

# *Dynamic Load Balancing for a Smart Grid*

**Title:** Dynamic Load Balancer for Smart Grid EV Charging Using Dockerized Microservices and Prometheus Metrics

**Name:** Samir Kumar Jyotishi

**Assignment :** 1 (Dynamic Load Balancing for a Smart Grid)

**Roll No :** G24AI2047

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## System Architecture:

### **Components:**

- `charge_request_service`: Entry point for EV charge requests.
- `load_balancer`: Determines which substation has the lowest load.
- `substation_service` (1,2,3): Simulates EV charging with Prometheus metrics.
- Prometheus: Scrapes metrics from substations.
- Grafana: Visualizes load distribution over time.

All services are containerized using Docker and communicate over an internal Docker network.

**Routing Logic:** The load balancer queries `ev_charging_load` from each substation via Prometheus-compatible `/metrics` endpoints and forwards requests to the one with the lowest load.

## Implementation

### **`charge_request_service/main.py`**

Receives POST `/charge request` → Forwards to `load_balancer`.

### **load\_balancer/main.py**

- Fetches real-time ev\_charging\_load metrics from all substations.
- Selects substation with minimum load.
- Forwards request via REST API (POST /charge).

### **substation\_service/main.py**

- Increments local ev\_charging\_load on each request.
- Simulates a delay (2–5s) to mimic charging.
- Exposes metrics via Prometheus on port 9100.

## **Docker Setup**

### ***Commands Used:***

docker-compose build

docker-compose up

### ***Ports Used:***

- Charge API: localhost:7000
- Load Balancer: localhost:6000
- Substations (metrics): 9101, 9102, 9103
- Prometheus: 9090
- Grafana: 3000

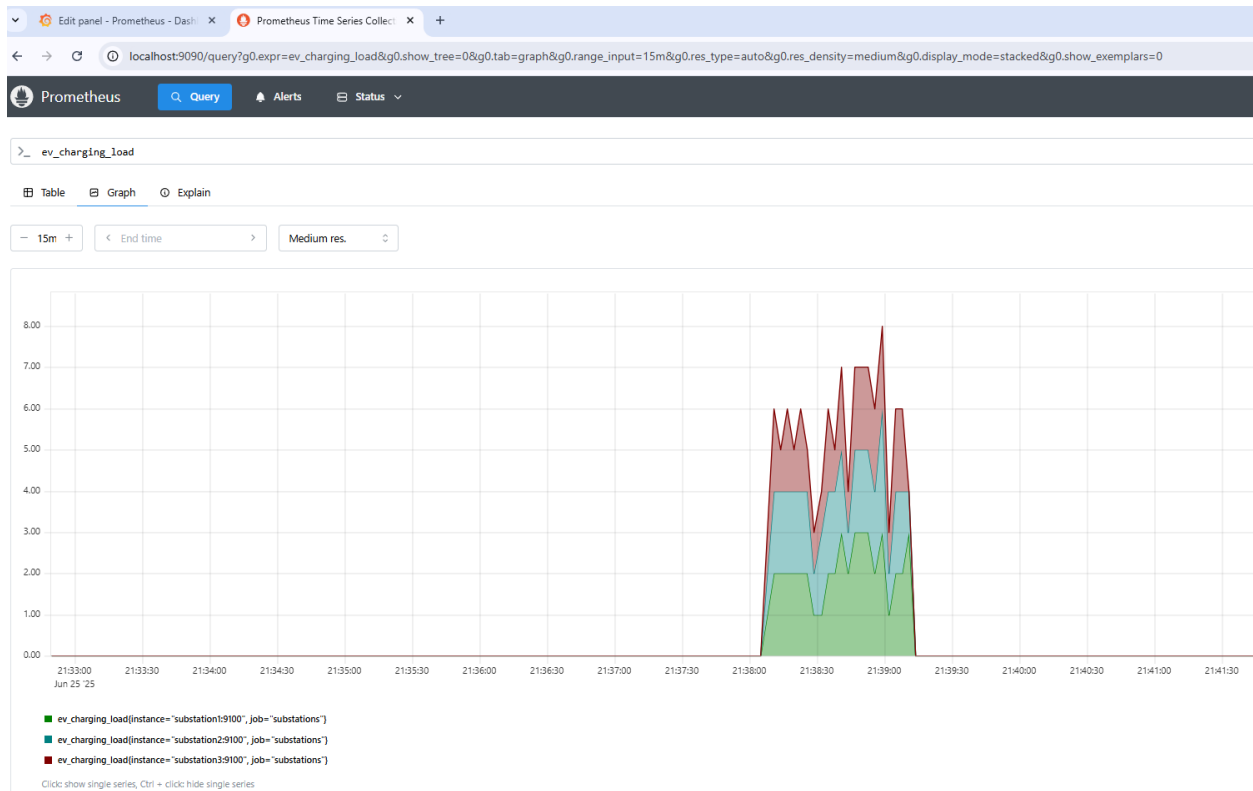
```
1 import requests
2 import time
3
4 substations = [
5     "http://localhost:8080/metrics", # substation1
6     "http://localhost:8080/metrics", # substation2
7     "http://localhost:8080/metrics", # substation3
8 ]
9
10 def get_load(url):
11     try:
12         resp = requests.get(url, timeout=5)
13         for line in resp.text.splitlines():
14             if line.startswith("ev_charging_load "):
15                 return float(line.split(" ")[-1])
16     except Exception as e:
17         print(f"Failed to get metrics from {url}: {e}")
18     return None
19
20 for i in range(100):
21     # Step 1: Get current load from all substations
22     loads = [get_load(url) for url in substations]
23     print(f"[{i}] Substation loads = {loads[0]}, {loads[1]}, {loads[2]}")
24
25     # Step 2: Send a charge request via the load balancer
26     try:
27         r = requests.post("http://localhost:8080/charge", timeout=5)
28         data = r.json()
29         print(f"[{i}] Requested to {data['details']['route_to']}")
30     except Exception as e:
31         print(f"Failed to send charge request: {e}")
```

