data on the generating capacity of each inverter, the total generating capacity of the terminals of the inverters of the RSP source to the system of the Power Company with an update cycle of at least once every 5 minutes

Source: https://cskh.evnhcmc.vn/Tct/TruyenThong_chitiet/118200

➔ The requirements of the system do not need to be responded to quickly, so the use of a PI controller is just enough to carry out the requirements of the system.

***Transmission function and method of calculating transmission function parameters:**

$$G_c(s) = K_P + \frac{K_I}{s} = \frac{K_p s + K_i}{s}$$

With:

K_p : proportional gain

K_i : integral gain

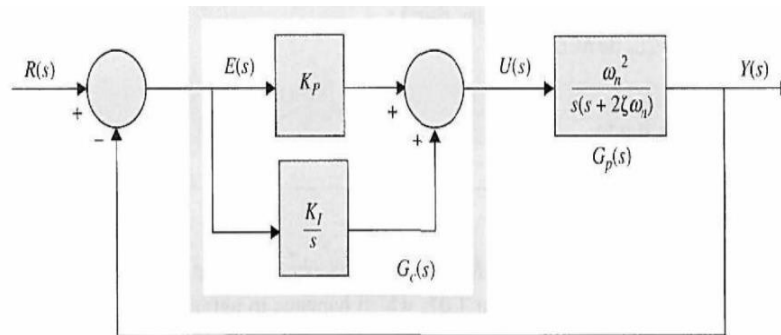


Figure 9-15 Control system with PI controller.

Figure 32 : PI Controller

TABLE 4-4 Inverting Op-Amp Transfer Functions

	Input Element	Feedback Element	Transfer Function	Comments
(a)	$\frac{R_1}{Z_1 = R_1}$	$\frac{R_2}{Z_2 = R_2}$	$-\frac{R_2}{R_1}$	Inverting gain, e.g., if $R_1 = R_2$, $e_o = -e_i$
(b)	$\frac{R_1}{Z_1 = R_1}$	$\frac{C_2}{Y_2 = sC_2}$	$\left(\frac{-1}{R_1 C_2}\right) \frac{1}{s}$	Pole at the origin, i.e., an integrator
(c)	$\frac{C_1}{Y_1 = sC_1}$	$\frac{R_2}{Z_2 = R_2}$	$(-R_2 C_1)s$	Zero at the origin, i.e., a differentiator
(d)	$\frac{R_1}{Z_1 = R_1}$	$\frac{R_2}{Y_2 = \frac{1}{R_2} + sC_2}$	$\frac{-1}{s + \frac{1}{R_2 C_2}}$	Pole at $\frac{-1}{R_2 C_2}$ with a dc gain of $-R_2/R_1$

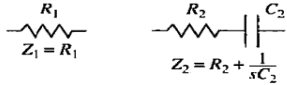
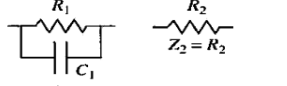
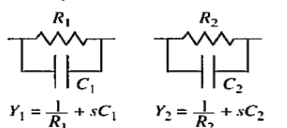
(e)		$\frac{-R_2}{R_1} \left(\frac{s + 1/R_2 C_2}{s} \right)$	Pole at the origin and a zero at $-1/R_2 C_2$, i.e., a PI controller
(f)		$-R_2 C_1 \left(s + \frac{1}{R_1 C_1} \right)$	Zero at $s = \frac{-1}{R_1 C_1}$, i.e., a PD controller
(g)		$\frac{-C_1}{C_2} \left(s + \frac{1}{R_1 C_1} \right) \frac{1}{s + \frac{1}{R_2 C_2}}$	Poles at $s = \frac{-1}{R_2 C_2}$ and a zero at $s = \frac{-1}{R_1 C_1}$, i.e., a lead or lag controller

