DESIGN OF A PV SYSTEM INCLUDING ITS SCADA FOR A HOUSE IN IRAN

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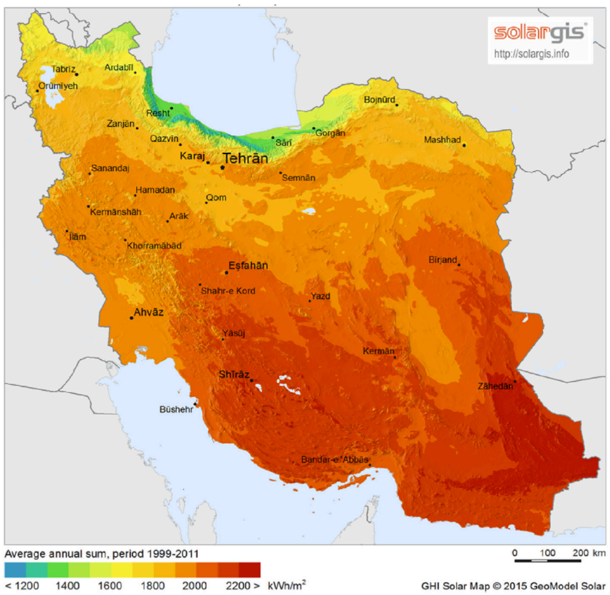
1. Introduction (Motivations)

- Achieving to the climate change alarm
- Decreasing the fossil fuel sources
- Increasing the load demand
- Affordable renewable power generation systems
- The need for an open-source SCADA system

1.Introduction (Iran’s renewable energy protentional)

- Solar energy is extensively available in most parts of Iran
- The radiation pattern changes between 2.8 – 5.4 kWh/m^2



Global horizontal irradiation (GHI) in Iran

2. Objective

The objective of this research is:

1. To size a reliable PV power system for a household in Iran based on the weather data, estimated load data, and building construction for the most optimum design and least system cost.
2. To build a dynamic model of the sized PV system in Simulink/MATLAB
3. To design a low-cost SCADA systems to remotely monitor and control the smart devices throughout the system

3. Literature review

Row No.	References	Thermal modeling	System sizing	Dynamic modeling and designing inverter control	SCADA system design	Comments
1	A. Iqbal	X	X	X		Design of a Stand-Alone PV System
2	B. Jiang	X	X	X		Design and Dynamic Modelling of a Hybrid Power System
3	L. Aghenta	X	X	X		Dynamic Modeling of an Isolated Hybrid Power System
4	H. Shahinzadeh		X			Optimal sizing and energy management of a grid-connected microgrid
5	M.Haratian		X			A renewable energy solution for standalone power generation
8	Y. Chen			X		DC-link capacitor selections for the grid-connected PV system
9	R.Faranda			X		Comparison of MPPT Techniques for PV Systems
10	A. Cagnano			X		Online Optimal Reactive Power Control Strategy of PV Inverters
11	S. Gonzalez			X		Effect of non-unity power factor operation in photovoltaic inverters
12	L. Aghenta				X	Open Source IoT-Based SCADA System Design
13	M. Lekić				X	IoT sensor integration to Node-RED platform
14	P. Rai				X	ESP32 Based Smart Surveillance System
15	M. Al-Kuwari				X	Smart-home automation using IoT-based sensing and monitoring platform
16	V. Pravalika				X	Home Monitoring and Device Control Using Esp32
17	R. K. Kodali				X	MQTT based home automation system using ESP8266

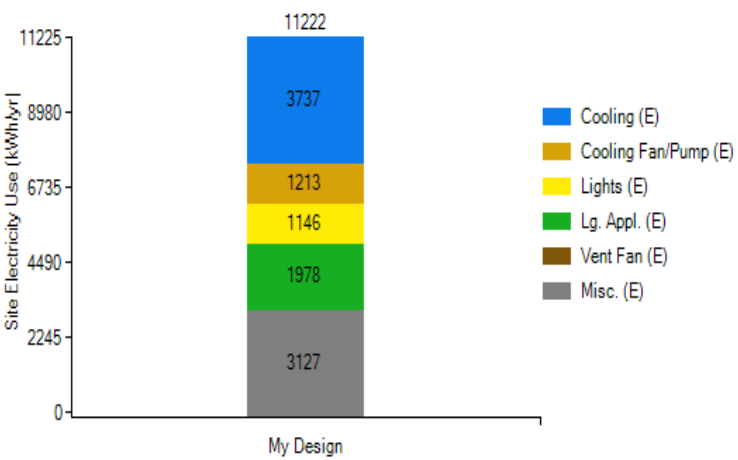
4. Optimal Sizing of a PV System in Golpayegan, Iran

Develop renewable energy solutions for both standalone and grid-connected power generation systems for a household in Golpayegan, Iran to fulfill the required electrical load demand of the considered place.

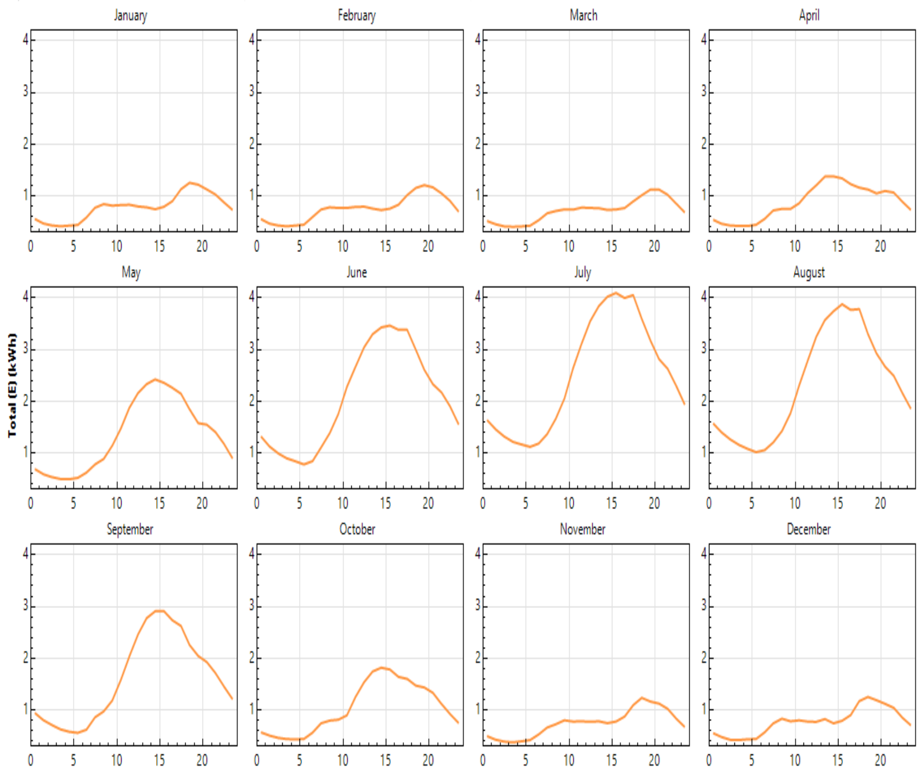
- Specifications of chosen site and load demand data
- Metrological data
- System components
- Operational control of the system