	Name	Container ID	Image	Port(s)	CPU (%)	Last started	Actions
<input checked="" type="checkbox"/>	smart-grid-load-balancer	-	-	-	1.3%	23 minutes ago	
<input type="checkbox"/>	charge_request	71f7508fa429	smart-grid-load-balancer-charge_request	7000:7000 C	0.01%	23 minutes ago	
<input type="checkbox"/>	load_balancer	befdf6e02b5a	smart-grid-load-balancer-load_balancer	6000:6000 C	0.01%	23 minutes ago	
<input type="checkbox"/>	substation3	f9233d7ec4c9	smart-grid-load-balancer-substation3	9103:9100 C	0.18%	23 minutes ago	
<input type="checkbox"/>	grafana	ef21d78d0f09	grafana/grafana	3000:3000 C	0.33%	23 minutes ago	
<input type="checkbox"/>	prometheus	1a5b74acc6fd	prom/prometheus	9090:9090 C	0.47%	23 minutes ago	
<input type="checkbox"/>	substation1	9a42a911f2ca	smart-grid-load-balancer-substation1	9101:9100 C	0.16%	23 minutes ago	
<input type="checkbox"/>	substation2	e5d531b2842a	smart-grid-load-balancer-substation2	9102:9100 C	0.14%	23 minutes ago	

## Prometheus:

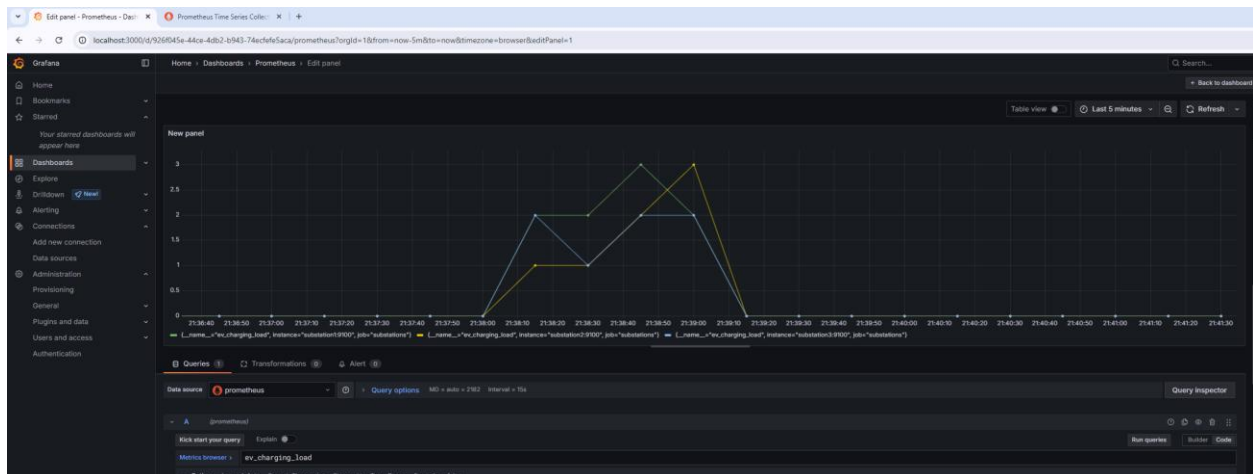
Scrapes ev\_charging\_load from each substation every 2s

Sample Query: ev\_charging\_load



## Grafana:

Visual dashboard shows real-time load changes across substations. Used to validate and demo the correctness of routing.



