

Smart Grid Load Balancer Project Report

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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:

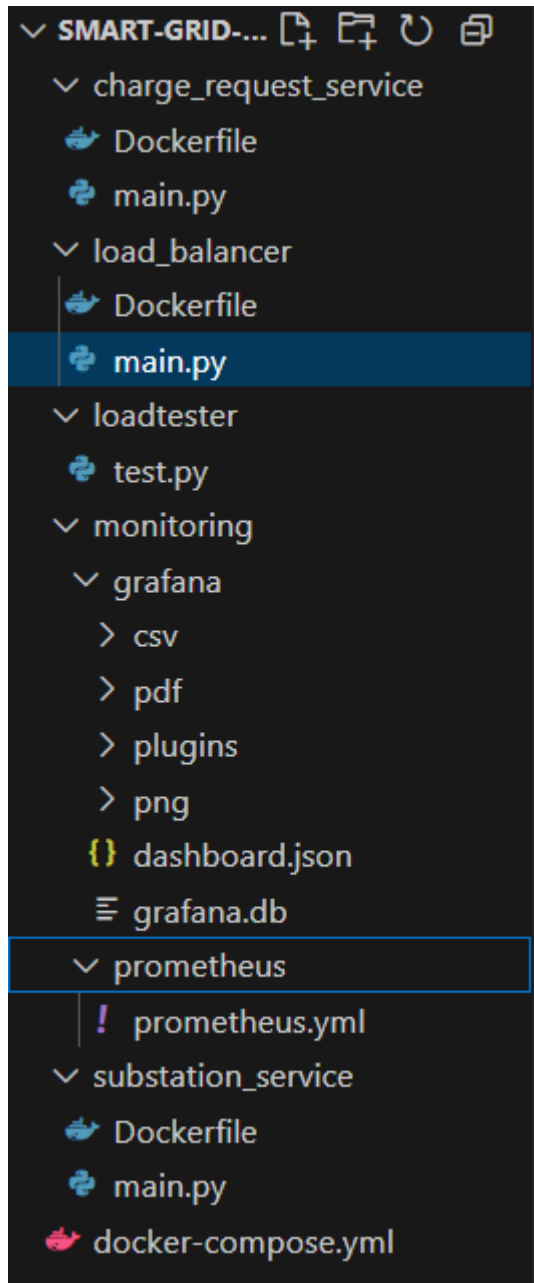
1. **Charge Request Service**
 - Entry point for EVs to send charge requests via REST API.
 2. **Load Balancer**
 - Core logic that polls real-time substation load using Prometheus metrics and routes each request to the least-loaded substation.
 3. **Substation Services (2 replicas)**
 - Simulate EV charging and expose a Prometheus gauge metric `substation_load`.
 4. **Observability Stack**
 - **Prometheus:** Scrapes metrics from substations.
 - **Grafana:** Visualizes substation load trends in a live dashboard.
 5. **Load Tester**
 - Python script simulating a high-traffic scenario with 50 EV charging requests.
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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
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4. File & Folder Structure



