Smart Grid EV Charging System - Final Project Report

1. Introduction

This project simulates a smart grid system that dynamically balances electric vehicle (EV) charging load across multiple substations. It uses microservices built with Python, containerized using Docker, and monitored with Prometheus and Grafana.

2. Objective

To prevent overloading any single charging substation by dynamically routing EV charging requests based on real-time substation load metrics.

3. System Architecture

The system consists of:
- A Charge Request Service as the public API.
- A Load Balancer Service that polls metrics from substations and routes requests.
- Multiple Substation Services that simulate charging and expose Prometheus metrics.
- Prometheus to scrape substation metrics.
- Grafana to visualize load data in real-time.

4. Technologies Used

- Python 3.10+
- Flask (microservices)
- Prometheus + Grafana (monitoring)
- Docker & Docker Compose (orchestration)

5. Microservice Overview

• Charge Request Service: Accepts EV charge requests and forwards them to the Load Balancer.
• Load Balancer Service: Chooses the least loaded substation using real-time Prometheus metrics.
• Substation Service: Simulates charging by holding the request for a moment and updating load metrics.

6. Observability Stack

Each substation exposes a metric `substation_current_load`. Prometheus scrapes it, and Grafana dashboards display real-time graphs.

7. Load Testing

A Python script simulates 100 concurrent EV charge requests. The system performance and load balancing behavior is observed through Grafana.

8. Docker Setup

Each microservice has its own Dockerfile. `docker-compose.yml` launches all services in one command, including multiple substations.

9. Screenshots

The following pages include screenshots of Docker, Prometheus, Grafana, source code, and test execution.

10. Conclusion

The system successfully distributes EV charging requests, avoids overloading, and gives full visibility into grid behavior. Future improvements could include predictive load distribution and fault tolerance.

Figure 1

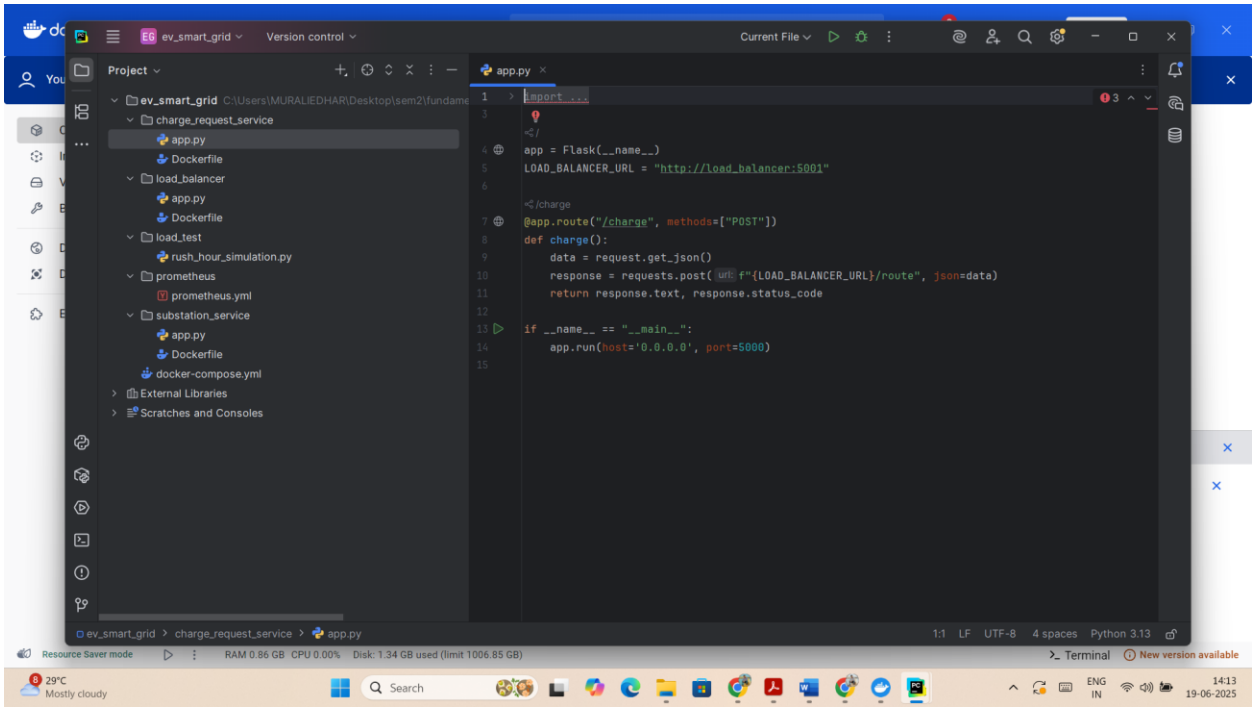
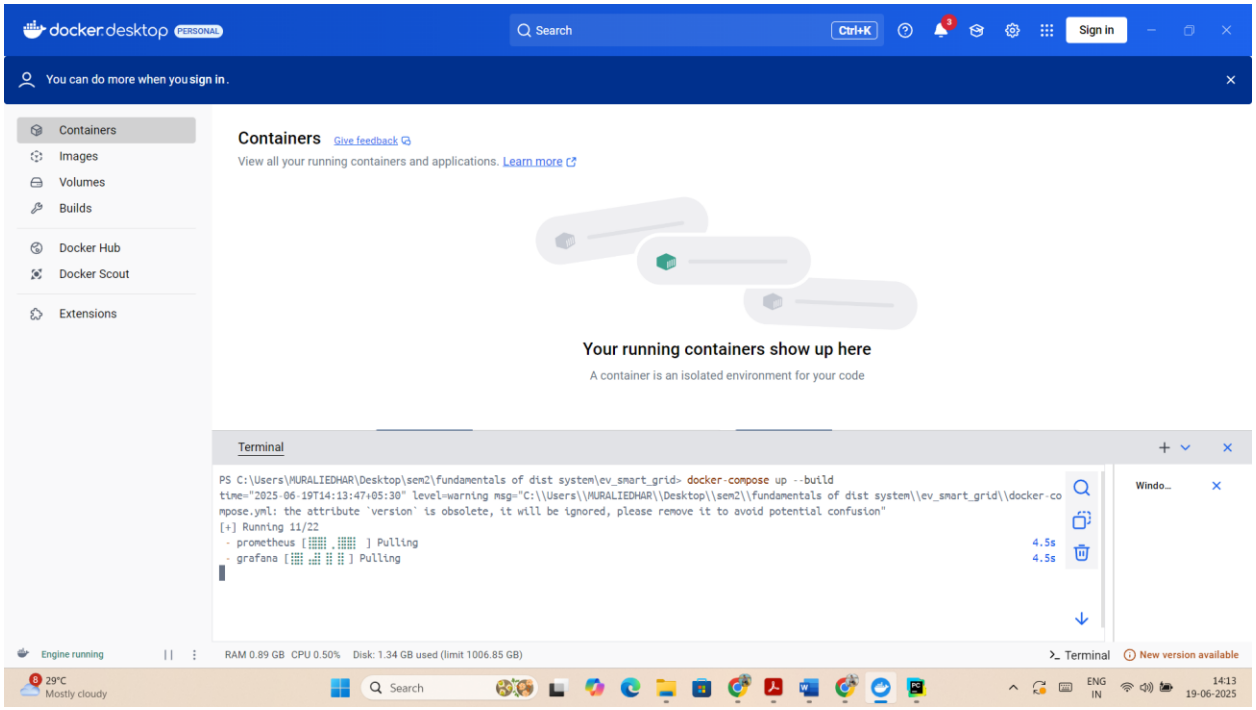