Figure 33 : OP-AMP transmission function table

From Table 4-4 above, we deduce the formula for calculating the Kp and Ki parameters of the PI controller

$$G_c(s) = \frac{E_o(s)}{E_{in}(s)} = \frac{R_2}{R_1} + \frac{R_2}{R_1 C_2 s} \quad \Rightarrow \quad K_P = \frac{R_2}{R_1} \quad K_I = \frac{R_2}{R_1 C_2}$$

+This formula represents the transmission function of a PI (Proportional + Integral) controller, which is generated from circuits using R and C. **With:**

Ampersand	Meaning
$G_c(s)$	Controller Transmission Function
$E_o(s)$	Controller Output (Laplace)
$E_{in}(s)$	Controller Input (Laplace)
R_1, R_2	Resistors in the circuit
C_2	Capacitor

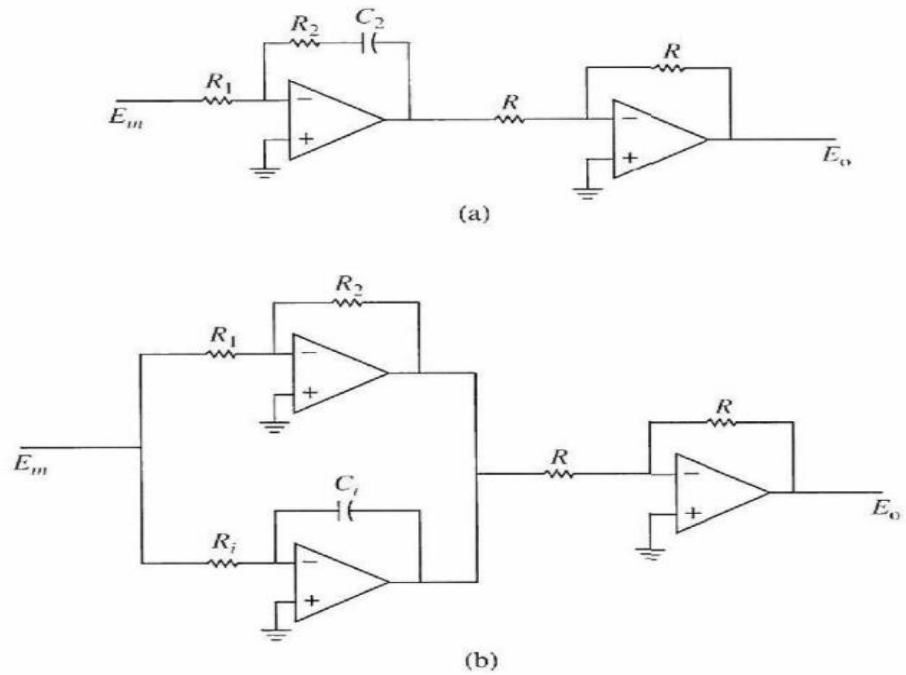


Figure 34 : Op-Amp (Amp) Circuit of PI Controller :

a) Circuit 2 Op-Amp Algorithm

b) Circuit 3 Op-Amp algorithm

***The PI(D) on Labview looks like :**

$$u(t) = K_c \left(e + \frac{1}{T_i} \int_0^t e dt + T_d \frac{de}{dt} \right)$$

→

$$u_p(t) = K_c e$$

$$u_I(t) = \frac{K_c}{T_i} \int_0^t e dt$$

$$u_D(t) = K_c T_d \frac{de}{dt}$$

_PI or PID on Labview is considered a u(t) control signal, so it will differ from the usual PID equation

$$G_c(s) = K_P + K_D s + \frac{K_I}{s} = (1 + K_{D1} s) \left(K_{P2} + \frac{K_{I2}}{s} \right) \quad \text{with}$$