4. Optimal Sizing of a PV System in Golpayegan, Iran : *Specifications of chosen site and load demand data*

Thermal modeling is completed with residential load estimation using BEOpt software.



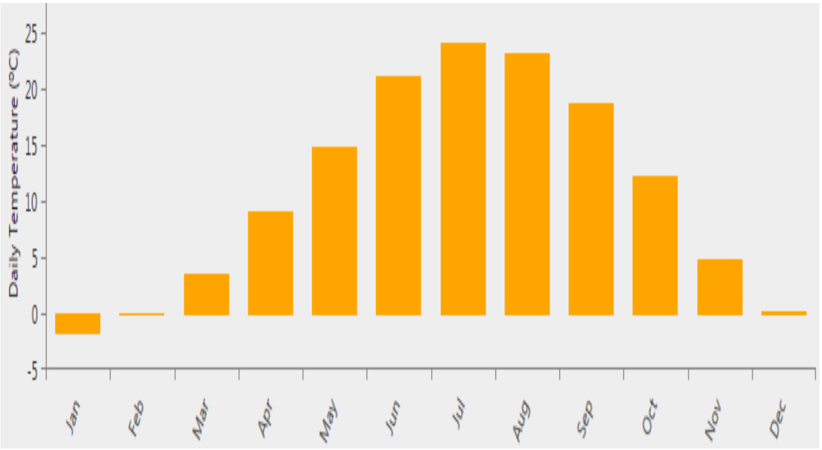
Annual energy consumption of the house based on BEopt modeling.



Monthly load flow data of the house for a typical year

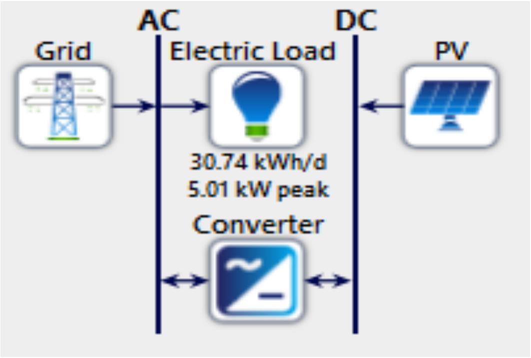
4. Optimal Sizing of a PV System in Golpayegan, Iran: *Metrological data*

Monthly solar and clearance index of the selected site.

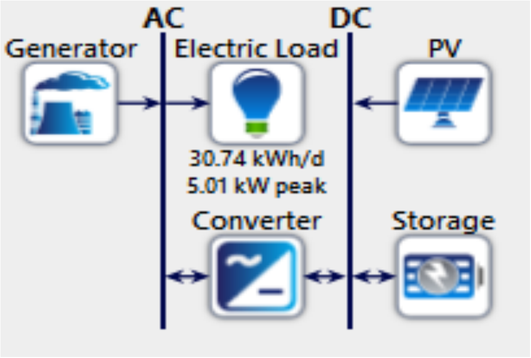


Monthly temperature of the selected site.

4. Optimal Sizing of a PV System in Golpayegan, Iran: *System components*



Grid-connected PV system



Standalone PV system

Component	Cost: Capital ($/kW)	Cost: O&M ($/kW)	Cost: Replacement ($/kW)	Other information
PV panel	1500	10 (1/year)	1125	Tracking system: fixed Temperature coefficient = -0.39%/° C Efficiency = 17.72% derating factor = 90% Nominal operating cell temperature = 45°C Lifetime: 25 years
Converter	350	10 (1/year)	300	Efficiency = 97% Lifetime: 10 years
Generator	220	0.03(1/h)	200	Lifetime: 15000 h
Battery	130	1 (1/year)	100	Nominal capacity: 200Ah Nominal voltage: 1.2V

4. Optimal Sizing of a PV System in Golpayegan, Iran: *Operational control of the system*

- load following (LF) strategy is presented as a RES controller. The system operation of this controller follows three principles, and the PV output power:

1) is equal to the load demand.
   - The PV generated power meets the load required power, and there is no excess power.

2) is higher than the load demand
   - a) In PV/grid configuration the excess energy is injected into the grid.
   - b) In PV/diesel/battery configuration the excess power charges the battery, otherwise is damped

3) is lower than the load demand
   - a) In PV/grid the required energy will be provided by the grid.
   - b) In PV/diesel/battery based on the battery SOC, generator or batteries supply the load with power.

4. Optimal Sizing of a PV System in Golpayegan, Iran: *Results of the system sizing*

- The technical feasibility is investigated to examine the ability of the available power to meet the load demand throughout the year.
- HOMER investigates the economic sustainability and environmental impacts of the proposed systems.
- The annual discount rate of 8% and a 25-year project lifetime is considered to perform the simulation.
- The system performance is set at a maximum capacity shortage of 1%, and the battery SOC_{min} of 25%.
- The grid power price and grid sellback price also are set at 0.1 $/kWh and 0.08$/kWh.

4. Optimal Sizing of a PV System in Golpayegan, Iran: *Results of the system sizing*

Optimization results of the PV/grid RES.