ev_smart_grid
Version control
Current File
Project
app.py
ev_smart_grid C:\Users\MURALIEDHAR\Desktop\sem2\fundame
charge_request_service
app.py
Dockerfile
load_balancer
app.py
Dockerfile
load_test
rush_hour_simulation.py
prometheus
prometheus.yml
substation_service
app.py
Dockerfile
docker-compose.yml
External Libraries
Scratches and Consoles
import ...
app = Flask(__name__)
LOAD_BALANCER_URL = "http://load_balancer:5001"
/charge
@app.route("/charge", methods=["POST"])
def charge():
data = request.get_json()
response = requests.post(url: f"{LOAD_BALANCER_URL}/route", json=data)
return response.text, response.status_code
if __name__ == "__main__":
app.run(host='0.0.0.0', port=5000)
ev_smart_grid > charge_request_service > app.py
1:1 LF UTF-8 4 spaces Python 3.13
Resource Saver mode
RAM 0.86 GB CPU 0.00% Disk: 1.34 GB used (limit 1006.85 GB)
Terminal
New version available
29°C
Mostly cloudy
Search
ENG
IN
14:13
19-06-2025

Figure 2


docker desktop
PERSONAL
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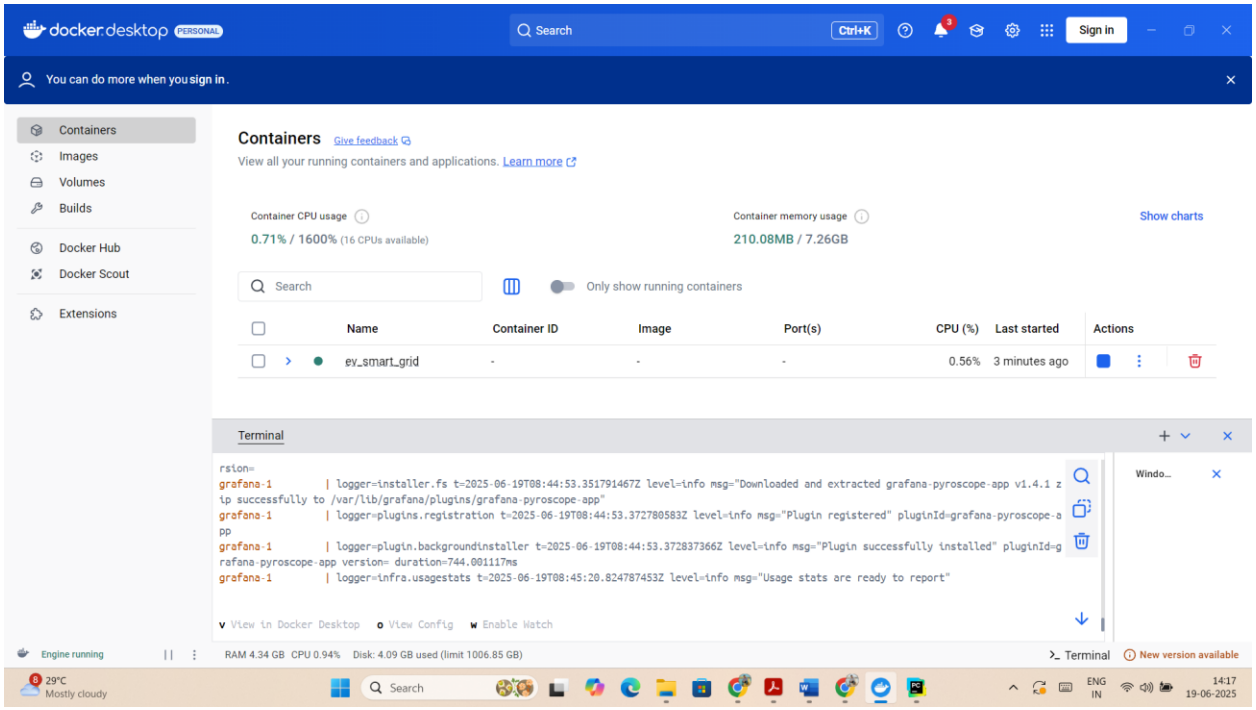
Containers
Images
Volumes
Builds
Docker Hub
Docker Scout
Extensions
Containers
Give feedback
View all your running containers and applications. Learn more
Your running containers show up here
A container is an isolated environment for your code
Terminal
PS C:\Users\MURALIEDHAR\Desktop\sem2\fundamentals of dist system\ev_smart_grid> docker-compose up --build
time="2025-06-19T14:13:47+05:30" level=warning msg="C:\\Users\\MURALIEDHAR\\Desktop\\sem2\\fundamentals of dist system\\ev_smart_grid\\docker-compose.yml: the attribute `version` is obsolete, it will be ignored, please remove it to avoid potential confusion"
[+] Running 11/22
- prometheus [ ] Pulling 4.5s
- grafana [ ] Pulling 4.5s
Engine running
RAM 0.89 GB CPU 0.50% Disk: 1.34 GB used (limit 1006.85 GB)
Terminal
New version available
29°C
Mostly cloudy
Search
ENG
IN
14:13
19-06-2025

Figure 3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Docker Hub
Docker Scout
Extensions
Containers
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Container CPU usage
0.71% / 1600% (16 CPUs available)
Container memory usage
210.08MB / 7.26GB
Show charts
Search
Only show running containers
Name
Container ID
Image
Port(s)
CPU (%)
Last started
Actions
ev_smart_grid
0.56%
3 minutes ago
Terminal
rsion=
grafana-1 | logger=installer.fs t=2025-06-19T08:44:53.351791467Z level=info msg="Downloaded and extracted grafana-pyroscope-app v1.4.1 zip successfully to /var/lib/grafana/plugins/grafana-pyroscope-app"
grafana-1 | logger=plugins.registration t=2025-06-19T08:44:53.372780583Z level=info msg="Plugin registered" pluginId=grafana-pyroscope-app
grafana-1 | logger=plugin.backgroundinstaller t=2025-06-19T08:44:53.372837366Z level=info msg="Plugin successfully installed" pluginId=grafana-pyroscope-app version= duration=744.001117ms
grafana-1 | logger=infra.usagestats t=2025-06-19T08:45:20.824787453Z level=info msg="Usage stats are ready to report"
View in Docker Desktop
View Config
Enable Watch
Windo...
Engine running
RAM 4.34 GB CPU 0.94% Disk: 4.09 GB used (limit 1006.85 GB)
Terminal
New version available
29°C
Mostly cloudy
Search
ENG
IN
14:17
19-06-2025