$$u(t) = K_p \cdot e(t) + K_i \int e(t) dt + K_d \cdot \frac{de(t)}{dt}$$

$$K_P = K_{P2} + K_{D1} K_{I2}$$

$$K_D = K_{D1} K_{P2}$$

$$K_I = K_{I2}$$

Basic PID equation

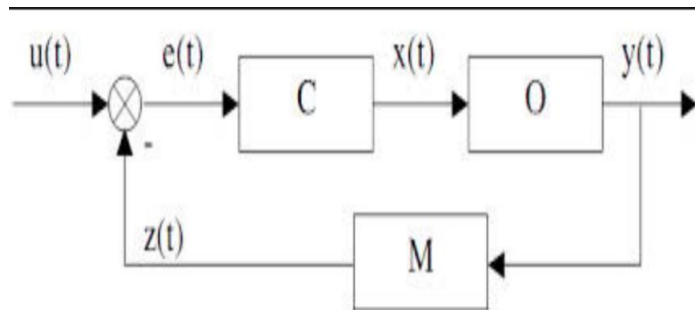


Figure 35 : Basic transmission function diagram of the system

In which:

Ampersand	Meaning	Role
u(t)	Reference input	Target value to be achieved (e.g., set power P*)
e(t)	$e(t)=u(t)-z(t)$	Deviation between the goal and the actual response
C	Controller	Deviation between the goal and the actual response
x(t)	Internal control signal	Controller C Output Signal
O	Control Object(Object/Plant)	Physical systems (e.g., inverters)
y(t)	Actual output of the system	Actual results of the process (e.g., real capacity)
M	Measurement Block	Power meter,Current and pressure sensor
z(t)	Measured signal	Estimating the output y(t) returns to the comparison loop

Matlab Simulation with Transfer Function Parameter (test)

*code Matlab :

```
clear all
% Greed? ?i?u when?n
Kp = 1;
Ki = 50;

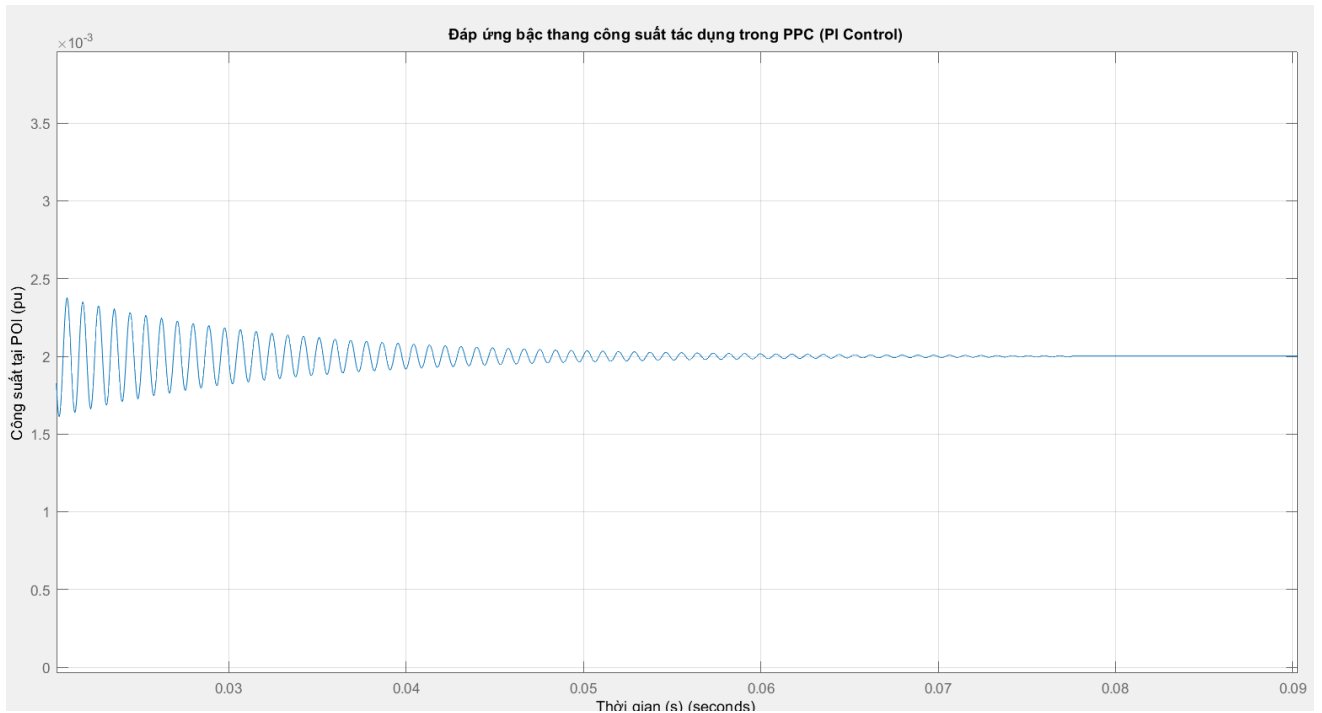
% We have been truy?n b? ?i?u khi?n PI
g_p = tf([kp's], [1 0]);

% ?? i t?? ng ?i?u khi?n (PV + inverter + Mesurement)
G_plant = tf([1],[0.01 1])
G_int = tf([1], [0.01 1]);
G_Mes = tf([1], [0.1 1]);
G_cl = feedback(G_plant * G_PI * G_Mes * G_int, 500);

% Tissue
pidTuner(G_PI , 'PI')

step(G_cl)
title('Enforcement of PPC (PI Control)')
ylabel('Công su?t t?i POI (pu)')
xlabel('Th?i gian (s)')
grid on
```