Item	Unit	Value
PV	kW	6.19
Converter	kW	5.03
NPC	$	12,180
COE	$/kWh	0.056
Renewable fraction	%	64.1
PV production	kWh/year	11,196
Grid purchases	kWh/year	5976
Total production	kWh/year	17,172
Excess energy	%	0.5
Carbon emission	kg/year	3,777
Capital cost	$	5,349.48
O&M cost	$	5,679.5
Replacement cost	$	1,332.5

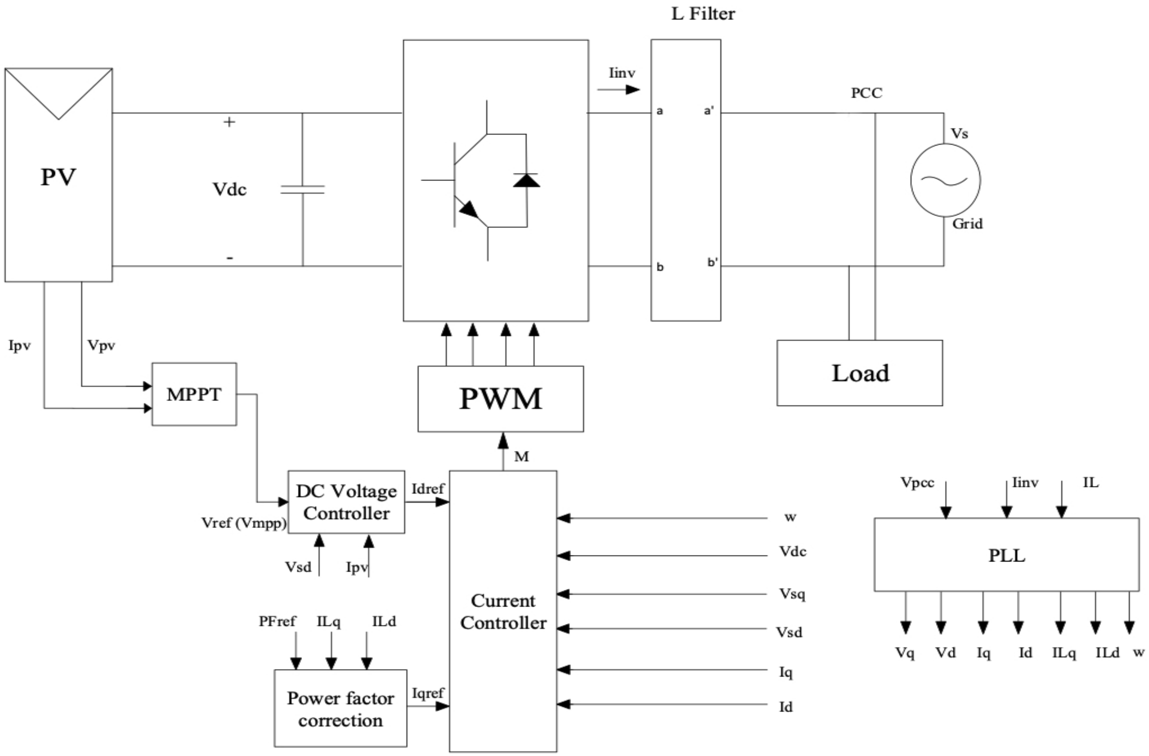
Optimization results of the PV/diesel/ battery RES.

Item	Unit	Value
PV	kW	5.17
Battery	Strings	36
Diesel generator	kW	10
Converter	kW	6.67
NPC	$	40.618
COE	$/kWh	0.28
Renewable fraction	%	64.2
PV production	kWh/year	9,346
Grid purchases	kWh/year	4,019
Total production	kWh/year	13,365
Excess energy	%	8
Carbon emission	kg/year	4,969
Capital cost	$	12,210
O&M cost	$	2,811
Replacement cost	$	1,827
Salvage cost	$	-819
Battery autonomy	hr	12.1
Fuel consumption	L/year	1902

PV/grid RES is selected for the selected house.

5.Dynamic Modeling and Control of a Single-Phase Grid-Connected PV System

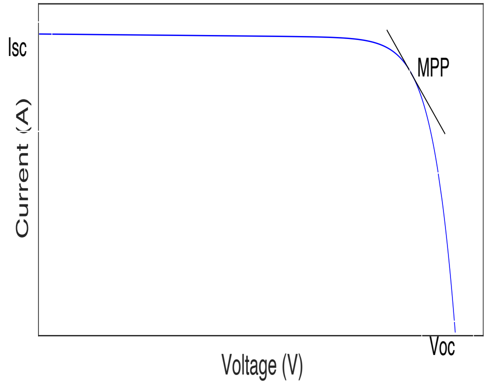
- Controller design for a single-phase grid-connected PV system
- Power factor correction in the distribution power system.
- modeling the grid interface inverter with the appropriate filter, and the DC link capacitor.



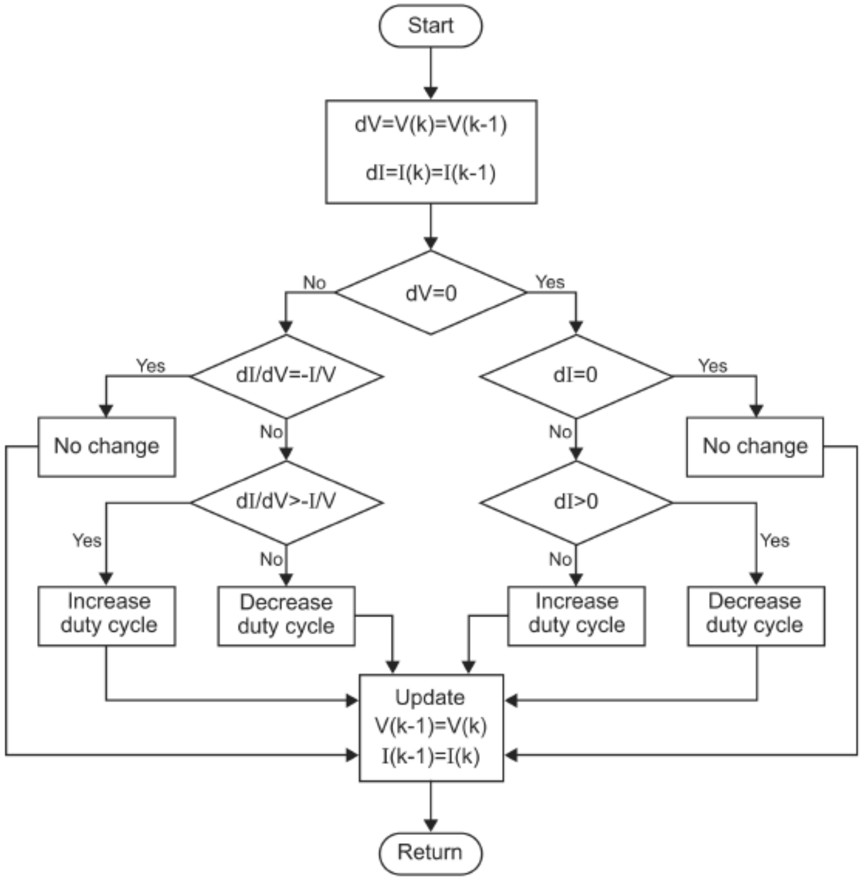
5.Dynamic Modeling and Control of a Single-Phase Grid-Connected PV System: The Inverter Controller Model