Figure 4

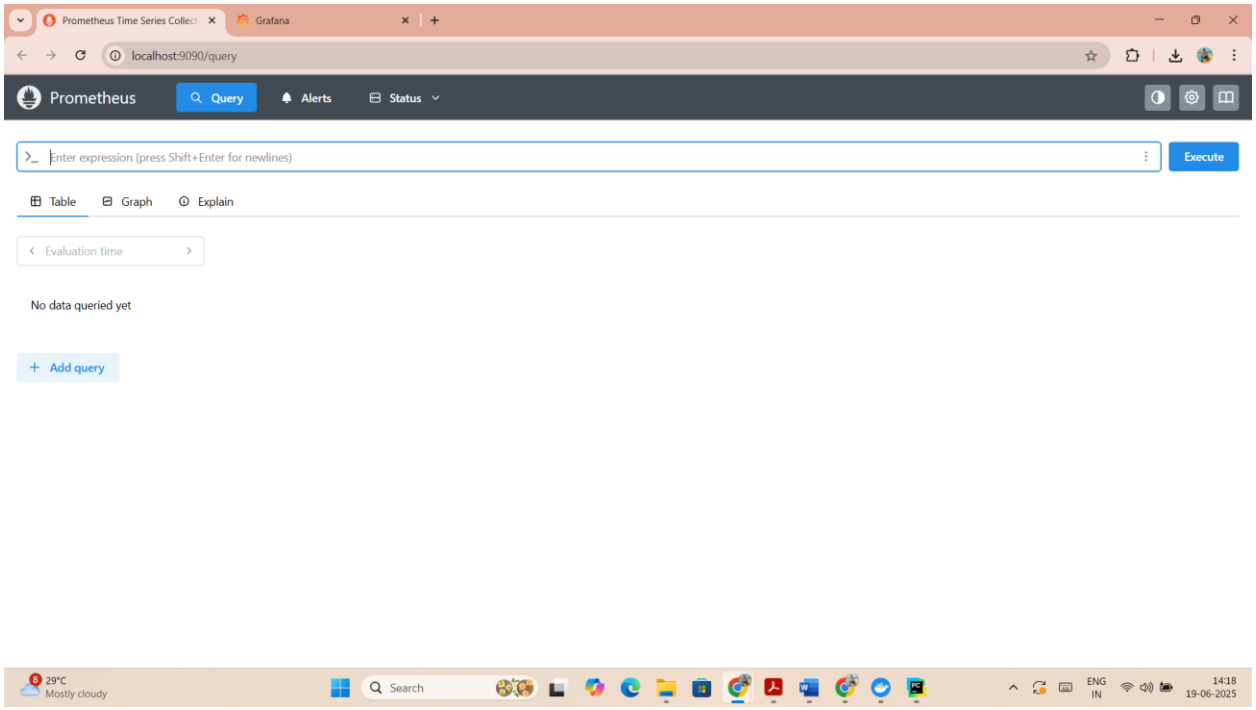

Prometheus Time Series Collec
Grafana
localhost:9090/query
Prometheus
Query
Alerts
Status
Enter expression (press Shift+Enter for newlines)
Execute
Table
Graph
Explain
Evaluation time
No data queried yet
Add query
29°C
Mostly cloudy
Search
ENG
IN
14:18
19-06-2025

Figure 5

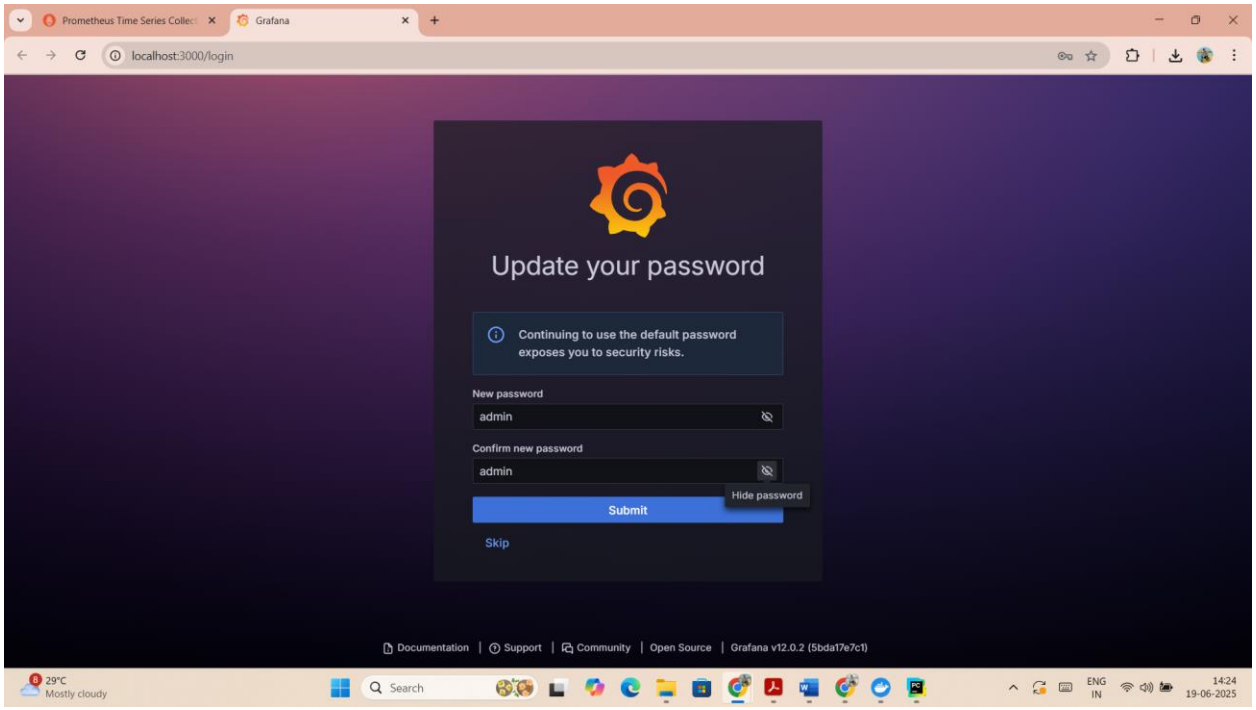

Prometheus Time Series Collec
Grafana
localhost:3000/login
Update your password
Continuing to use the default password exposes you to security risks.
New password
admin
Confirm new password
admin
Hide password
Submit
Skip
Documentation
Support
Community
Open Source
Grafana v12.0.2 (5bda17e7c1)
29°C
Mostly cloudy
Search
ENG
IN
14:24
19-06-2025

