Smart Grid Load Balancer Project Report

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Assignment 1: Smart Grid Load Balancer Project Report

GitHub Link

1. Objective

The objective of this project is to design and implement a scalable Smart Grid Load Balancer system that dynamically distributes electric vehicle (EV) charging requests across multiple substations based on real-time load. This system aims to optimize charging efficiency, prevent substation overload, and provide full observability into system performance using modern monitoring tools.

2. System Architecture

Components:

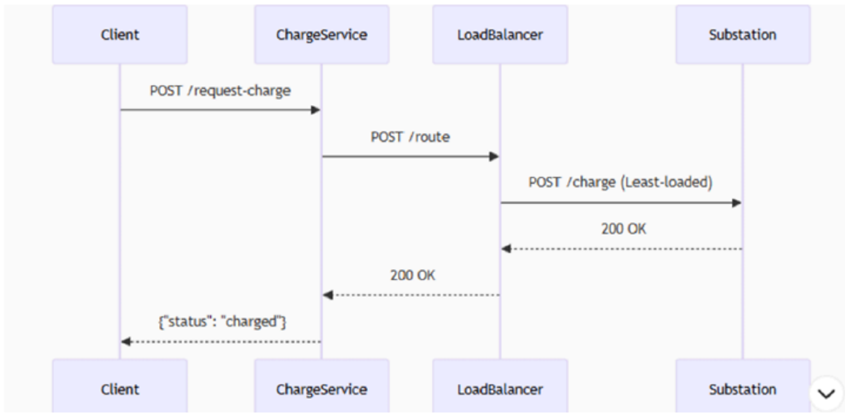
1. Charge Request Service
o Entry point for EVs to send charge requests via REST API.

2. Load Balancer
o Core logic that polls real-time substation load using Prometheus metrics and routes each request to the least-loaded substation.

3. Substation Services (2 replicas)
o Simulate EV charging and expose a Prometheus gauge metric substation_load.

4. Observability Stack
o Prometheus: Scrapes metrics from substations.
o Grafana: Visualizes substation load trends in a live dashboard.

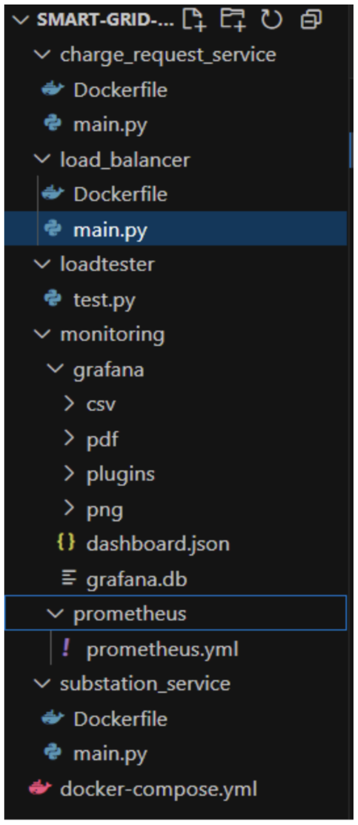
5. Load Tester
o Python script simulating a high-traffic scenario with 50 EV charging requests.



3. Technologies Used

• Python 3.10 for all microservices
• Flask for REST APIs
• Prometheus Client for exposing metrics
• Docker & Docker Compose for containerization
• Prometheus for metric collection
• Grafana for real-time visualization