## Load Testing:

Using a custom test.py script which

- Fires multiple concurrent POST requests to /charge
- Logs real-time substation load before each request
- Confirms the request is routed to the least-loaded node

```
1 #!/usr/bin/env python3
2
3 import sys
4 import os
5 import time
6 import requests
7 import json
8
9 # Substitutions for metrics
10 substitutions = [
11     ("http://localhost:9102/metrics", "substitution1"),
12     ("http://localhost:9102/metrics", "substitution2"),
13     ("http://localhost:9102/metrics", "substitution3")
14 ]
15
16 # Main function to get metrics
17 def get_metrics(url):
18     try:
19         response = requests.get(url, timeout=5)
20         for line in response.iter_lines():
21             if line.startswith("Content-Type:"):
22                 return line.split(":")[1].strip()
23     except Exception as e:
24         print(f"Failed to get metrics from {url}: {e}")
25     return None
26
27 # Step 1: Get current load from all substitutions
28 def get_load():
29     load = {}
30     for i in range(0, len(substitutions)):
31         url = substitutions[i]
32         load[i] = get_metrics(url)
33     return load
34
35 # Step 2: Send a charge request via the load balancer
36 def send_charge_request():
37     url = "http://localhost:9000/charge"
38     data = {"type": "charge"}
39     response = requests.post(url, data=json.dumps(data))
40     print(f"Request to {url} resulted in: {response.status_code}")
41
42 # Main execution
43 if __name__ == "__main__":
44     # Step 1: Get current load
45     load = get_load()
46     print(f"Current load: {load}")
47
48     # Step 2: Send a charge request
49     send_charge_request()
50
51     # Step 3: Get load again after charge
52     load = get_load()
53     print(f"Load after charge: {load}")
```

**Logs observed**

[0] Substation Loads → [S1: 0.0, S2: 0.0, S3: 0.0]

```
[0] Routed to: http://substation1:5000/charge
```

[1] Substation Loads → [S1: 1.0, S2: 0.0, S3: 0.0]

```
[1] Routed to: http://substation2:5000/charge
```

[2] Substation Loads → [S1: 1.0, S2: 1.0, S3: 0.0]

[2] Routed to: <http://substation3:5000/charge>

[3] Substation Loads → [S1: 1.0, S2: 1.0, S3: 1.0]

```
[3] Routed to: http://substation1:5000/charge
```

[4] Substation Loads → [S1: 2.0, S2: 1.0, S3: 1.0]

[4] Routed to: <http://substation2:5000/charge>

[5] Substation Loads → [S1: 2.0, S2: 1.0, S3: 1.0]

[5] Routed to: <http://substation2:5000/charge>

[6] Substation Loads → [S1: 2.0, S2: 2.0, S3: 1.0]  
[6] Routed to: <http://substation3:5000/charge>  
[7] Substation Loads → [S1: 1.0, S2: 2.0, S3: 2.0]  
[7] Routed to: <http://substation1:5000/charge>  
[8] Substation Loads → [S1: 2.0, S2: 1.0, S3: 2.0]  
[8] Routed to: <http://substation2:5000/charge>  
[9] Substation Loads → [S1: 2.0, S2: 2.0, S3: 2.0]  
[9] Routed to: <http://substation1:5000/charge>  
[10] Substation Loads → [S1: 3.0, S2: 1.0, S3: 1.0]  
[10] Routed to: <http://substation2:5000/charge>  
[11] Substation Loads → [S1: 1.0, S2: 2.0, S3: 0.0]  
[11] Routed to: <http://substation3:5000/charge>  
[12] Substation Loads → [S1: 1.0, S2: 2.0, S3: 1.0]  
[12] Routed to: <http://substation1:5000/charge>  
[13] Substation Loads → [S1: 2.0, S2: 2.0, S3: 1.0]  
[13] Routed to: <http://substation3:5000/charge>  
[14] Substation Loads → [S1: 1.0, S2: 2.0, S3: 2.0]  
[14] Routed to: <http://substation1:5000/charge>  
[15] Substation Loads → [S1: 2.0, S2: 1.0, S3: 2.0]  
[15] Routed to: <http://substation2:5000/charge>  
[16] Substation Loads → [S1: 2.0, S2: 1.0, S3: 1.0]  
[16] Routed to: <http://substation2:5000/charge>  
[17] Substation Loads → [S1: 2.0, S2: 2.0, S3: 1.0]  
[17] Routed to: <http://substation3:5000/charge>  
[18] Substation Loads → [S1: 2.0, S2: 2.0, S3: 2.0]  
[18] Routed to: <http://substation1:5000/charge>

