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
Date : 25-June-2025

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

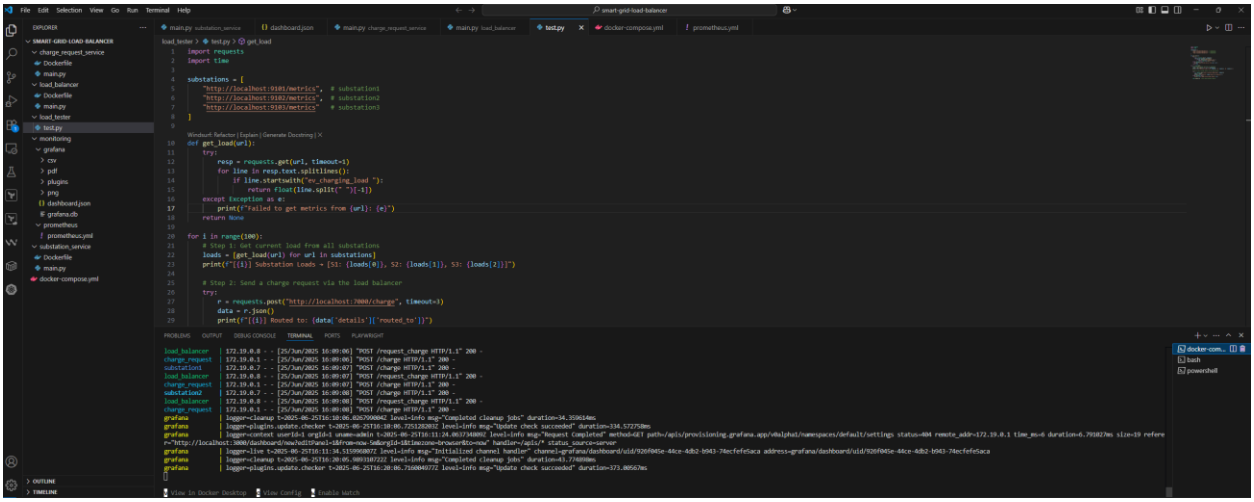
- Increments local ev_charging_load on each request.
- Simulates a delay (2–5s) to mimic charging.
- Exposes metrics via Prometheus on port 9100.