MPPT Controller

- At MPP, the PV system operates with maximum efficiency and delivers its maximum output power.
- the incremental conductance algorithm is used to find out the MPP



Typical I/V Characteristics of a PV Cell.

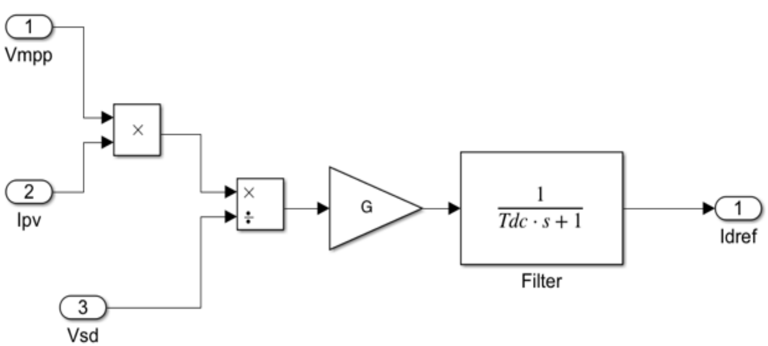


Flow chart of the incremental conductance MPPT controller.

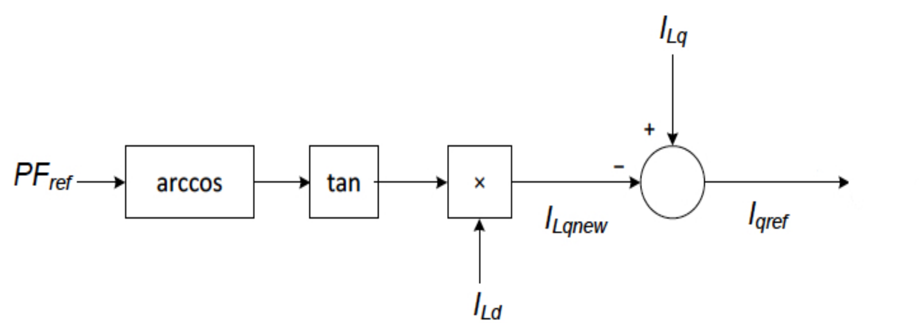
5.Dynamic Modeling and Control of a Single-Phase Grid-Connected PV System: *The Inverter Controller Model*

DC Bus Voltage Control → utilizes a compensator to generate the reference current, I_{dref}, to control the DC link voltage to the desired value.

Power Factor Control → utilizes I_{dL} and I_{qL} to generate the reference current, I_{qref}, to control the power factor.



DC Bus voltage controller.