*The chart is drawn after running the above program :



➔The system stabilized at 0.08 seconds, meeting the set requirements.

+ Prepare input and output data on excel to be included and read by Matlab including:

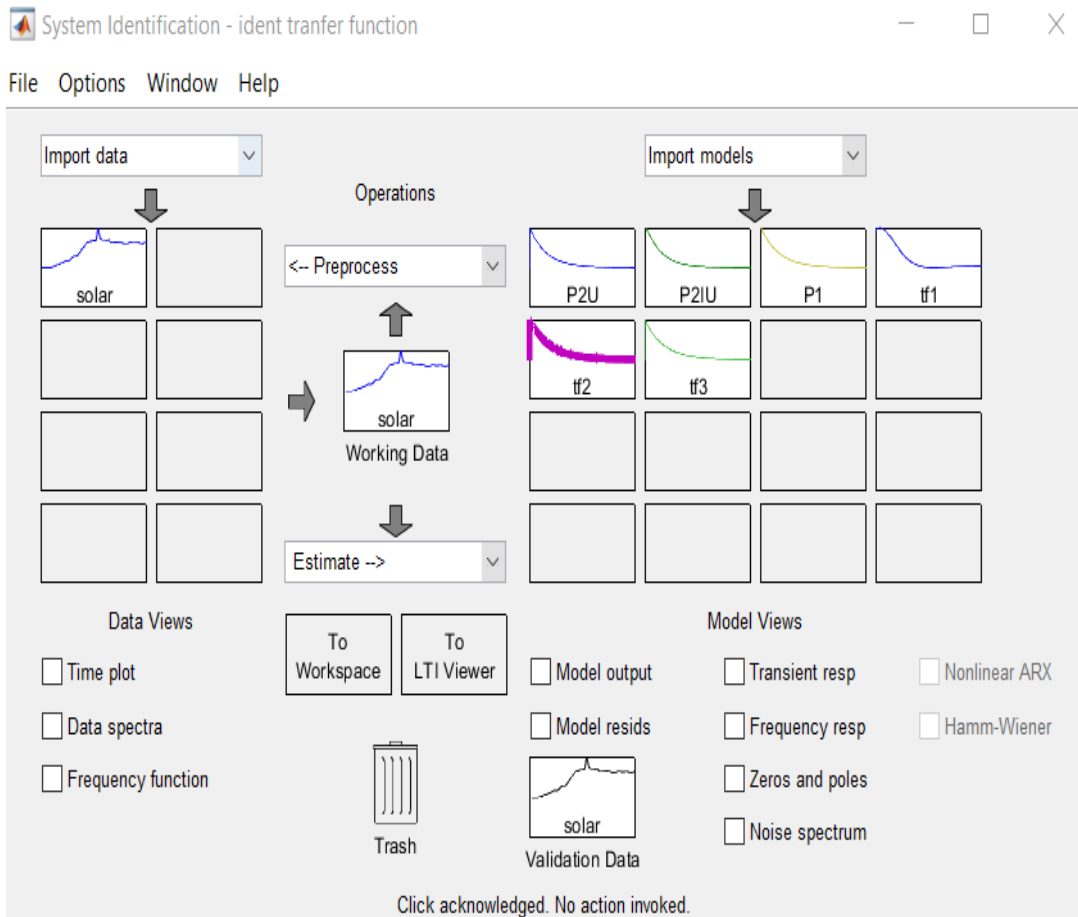
*Input power

*Output Power (Feedback Measurement Signal)

	A	B	C
1	Time	Tín hiệu đo lường(kW)	Công suất đầu vào (kW)
2	2025/04/20 02:19:47	0	0.4
3	2025/04/20 05:15:00	0	0.64
4	2025/04/20 05:19:47	0	0.6
5	2025/04/20 05:20:00	0	0.56
6	2025/04/20 05:25:00	0	0.6
7	2025/04/20 05:30:00	0.01	0.51
8	2025/04/20 05:40:00	0.07	0.45
9	2025/04/20 05:45:00	0.15	0.51
10	2025/04/20 05:50:00	0.2	0.6
11	2025/04/20 05:55:00	0.27	0.57
12	2025/04/20 06:00:00	0.35	2.15
13	2025/04/20 06:05:00	0.43	4.35
14	2025/04/20 06:10:00	0.5	4.28
15	2025/04/20 06:15:00	0.49	1.96
16	2025/04/20 06:20:00	0.6	1.93
17	2025/04/20 06:30:00	0.77	2.01
18	2025/04/20 06:35:00	0.86	2.06
19	2025/04/20 06:40:00	0.86	1.89
20	2025/04/20 06:45:00	1.04	1.93
21	2025/04/20 06:50:00	1.31	1.95
22	2025/04/20 06:55:00	1.47	1.98
23	2025/04/20 07:00:00	1.75	1.86
24	2025/04/20 07:05:00	1.89	1.91
25	2025/04/20 07:15:00	1.94	1.96
26	2025/04/20 07:20:00	1.99	2.01
27	2025/04/20 07:25:00	2.02	2.04

Figure 36 : Input data

+Using the ident command on Matlab:



+ Then import the data from the excel file into the import data section :