Figure 6

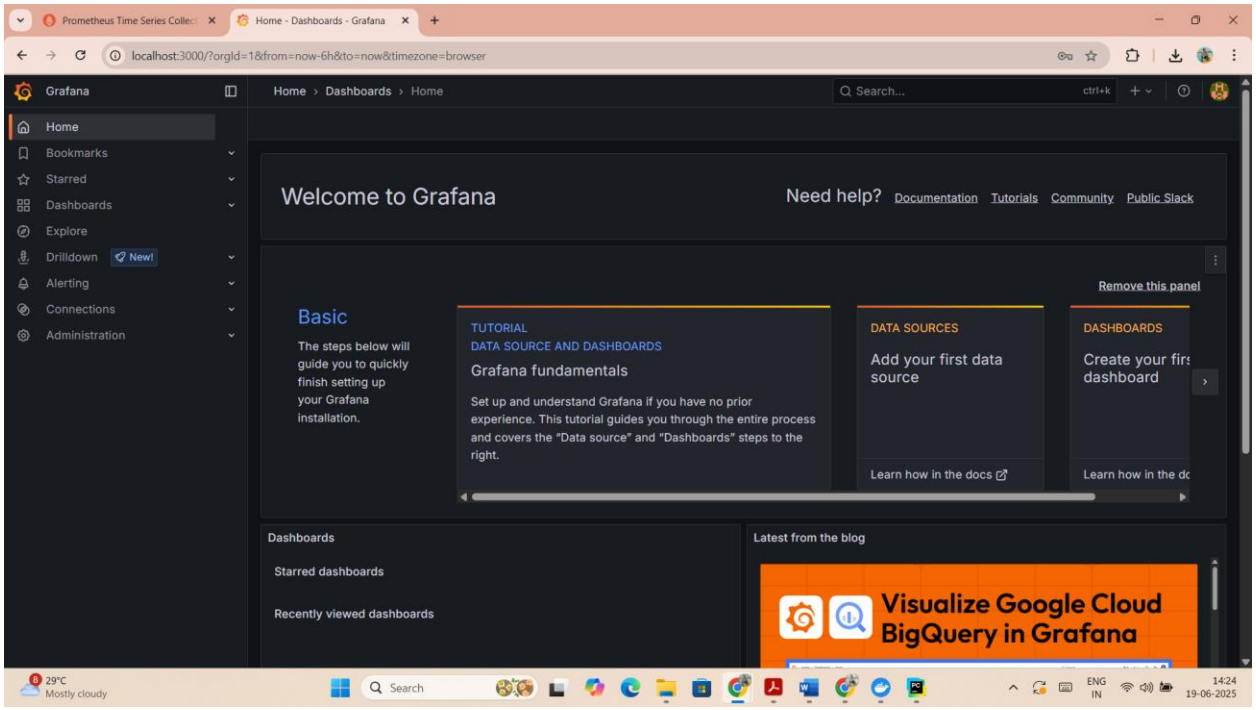
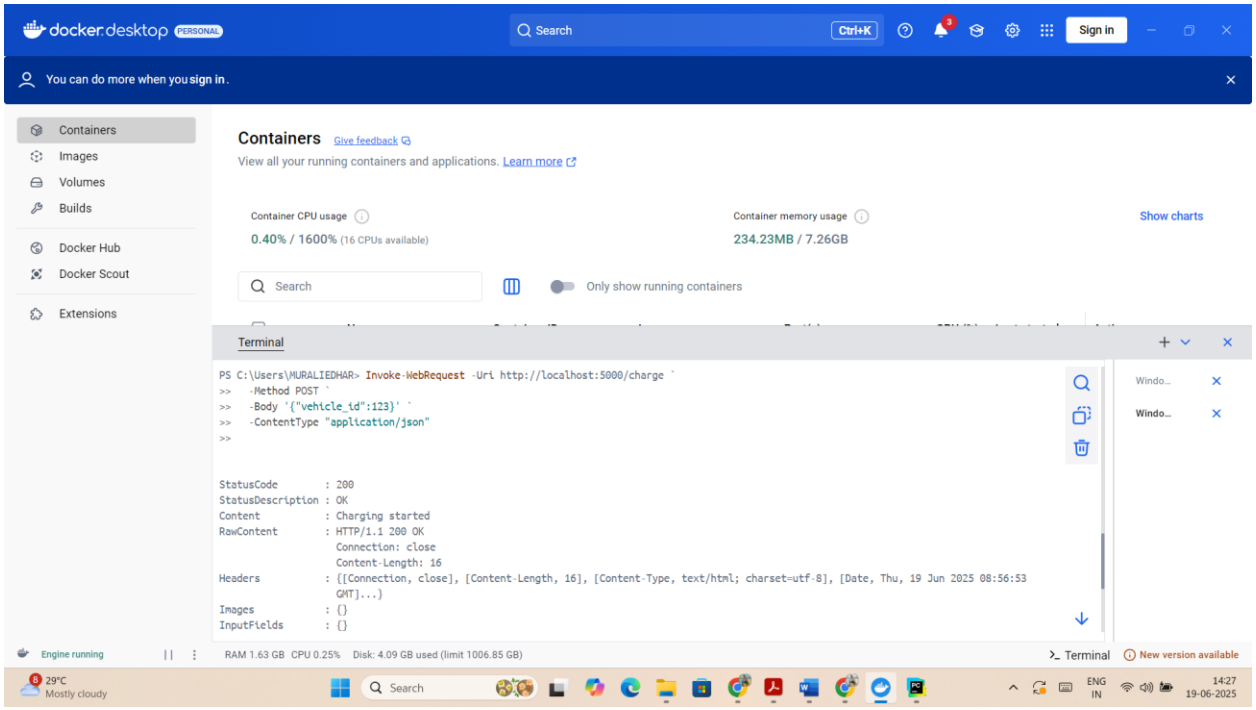