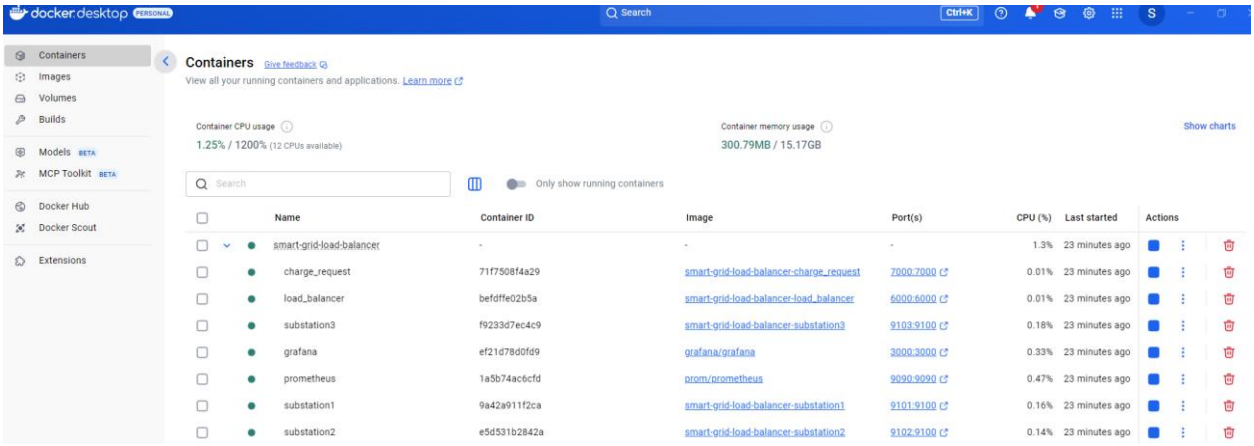
Docker Setup

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

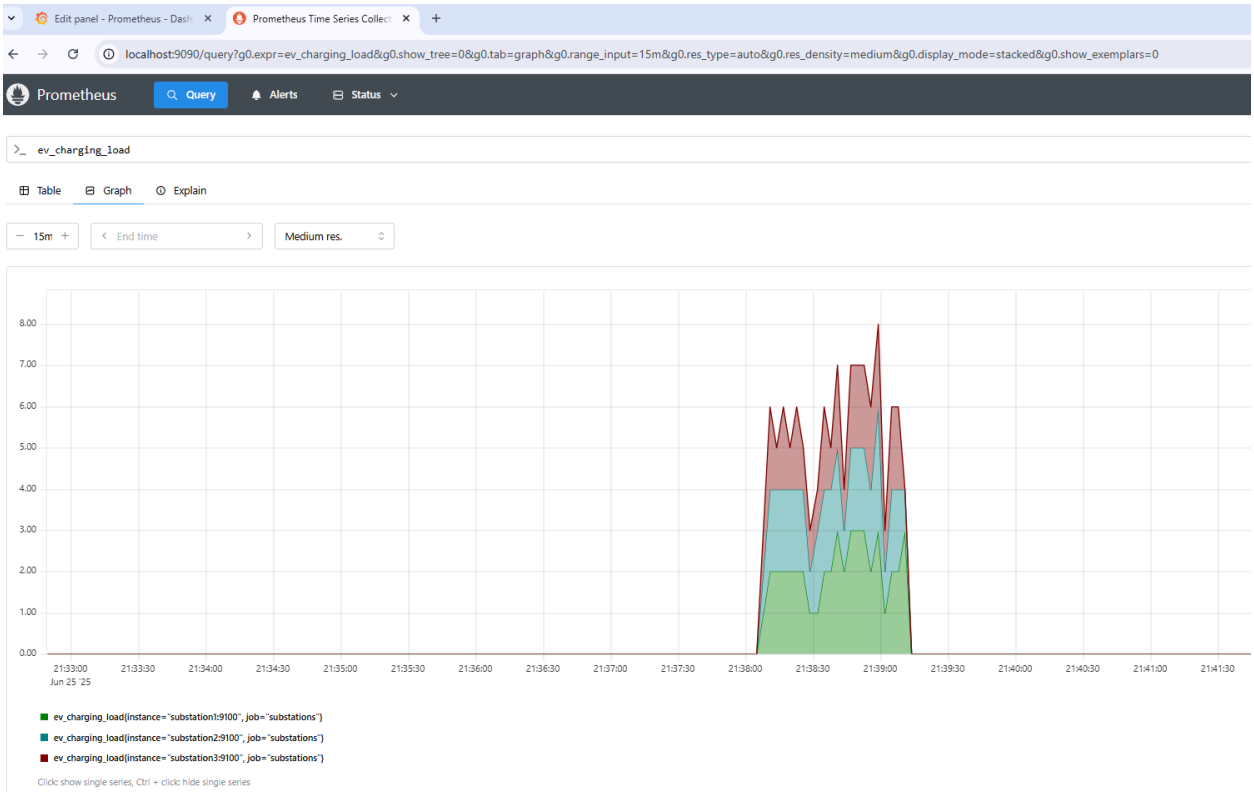




Prometheus:

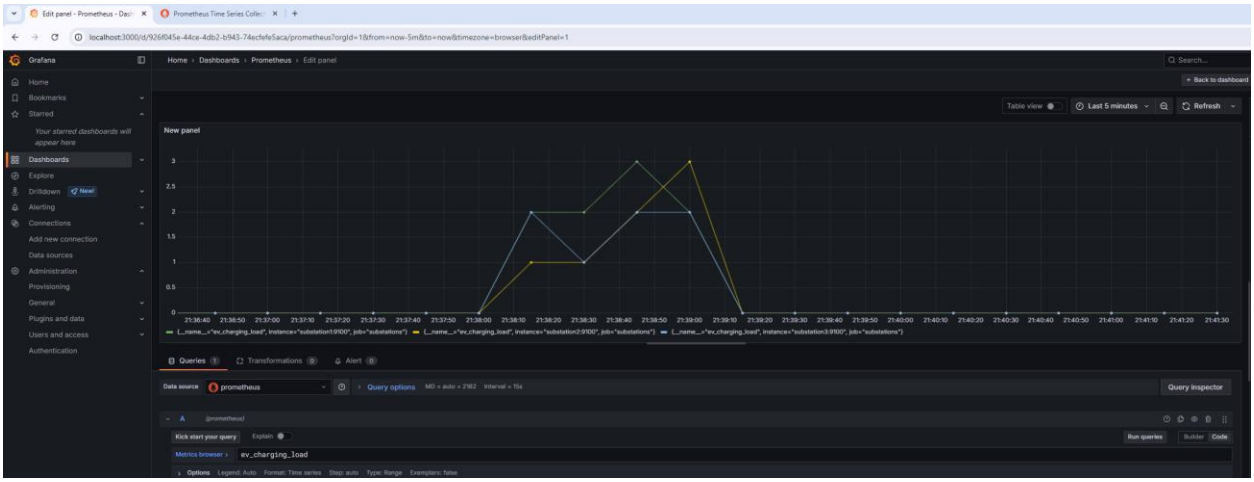
Scrapes ev_charging_load from each substation every 2s

Sample Query: ev_charging_load



Grafana:

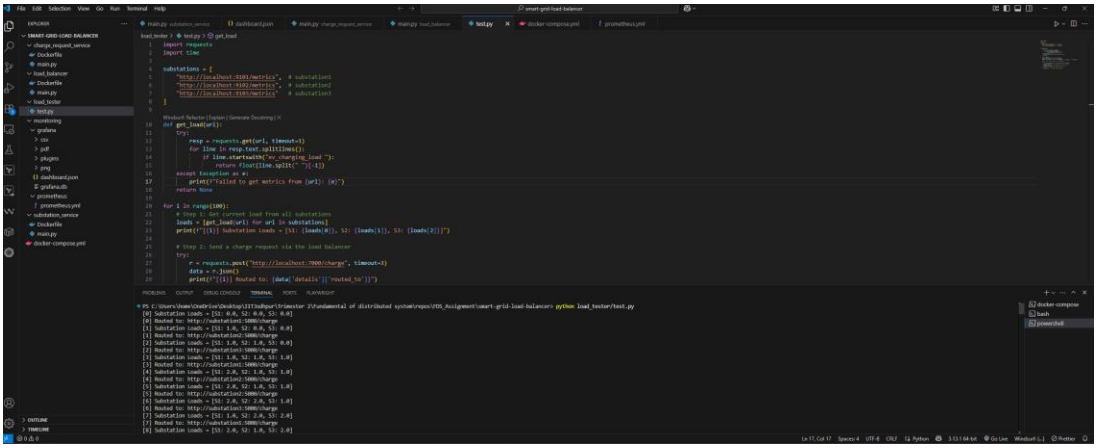
Visual dashboard shows real-time load changes across substations. Used to validate and demo the correctness of routing.



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



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

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

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[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

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[53] Routed to: http://substation2:5000/charge

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

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[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]

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[62] Routed to: http://substation1:5000/charge

[63] Substation Loads → [S1: 3.0, S2: 0.0, S3: 2.0]

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

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

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

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[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

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[84] Routed to: http://substation3:5000/charge

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[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]

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[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]

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[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

Video:

Attached in the GitHub