[19] Substation Loads → [S1: 1.0, S2: 2.0, S3: 2.0]

[19] Routed to: <http://substation1:5000/charge>

[20] Substation Loads → [S1: 2.0, S2: 0.0, S3: 1.0]

[20] Routed to: <http://substation2:5000/charge>

[21] Substation Loads → [S1: 2.0, S2: 1.0, S3: 1.0]

[21] Routed to: <http://substation2:5000/charge>

[22] Substation Loads → [S1: 2.0, S2: 2.0, S3: 0.0]

[22] Routed to: <http://substation3:5000/charge>

[23] Substation Loads → [S1: 2.0, S2: 2.0, S3: 1.0]

[23] Routed to: <http://substation3:5000/charge>

[24] Substation Loads → [S1: 2.0, S2: 2.0, S3: 2.0]

[24] Routed to: <http://substation1:5000/charge>

[25] Substation Loads → [S1: 2.0, S2: 1.0, S3: 2.0]

[25] Routed to: <http://substation2:5000/charge>

[26] Substation Loads → [S1: 2.0, S2: 2.0, S3: 2.0]

[26] Routed to: <http://substation1:5000/charge>

[27] Substation Loads → [S1: 2.0, S2: 2.0, S3: 2.0]

[27] Routed to: <http://substation1:5000/charge>

[28] Substation Loads → [S1: 2.0, S2: 1.0, S3: 2.0]

[28] Routed to: <http://substation2:5000/charge>

[29] Substation Loads → [S1: 2.0, S2: 2.0, S3: 1.0]

[29] Routed to: <http://substation3:5000/charge>

[30] Substation Loads → [S1: 2.0, S2: 1.0, S3: 1.0]

[30] Routed to: <http://substation2:5000/charge>

[31] Substation Loads → [S1: 2.0, S2: 2.0, S3: 1.0]

[31] Routed to: <http://substation3:5000/charge>

[32] Substation Loads → [S1: 1.0, S2: 1.0, S3: 2.0]

[32] Routed to: <http://substation1:5000/charge>

[33] Substation Loads → [S1: 2.0, S2: 1.0, S3: 2.0]

[33] Routed to: <http://substation2:5000/charge>

[34] Substation Loads → [S1: 1.0, S2: 2.0, S3: 2.0]

[34] Routed to: <http://substation1:5000/charge>

[35] Substation Loads → [S1: 2.0, S2: 1.0, S3: 1.0]

[35] Routed to: <http://substation2:5000/charge>

[36] Substation Loads → [S1: 1.0, S2: 2.0, S3: 0.0]

[36] Routed to: <http://substation3:5000/charge>

[37] Substation Loads → [S1: 1.0, S2: 1.0, S3: 1.0]

[37] Routed to: <http://substation1:5000/charge>

[38] Substation Loads → [S1: 2.0, S2: 1.0, S3: 1.0]

[38] Routed to: <http://substation2:5000/charge>

[39] Substation Loads → [S1: 1.0, S2: 2.0, S3: 1.0]

[39] Routed to: <http://substation1:5000/charge>

[40] Substation Loads → [S1: 2.0, S2: 2.0, S3: 1.0]

[40] Routed to: <http://substation3:5000/charge>

[41] Substation Loads → [S1: 1.0, S2: 2.0, S3: 1.0]

[41] Routed to: <http://substation1:5000/charge>

[42] Substation Loads → [S1: 2.0, S2: 1.0, S3: 1.0]

[42] Routed to: <http://substation2:5000/charge>

[43] Substation Loads → [S1: 1.0, S2: 2.0, S3: 1.0]

[43] Routed to: <http://substation1:5000/charge>

[44] Substation Loads → [S1: 2.0, S2: 2.0, S3: 1.0]