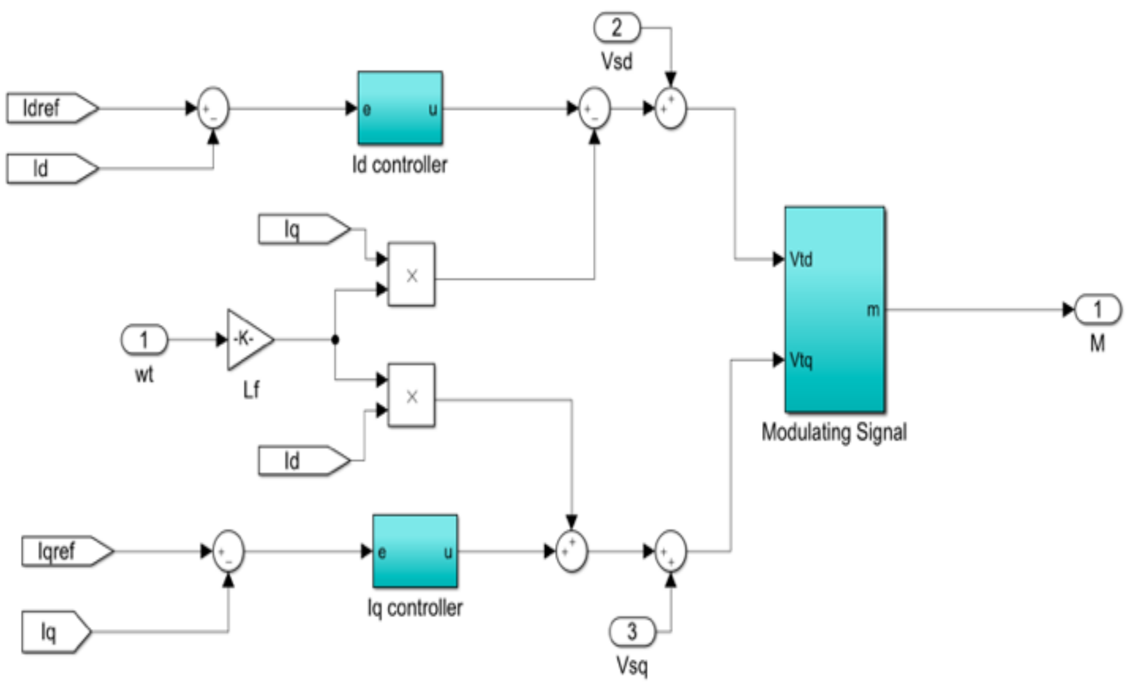


Power factor controller

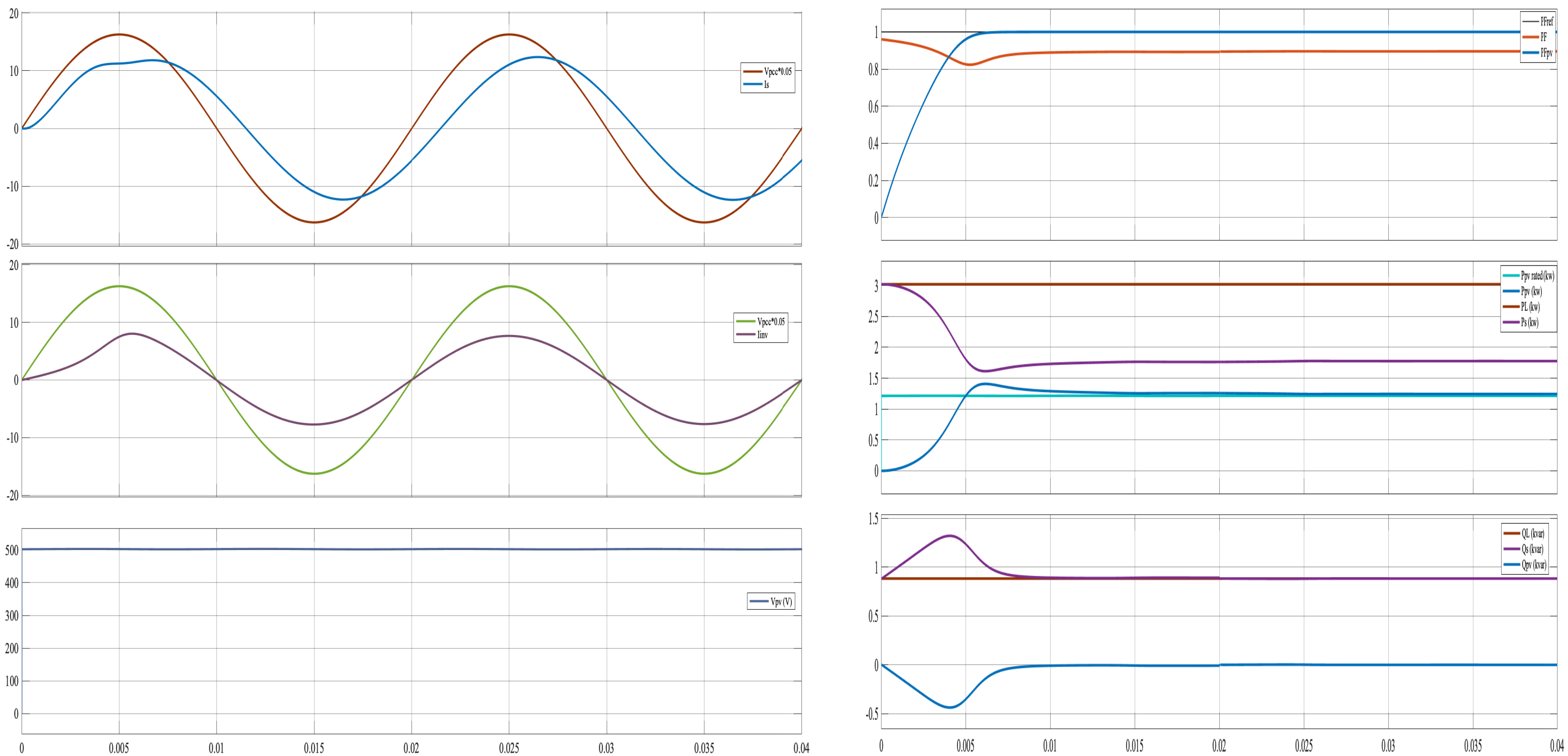
5.Dynamic Modeling and Control of a Single-Phase Grid-Connected PV System: *The Inverter Controller Model*

Current Controller

- It has two control loops that independently control the direct axis and quadrature axis components of the VSC currents I_d and I_q to generate modulation signal to control the inverter .



5.Dynamic Modeling and Control of a Single-Phase Grid-Connected PV System: Results

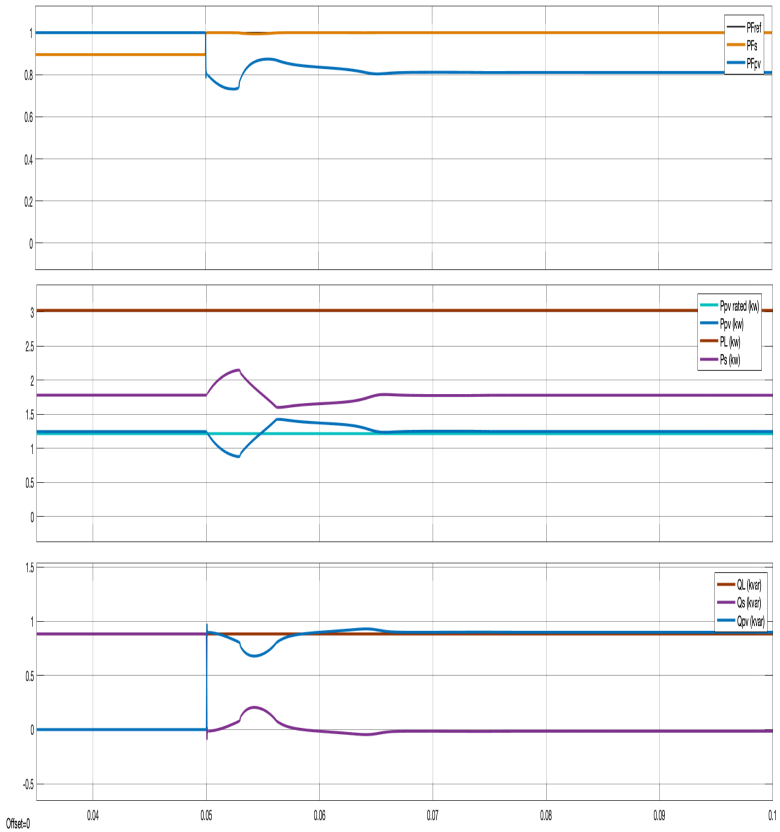


(a)