4. File & Folder Structure



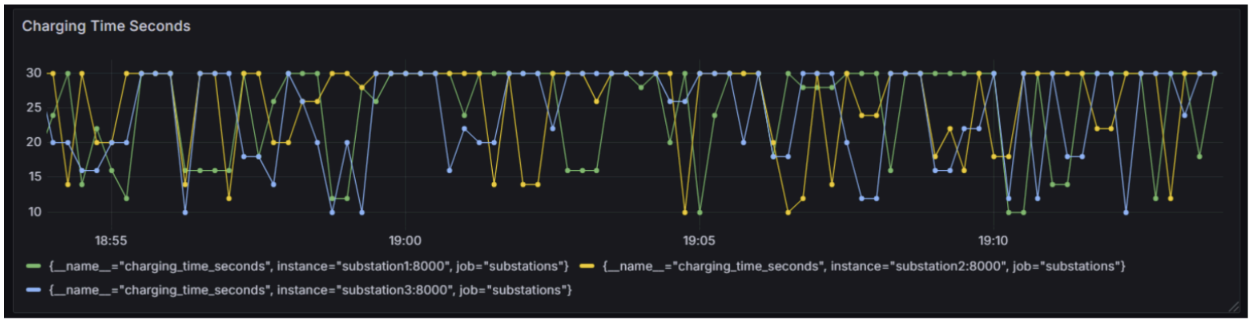
```
SMART-GRID-...
  charge_request_service
    Dockerfile
    main.py
  load_balancer
    Dockerfile
    main.py
  loadtester
    test.py
  monitoring
    grafana
      > csv
      > pdf
      > plugins
      > png
      dashboard.json
      grafana.db
    prometheus
      prometheus.yml
  substation_service
    Dockerfile
    main.py
  docker-compose.yml
```

5. Load Balancing Logic
• The Load Balancer queries each substation's /metrics endpoint to fetch current load.
• It compares load values and routes the incoming charge request to the substation with the lowest load.
• This ensures optimal distribution of EV requests, minimizing overload risk.

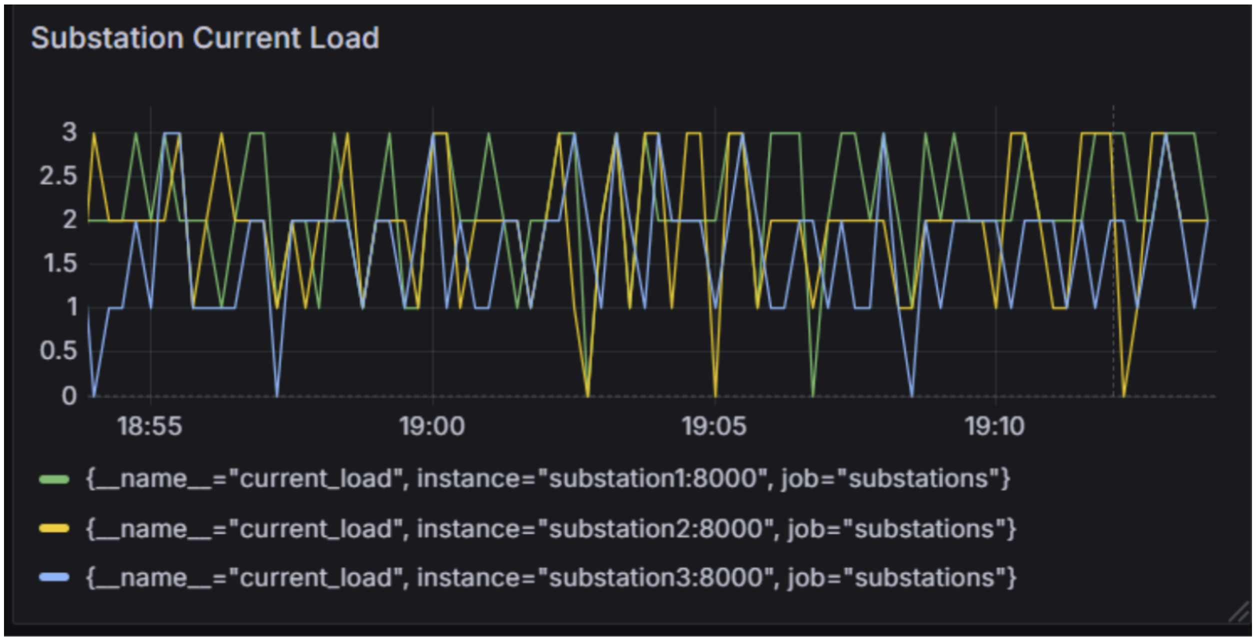
6. Observability and Monitoring
• Each substation exposes a substation_load metric.
• Prometheus scrapes these metrics at regular intervals.