[44] Routed to: <http://substation3:5000/charge>



[45] Substation Loads → [S1: 2.0, S2: 2.0, S3: 2.0]  
[45] Routed to: <http://substation1:5000/charge>  
[46] Substation Loads → [S1: 3.0, S2: 1.0, S3: 2.0]  
[46] Routed to: <http://substation2:5000/charge>  
[47] Substation Loads → [S1: 2.0, S2: 1.0, S3: 2.0]  
[47] Routed to: <http://substation2:5000/charge>  
[48] Substation Loads → [S1: 1.0, S2: 2.0, S3: 1.0]  
[48] Routed to: <http://substation1:5000/charge>  
[49] Substation Loads → [S1: 1.0, S2: 2.0, S3: 1.0]  
[49] Routed to: <http://substation1:5000/charge>  
[50] Substation Loads → [S1: 2.0, S2: 2.0, S3: 1.0]  
[50] Routed to: <http://substation3:5000/charge>  
[51] Substation Loads → [S1: 2.0, S2: 2.0, S3: 1.0]  
[51] Routed to: <http://substation3:5000/charge>  
[52] Substation Loads → [S1: 2.0, S2: 2.0, S3: 2.0]  
[52] Routed to: <http://substation1:5000/charge>  
[53] Substation Loads → [S1: 3.0, S2: 1.0, S3: 2.0]  
[53] Routed to: <http://substation2:5000/charge>  
[54] Substation Loads → [S1: 3.0, S2: 2.0, S3: 2.0]  
[54] Routed to: <http://substation2:5000/charge>  
[55] Substation Loads → [S1: 2.0, S2: 2.0, S3: 2.0]  
[55] Routed to: <http://substation1:5000/charge>  
[56] Substation Loads → [S1: 3.0, S2: 2.0, S3: 2.0]  
[56] Routed to: <http://substation2:5000/charge>  
[57] Substation Loads → [S1: 2.0, S2: 2.0, S3: 2.0]  
[57] Routed to: <http://substation1:5000/charge>

[58] Substation Loads → [S1: 3.0, S2: 1.0, S3: 0.0]  
[58] Routed to: <http://substation3:5000/charge>  
[59] Substation Loads → [S1: 2.0, S2: 1.0, S3: 1.0]  
[59] Routed to: <http://substation2:5000/charge>  
[60] Substation Loads → [S1: 1.0, S2: 2.0, S3: 1.0]  
[60] Routed to: <http://substation1:5000/charge>  
[61] Substation Loads → [S1: 2.0, S2: 2.0, S3: 1.0]  
[61] Routed to: <http://substation3:5000/charge>  
[62] Substation Loads → [S1: 2.0, S2: 2.0, S3: 2.0]  
[62] Routed to: <http://substation1:5000/charge>  
[63] Substation Loads → [S1: 3.0, S2: 0.0, S3: 2.0]  
[63] Routed to: <http://substation2:5000/charge>  
[64] Substation Loads → [S1: 2.0, S2: 1.0, S3: 2.0]  
[64] Routed to: <http://substation2:5000/charge>  
[65] Substation Loads → [S1: 2.0, S2: 2.0, S3: 2.0]  
[65] Routed to: <http://substation1:5000/charge>  
[66] Substation Loads → [S1: 3.0, S2: 2.0, S3: 1.0]  
[66] Routed to: <http://substation3:5000/charge>  
[67] Substation Loads → [S1: 3.0, S2: 1.0, S3: 2.0]  
[67] Routed to: <http://substation2:5000/charge>  
[68] Substation Loads → [S1: 2.0, S2: 2.0, S3: 2.0]  
[68] Routed to: <http://substation1:5000/charge>  
[69] Substation Loads → [S1: 3.0, S2: 2.0, S3: 1.0]  
[69] Routed to: <http://substation3:5000/charge>  
[70] Substation Loads → [S1: 2.0, S2: 2.0, S3: 2.0]  
[70] Routed to: <http://substation1:5000/charge>

[71] Substation Loads → [S1: 3.0, S2: 1.0, S3: 1.0]

[71] Routed to: <http://substation2:5000/charge>

[72] Substation Loads → [S1: 3.0, S2: 1.0, S3: 1.0]

[72] Routed to: <http://substation2:5000/charge>

[73] Substation Loads → [S1: 2.0, S2: 2.0, S3: 1.0]

[73] Routed to: <http://substation3:5000/charge>

[74] Substation Loads → [S1: 2.0, S2: 2.0, S3: 2.0]