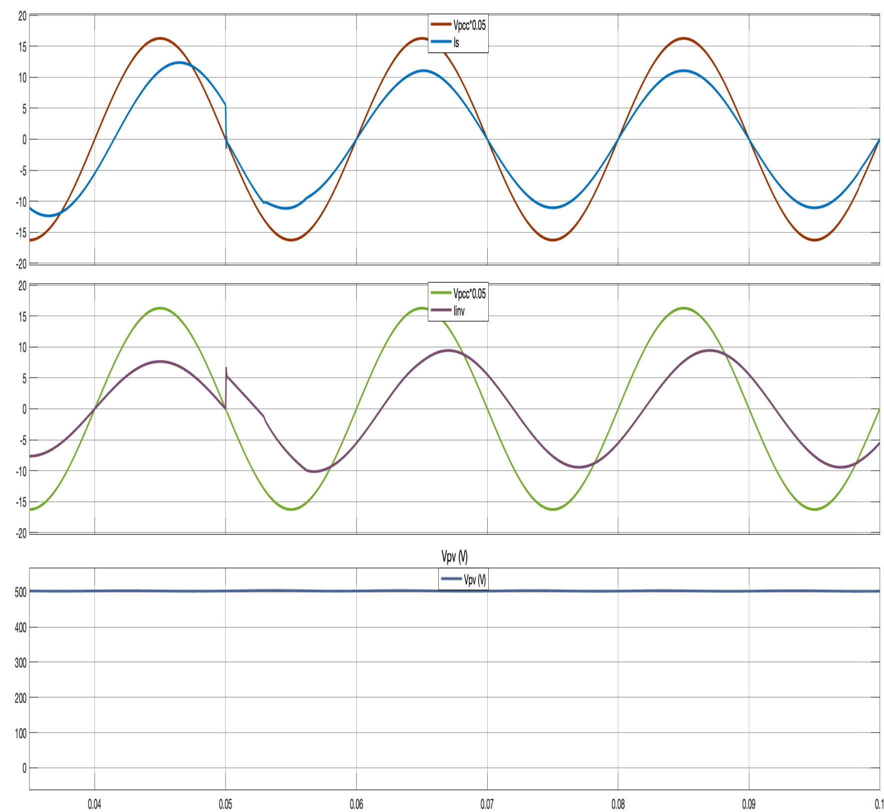
(b)

(a) Voltage at PCC and DC side- Inverter and Source current. (b) active and reactive power of load, inverter, and source.

5.Dynamic Modeling and Control of a Single-Phase Grid-Connected PV System: Results



(a)



(b)

(a) Voltage at PCC and DC side- Inverter and Source current. (b) active and reactive power of load, inverter, and source.

6. Low-Cost ESP32, Raspberry Pi, Node-Red, and MQTT Protocol Based SCADA System

- Growing energy cost and demand has motivated many organizations to achieve smart ways to monitor, control, and save energy.
- Smart automation can reduce costs while still satisfying energy demand.
- The residential, commercial, and industrial sectors can utilize the technologies of the Internet of Things (IoT) to manage energy consumption better.
- The designed system helps the users to monitor various conditions in their system. Thus, users can remotely monitor various devices and make decisions based on the feedback of sensors.

6. Low-Cost ESP32, Raspberry Pi, Node-Red, and MQTT Protocol Based SCADA System

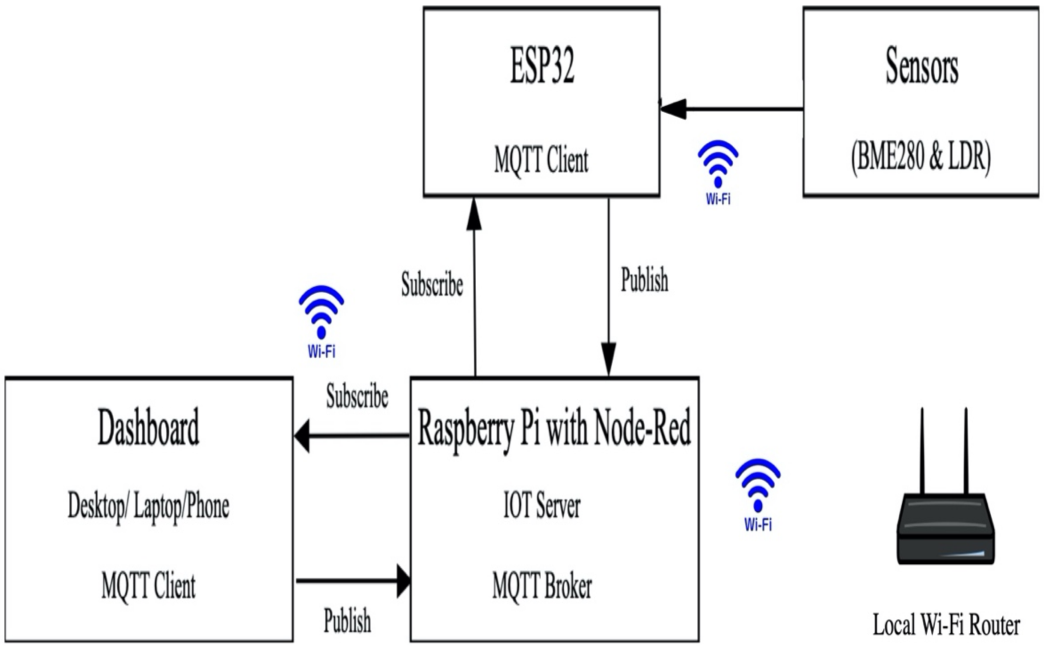
A low-cost and open-source SCADA system is developed that uses:

- .Wi-Fi
- . MQTT protocol
- . Node-Red

The proposed system provide detailed measurements of temperature, pressure, humidity, and light density.

The user can remotely monitor and control home devices such as lights, fans, air conditioners, or heating/cooling systems.

6. Low-Cost ESP32, Raspberry Pi, Node-Red, and MQTT Protocol Based SCADA System



The proposed SCADA system block diagram

6. Low-Cost ESP32, Raspberry Pi, Node-Red, and MQTT Protocol Based SCADA System: *Hardware*

Raspberry Pi

The Raspberry Pi2 model B is used as the local server at a local network, including MQTT broker, Node-Red, SQLite.

ESP32 Thing

The ESP32 Thing is developed by SparkFun Electronics. It is one of the most low-cost, low-power, and small microcontrollers included Wi-Fi and Bluetooth modules.

SparkFun Atmospheric Sensor Breakout BME280

The SparkFun BME280 Atmospheric Sensor Breakout is used to measure pressure, humidity, and temperature readings, all with a tiny breakout.