Prometheus Time Series Collec
Home - Dashboards - Grafana
localhost:3000/?orgId=1&from=now-6h&to=now&timezone=browser
Grafana
Home
Bookmarks
Starred
Dashboards
Explore
Drilldown
New!
Alerting
Connections
Administration
Home › Dashboards › Home
Search...
ctrl+k
Welcome to Grafana
Need help?
Documentation
Tutorials
Community
Public Slack
Remove this panel
Basic
The steps below will guide you to quickly finish setting up your Grafana installation.
TUTORIAL
DATA SOURCE AND DASHBOARDS
Grafana fundamentals
Set up and understand Grafana if you have no prior experience. This tutorial guides you through the entire process and covers the "Data source" and "Dashboards" steps to the right.
DATA SOURCES
Add your first data source
Learn how in the docs
DASHBOARDS
Create your firs dashboard
Learn how in the dc
Dashboards
Starred dashboards
Recently viewed dashboards
Latest from the blog
Visualize Google Cloud BigQuery in Grafana
29°C
Mostly cloudy
Search
ENG
IN
14:24
19-06-2025

Figure 7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Container CPU usage
0.40% / 1600% (16 CPUs available)
Container memory usage
234.23MB / 7.26GB
Show charts
Search
Only show running containers
Terminal
PS C:\Users\MURALIEDHAR> Invoke-WebRequest -Uri http://localhost:5000/charge `
>> -Method POST `
>> -Body '{"vehicle_id":123}' `
>> -ContentType "application/json"
>>
StatusCode : 200
StatusDescription : OK
Content : Charging started
RawContent : HTTP/1.1 200 OK
Connection: close
Content-Length: 16
Headers : {[Connection, close], [Content-Length, 16], [Content-Type, text/html; charset=utf-8], [Date, Thu, 19 Jun 2025 08:56:53
GMT]...}
Images : {}
InputFields : {}
Engine running
RAM 1.63 GB CPU 0.25% Disk: 4.09 GB used (limit 1006.85 GB)
Terminal
New version available
29°C
Mostly cloudy
Search
ENG
IN
14:27
19-06-2025