Data/model Info: solar

Data name: solar

Color: [0,0,1]

Time domain data set with 118 samples.
Sample time: 0.01 seconds
Name: solar

Outputs	Unit (if specified)
Công suất đo lường	Kw

Diary and Notes

```
% Import solar
```

☐ Use as Working Data
☐ Use as Validation Data

Apply

Present Export Close Help

+ Select the transmission function model for the Inverter:

- Inverter transmission function is a second-order transmission function:

$$G(s) = \frac{\omega_c^2}{s^2 + 2\xi\omega_c s + \omega_c^2}$$

➔ Approximate transmission function parameters of Inverter:

from input công suất vào to output công

3.031e04

s^2 + 3260 s + 2.949e04

..

LIST OF ABBREVIATIONS

Abbreviation :

- **P : Active Power**
- **Q : Reactive Power**
- **PF : Power Factor**
- **PPC : Power Plant Controller**
- **S : Apparent Power**
- **U : Voltage**
- **PV Panel Solar : Photovoltaic cells Panel Solar**
- **AC Power : Alternating current**
- **DC Power : Direct current**
- **V : effective current**
- **I : effective voltage**
- **F : Frequency**
- **C : Capacitor**
- **R : Resistor**
- **RTU : Remote Terminal Unit**
- **TCP : Transmission Control Protocol**
- **IP : Internet Protocol**
- **IEC : International Electrotechnical Commission**
- **API : Application program interface**
- **OPC UA : Open Platform Communications Unified Architecture**