Light Dependent Resistor (LDR)

The LDR is used to measure the light intensity. Its variable resistance feature makes it suitable for LED control purposes.

6. Low-Cost ESP32, Raspberry Pi, Node-Red, and MQTT Protocol Based SCADA System: *Software*

MQTT Communication Protocol

- MQTT is a publish/subscribe protocol.
- provides simple communication between the server (MQTT broker) and clients (ESP32 microcontroller and computers and mobile devices)
- Clients can subscribe to the topics or publish the data to topics of any kind of data. The broker then distributes the data to any client that has subscribed to that topic.
- Eclipse Mosquitto software is being run as a broker on the local server (Raspberry Pi2).
- the ESP32 microcontroller publishes the sensors data with specific topics to the MQTT broker (Mosquitto broker), while personal computers and mobile devices subscribe to the topics to visualize the published data on the server

Node-Red

Node-RED is an open-source programming tool used for wiring together hardware devices, APIs, and online services smartly

It has been installed on Raspberry Pi, and it provides a browser-based editor

6. Low-Cost ESP32, Raspberry Pi, Node-Red, and MQTT Protocol Based SCADA System: *Software*

Database and dashboard

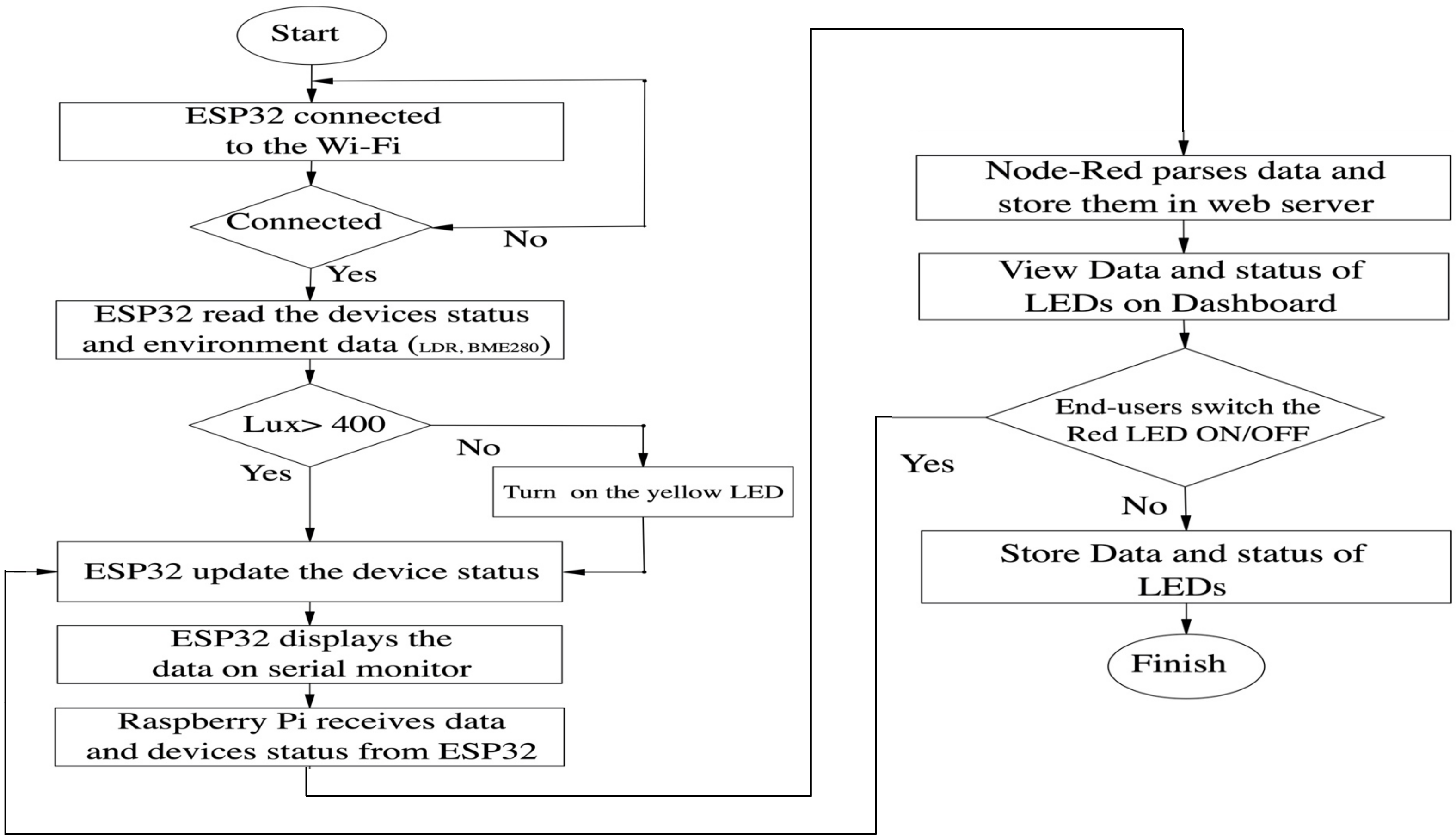
- An SQLite database using the litedb node on the Node-RED platform is installed to create database tables and store data.
- As a very lightweight relational database, SQLite does not need complex setup procedures, making it an ideal database management system to use for embedded systems and rapid prototyping.
- In this work, SQLite is set up to generate database, then store data
- An easy-to-use dashboard (Node-Red dashboard) is used to display the acquired data from the data base.
- Node-Red dashboard is a web-based data monitoring tool that can be combined to SQLite.