Figure 8

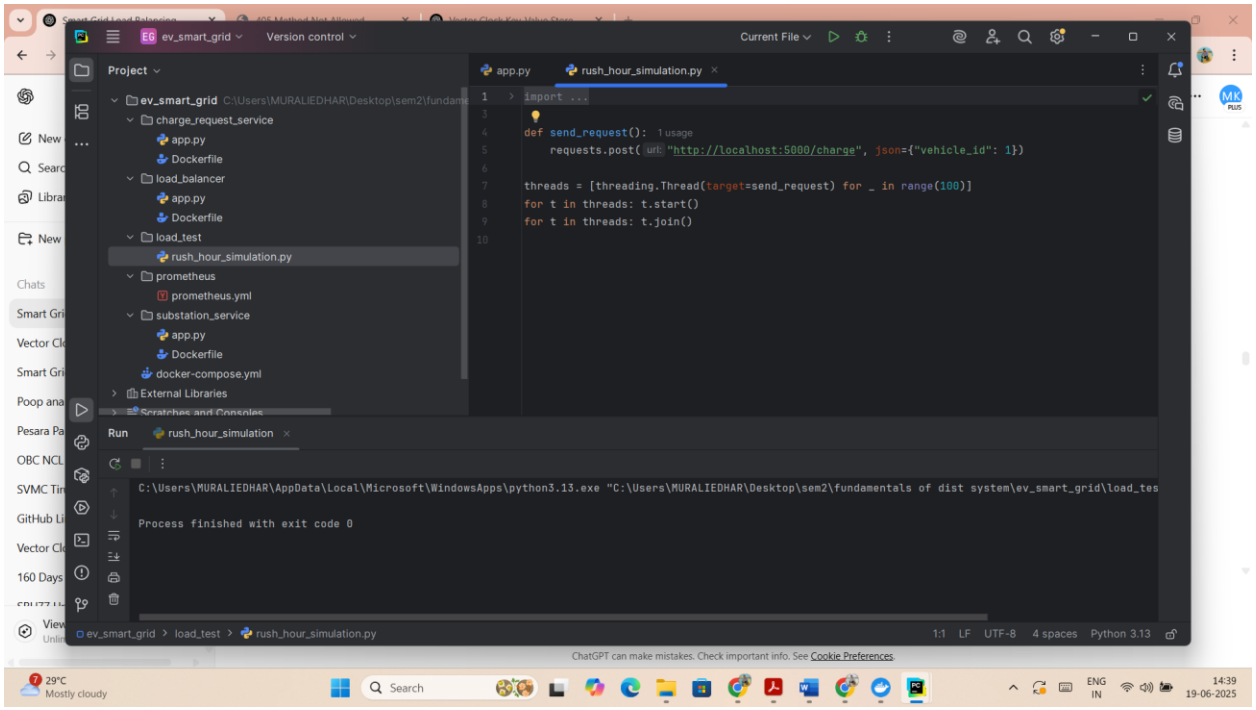
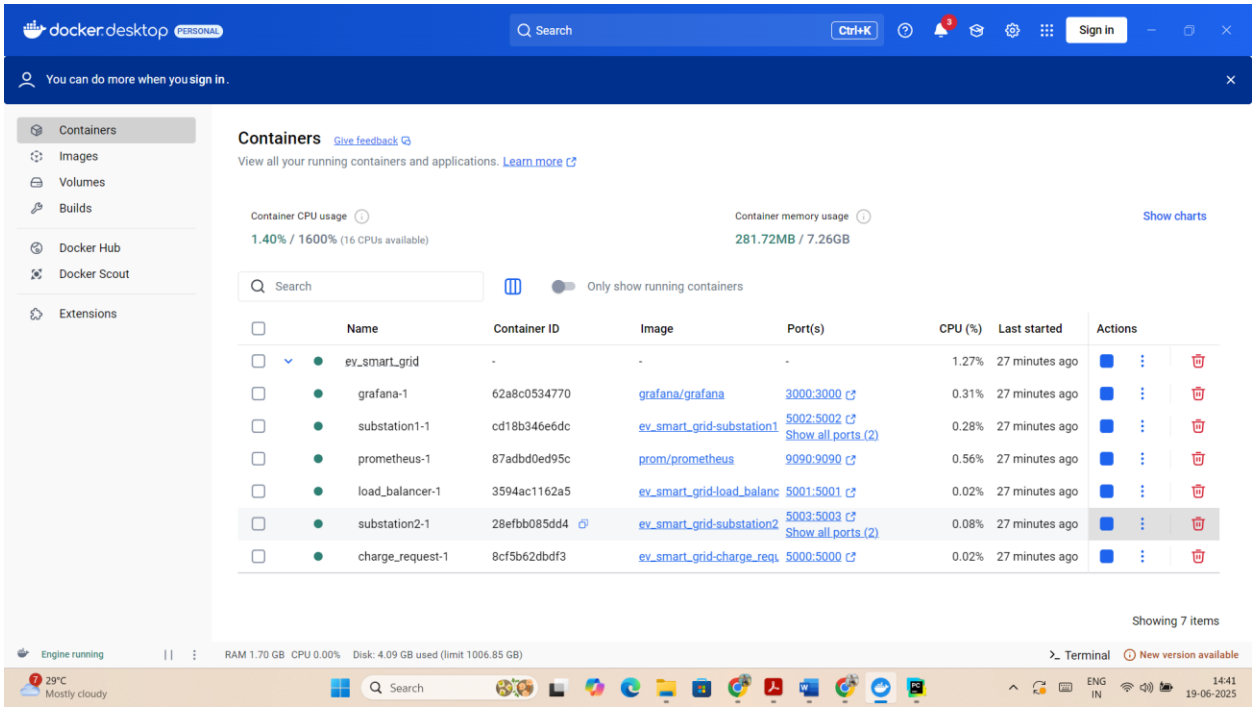

ev_smart_grid
Version control
Current File
Project
app.py
rush_hour_simulation.py
import ...
def send_request(): 1 usage
requests.post(url: "http://localhost:5000/charge", json={"vehicle_id": 1})
threads = [threading.Thread(target=send_request) for _ in range(100)]
for t in threads: t.start()
for t in threads: t.join()
charge_request_service
app.py
Dockerfile
load_balancer
app.py
Dockerfile
load_test
rush_hour_simulation.py
prometheus
prometheus.yml
substation_service
app.py
Dockerfile
docker-compose.yml
External Libraries
Run
rush_hour_simulation
C:\Users\MURALIEDHAR\AppData\Local\Microsoft\WindowsApps\python3.13.exe "C:\Users\MURALIEDHAR\Desktop\sem2\fundamentals of dist system\ev_smart_grid\load_tes
Process finished with exit code 0
ev_smart_grid > load_test > rush_hour_simulation.py
1:1 LF UTF-8 4 spaces Python 3.13
ChatGPT can make mistakes. Check important info. See Cookie Preferences.
29°C
Mostly cloudy
Search
ENG
IN
14:39
19-06-2025