[74] Routed to: <http://substation1:5000/charge>

[75] Substation Loads → [S1: 2.0, S2: 2.0, S3: 2.0]

[75] Routed to: <http://substation1:5000/charge>

[76] Substation Loads → [S1: 3.0, S2: 2.0, S3: 1.0]

[76] Routed to: <http://substation3:5000/charge>

[77] Substation Loads → [S1: 3.0, S2: 1.0, S3: 2.0]

[77] Routed to: <http://substation2:5000/charge>

[78] Substation Loads → [S1: 2.0, S2: 2.0, S3: 1.0]

[78] Routed to: <http://substation3:5000/charge>

[79] Substation Loads → [S1: 1.0, S2: 1.0, S3: 2.0]

[79] Routed to: <http://substation1:5000/charge>

[80] Substation Loads → [S1: 2.0, S2: 1.0, S3: 2.0]

[80] Routed to: <http://substation2:5000/charge>

[81] Substation Loads → [S1: 2.0, S2: 2.0, S3: 2.0]

[81] Routed to: <http://substation1:5000/charge>

[82] Substation Loads → [S1: 3.0, S2: 2.0, S3: 2.0]

[82] Routed to: <http://substation2:5000/charge>

[83] Substation Loads → [S1: 2.0, S2: 3.0, S3: 1.0]

[83] Routed to: <http://substation3:5000/charge>

[84] Substation Loads → [S1: 2.0, S2: 3.0, S3: 1.0]  
[84] Routed to: <http://substation3:5000/charge>  
[85] Substation Loads → [S1: 2.0, S2: 2.0, S3: 2.0]  
[85] Routed to: <http://substation1:5000/charge>  
[86] Substation Loads → [S1: 3.0, S2: 1.0, S3: 2.0]  
[86] Routed to: <http://substation2:5000/charge>  
[87] Substation Loads → [S1: 2.0, S2: 1.0, S3: 1.0]  
[87] Routed to: <http://substation2:5000/charge>  
[88] Substation Loads → [S1: 1.0, S2: 2.0, S3: 1.0]  
[88] Routed to: <http://substation1:5000/charge>  
[89] Substation Loads → [S1: 2.0, S2: 2.0, S3: 0.0]  
[89] Routed to: <http://substation3:5000/charge>  
[90] Substation Loads → [S1: 1.0, S2: 2.0, S3: 1.0]  
[90] Routed to: <http://substation1:5000/charge>  
[91] Substation Loads → [S1: 2.0, S2: 1.0, S3: 1.0]  
[91] Routed to: <http://substation2:5000/charge>  
[92] Substation Loads → [S1: 2.0, S2: 2.0, S3: 1.0]  
[92] Routed to: <http://substation3:5000/charge>  
[93] Substation Loads → [S1: 2.0, S2: 2.0, S3: 2.0]  
[93] Routed to: <http://substation1:5000/charge>  
[94] Substation Loads → [S1: 2.0, S2: 1.0, S3: 2.0]  
[94] Routed to: <http://substation2:5000/charge>  
[95] Substation Loads → [S1: 1.0, S2: 1.0, S3: 2.0]  
[95] Routed to: <http://substation1:5000/charge>  
[96] Substation Loads → [S1: 2.0, S2: 1.0, S3: 2.0]  
[96] Routed to: <http://substation2:5000/charge>

[97] Substation Loads → [S1: 2.0, S2: 2.0, S3: 1.0]

[97] Routed to: <http://substation3:5000/charge>

[98] Substation Loads → [S1: 2.0, S2: 2.0, S3: 2.0]

[98] Routed to: <http://substation1:5000/charge>

[99] Substation Loads → [S1: 3.0, S2: 2.0, S3: 2.0]

[99] Routed to: <http://substation2:5000/charge>

## Steps to execute:

- In shell run docker-compose up
- Check for containers are running in Docker Desktop / Logs
- Open Prometheus in <http://localhost:9090/> and use query `ev_charging_load`
- Open Grafana in <http://localhost:3000/> and use Prometheus as data source and in dashboard query enter `ev_charging_load`
- In another shell run “python load\_tester/test.py” or “python3 load\_tester/test.py”
- Execute queries/refresh as per requirement.

## Github Link:

[https://github.com/samirkj/smart\\_grid\\_load\\_balancer\\_g24ai2047.git](https://github.com/samirkj/smart_grid_load_balancer_g24ai2047.git)

## Video:

Attached in the GitHub