• Grafana displays a time-series graph showing load on each substation.
Grafana Dashboard for monitoring load:

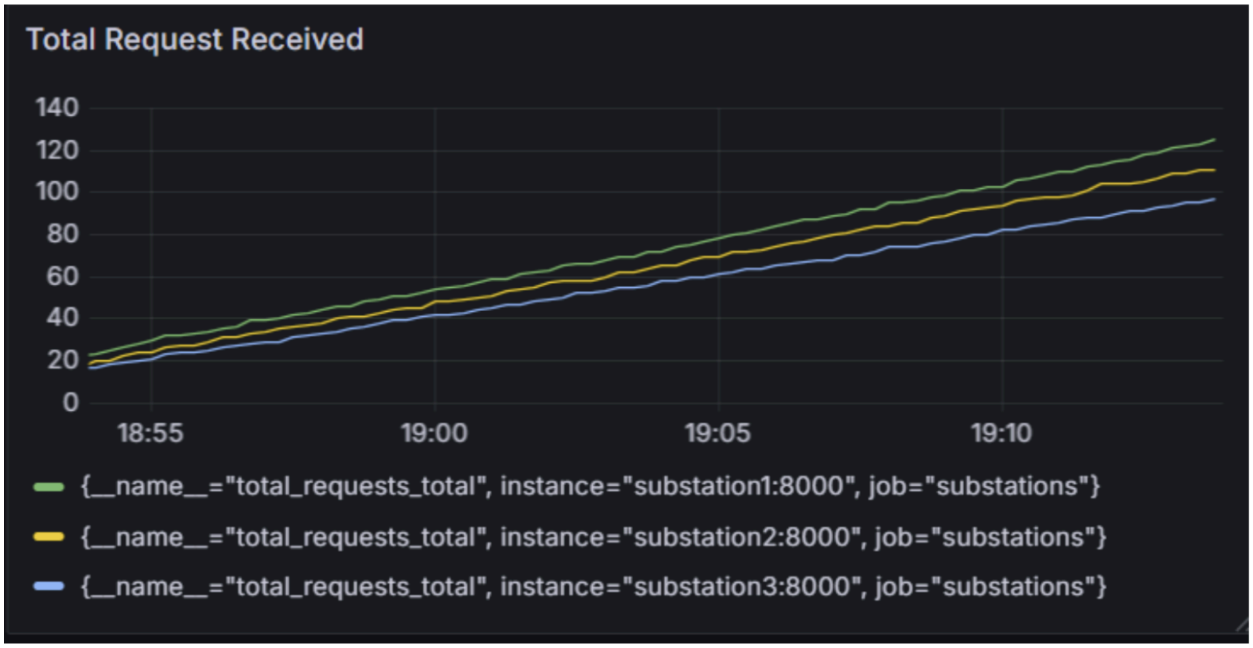
<u>Charging Time (in sec)</u>



Substation Load



Total Request Received per Substation



{__name__="total_requests_total", instance="substation1:8000", job="substations"}
{__name__="total_requests_total", instance="substation2:8000", job="substations"}
{__name__="total_requests_total", instance="substation3:8000", job="substations"}

7. Load Test Results
• A Python script sends 50 EV requests in a simulated "rush hour."
• The load is observed to be dynamically balanced between both substations.
• Grafana charts confirm that requests were evenly distributed over time.

8. **Demo Video Link-**

https://drive.google.com/file/d/1nI9nITCt0IP42XyLnIpeOWR4pc1ydl6X/view?usp=sharing

9. Conclusion
This project successfully demonstrates a cloud-native EV charging management system that balances load across substations using real-time metrics. It is scalable, observable, and designed following distributed systems best practices.