Figure 9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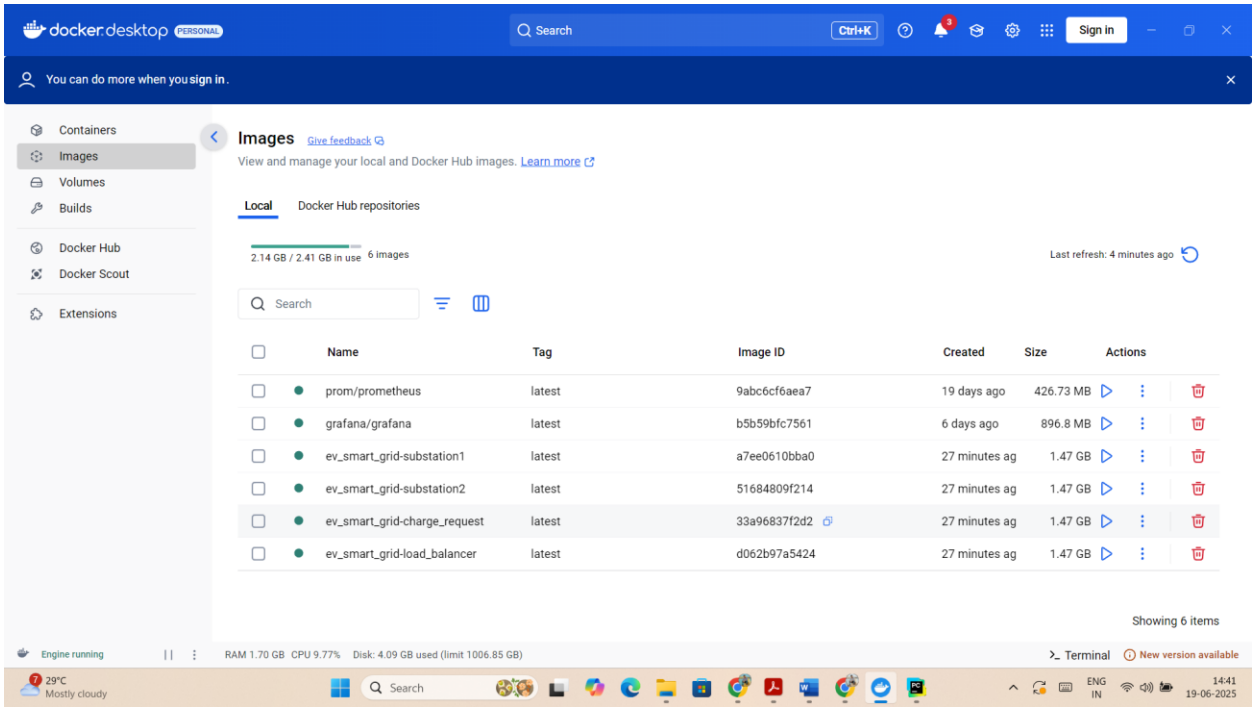
Container CPU usage
1.40% / 1600% (16 CPUs available)
Container memory usage
281.72MB / 7.26GB
Show charts
Search
Only show running containers
Name
Container ID
Image
Port(s)
CPU (%)
Last started
Actions
ev_smart_grid
grafana-1
62a8c0534770
grafana/grafana
3000:3000
0.31%
27 minutes ago
substation1-1
cd18b346e6dc
ev_smart_grid-substation1
5002:5002
Show all ports (2)
0.28%
27 minutes ago
prometheus-1
87adbd0ed95c
prom/prometheus
9090:9090
0.56%
27 minutes ago
load_balancer-1
3594ac1162a5
ev_smart_grid-load_balanc
5001:5001
0.02%
27 minutes ago
substation2-1
28efbb085dd4
ev_smart_grid-substation2
5003:5003
Show all ports (2)
0.08%
27 minutes ago
charge_request-1
8cf5b62dbdf3
ev_smart_grid-charge_requ
5000:5000
0.02%
27 minutes ago
Showing 7 items
Engine running
RAM 1.70 GB CPU 0.00% Disk: 4.09 GB used (limit 1006.85 GB)
Terminal
New version available
29°C
Mostly cloudy
Search
ENG
IN
14:41
19-06-2025

Figure 10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Docker Hub
Docker Scout
Extensions
Images
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View and manage your local and Docker Hub images. Learn more
Local
Docker Hub repositories
2.14 GB / 2.41 GB in use 6 images
Last refresh: 4 minutes ago
Search
Name Tag Image ID Created Size Actions
prom/prometheus latest 9abc6cf6aea7 19 days ago 426.73 MB
grafana/grafana latest b5b59bfc7561 6 days ago 896.8 MB
ev_smart_grid-substation1 latest a7ee0610bba0 27 minutes ag 1.47 GB
ev_smart_grid-substation2 latest 51684809f214 27 minutes ag 1.47 GB
ev_smart_grid-charge_request latest 33a96837f2d2 27 minutes ag 1.47 GB
ev_smart_grid-load_balancer latest d062b97a5424 27 minutes ag 1.47 GB
Showing 6 items
Engine running
RAM 1.70 GB CPU 9.77% Disk: 4.09 GB used (limit 1006.85 GB)
Terminal
New version available
29°C
Mostly cloudy
Search
ENG
IN
14:41
19-06-2025