6. Low-Cost ESP32, Raspberry Pi, Node-Red, and MQTT Protocol Based SCADA System: *Software*

The open-source Arduino Software (IDE)

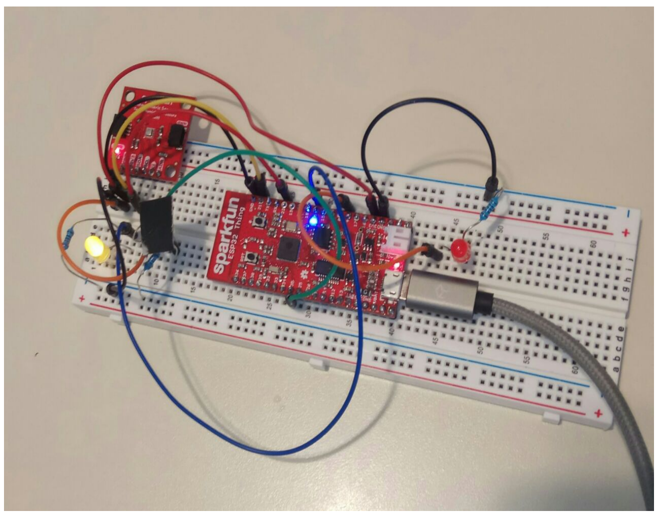
- The microcontroller is programmed with the Arduino software integrated development environment (IDE).
- The Arduino IDE allows experts to write the desired programs and upload them to the board via a USB cable.
- ESP32 microcontroller is programmed as an MQTT client using the Arduino IDE software.
- The MQTT Client Library called PubSubClient is added to the Arduino IDE library.
- The programed board collects the measured real-time values of desired variables, displays them on the Arduino IDE Serial Monitor, and continuously publishes real-time data to the MQTT broker.

6. Low-Cost ESP32, Raspberry Pi, Node-Red, and MQTT Protocol Based SCADA System



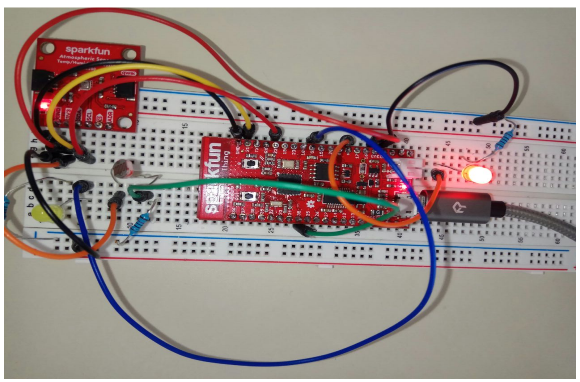
The flow chart of the proposed SCADA system

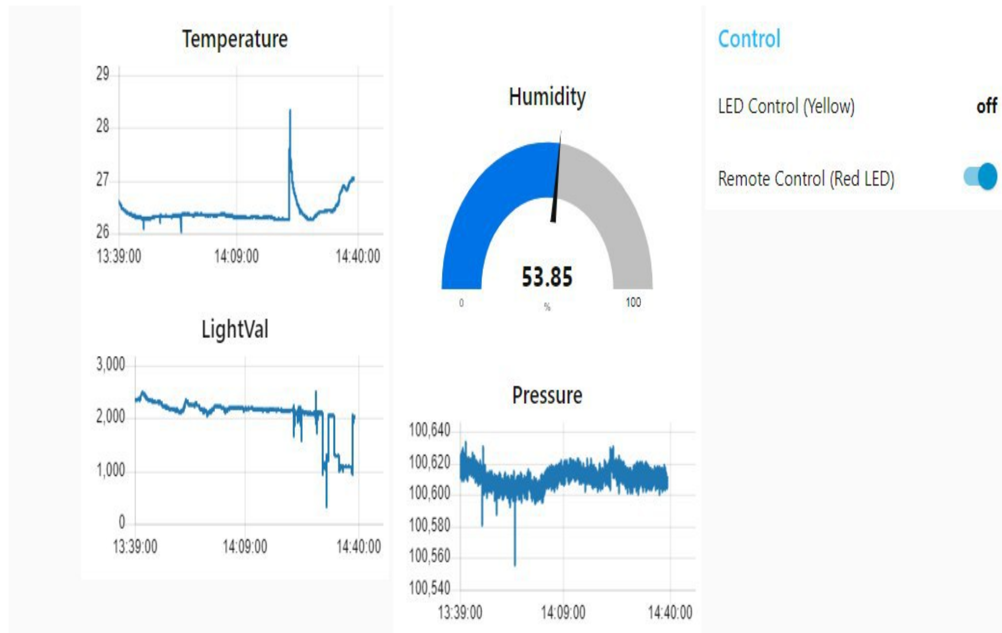
6. Low-Cost ESP32, Raspberry Pi, Node-Red, and MQTT Protocol Based SCADA System: *Test and Results*



The LED is turned on automatically based on the threshold value.

6. Low-Cost ESP32, Raspberry Pi, Node-Red, and MQTT Protocol Based SCADA System: _Test and Results_





The user remotely turned the Red LED on

7. Summary and conclusions

The output of this research can be summarize as follows:

- The designed grid-connected PV power system achieved high reliability and minimum NPC and carbon emission
- The designed dynamic model and control system maintain whole the system steady state.
- The designed power factor control unit makes the employing PV systems more affordable since the designed system is a candidate for reactive power support to the utility grid.
- The developed SCADA system makes the remote monitoring and control possible.
- The designed SCADA system is low-cost, open-source, and flexible to add more devices and sensors.

8. Future Works

Future works

- Add the wind turbine to the designed power system for the selected house for higher renewable penetration.
- Develop a wiring system by Helioscope
- Add switches and breakers to the system for the protection and safety proposes.
- Develop the designed SCADA system to monitor and control other systems remotely.
- Include a data analysis based on the obtained data

9. List of Publications:

- Zare, M.T. Iqbal, "Low-Cost ESP32, Raspberry Pi, Node-Red, and MQTT Protocol Based SCADA System," *2020 IEEE International IOT, Electronics and Mechatronics Conference (IEMTRONICS)*, Vancouver, BC, Canada, 2020, pp. 1-5, doi: 10.1109/IEMTRONICS51293.2020.9216412.
- A Zare, M. Tariq Iqbal, "Dynamic Modeling and Control of a Single-Phase Grid-Connected photovoltaic System," *submitted to 2020 IEEE 17th International Conference on Smart Communities.*
- A Zare, M. Tariq Iqbal, "Optimal sizing of a PV system in Golpayegan, Iran using thermal modeling-based load demand," *submitted to 2020 IEEE 17th International Conference on Smart Communities.*
- A. Rehman, H. Elsaraf, A. Zare, and M. Tariq Iqbal, "Design and analysis of a rooftop PV system for an apartment building in Newfoundland," *Accepted for presentation at the 29th IEEE NECEC 2020, St. John's, NL, Canada*.

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Thank you