5. Load Balancing Logic

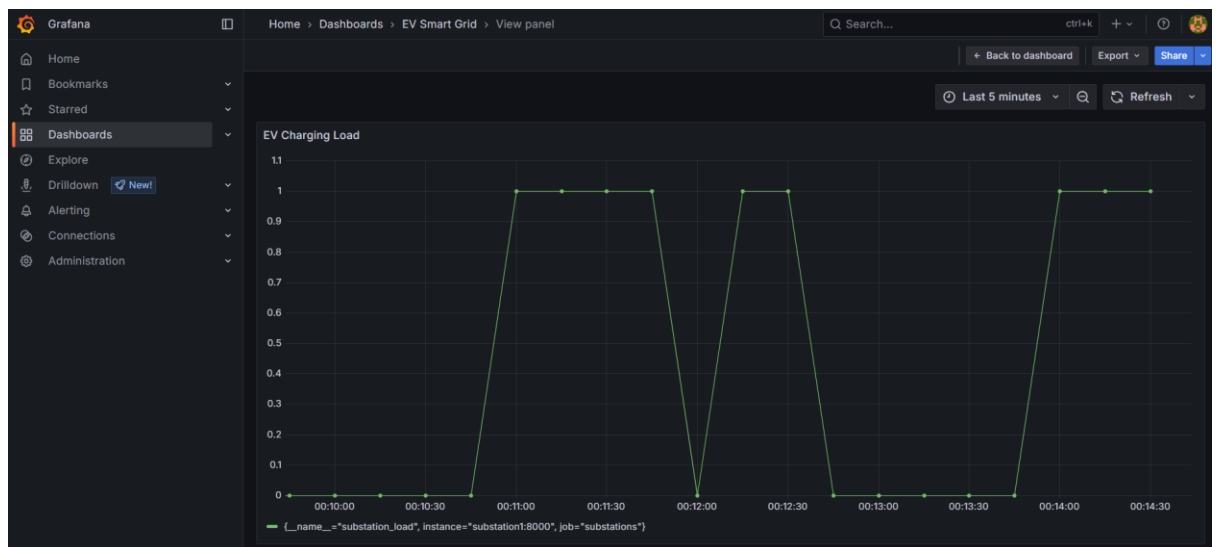
- The Load Balancer queries each substation's /metrics endpoint to fetch current load.
- It compares load values and routes the incoming charge request to the substation with the lowest load.
- This ensures optimal distribution of EV requests, minimizing overload risk.

6. Observability and Monitoring

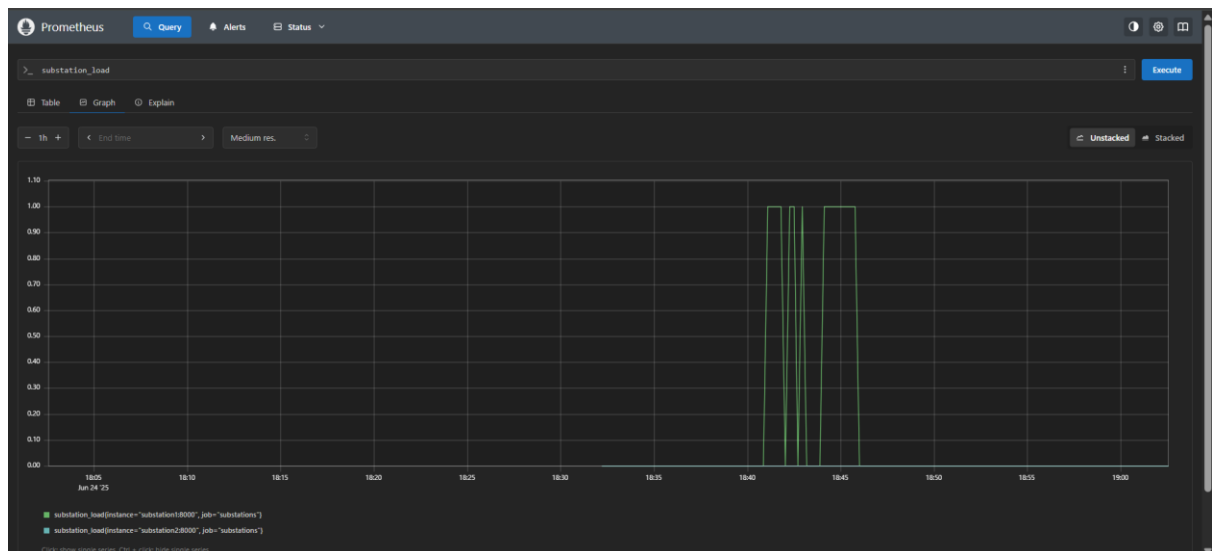
- Each substation exposes a substation_load metric.
- Prometheus scrapes these metrics at regular intervals.
- Grafana displays a time-series graph showing load on each substation.

Screenshot Sample: *(Add actual screenshots here)*

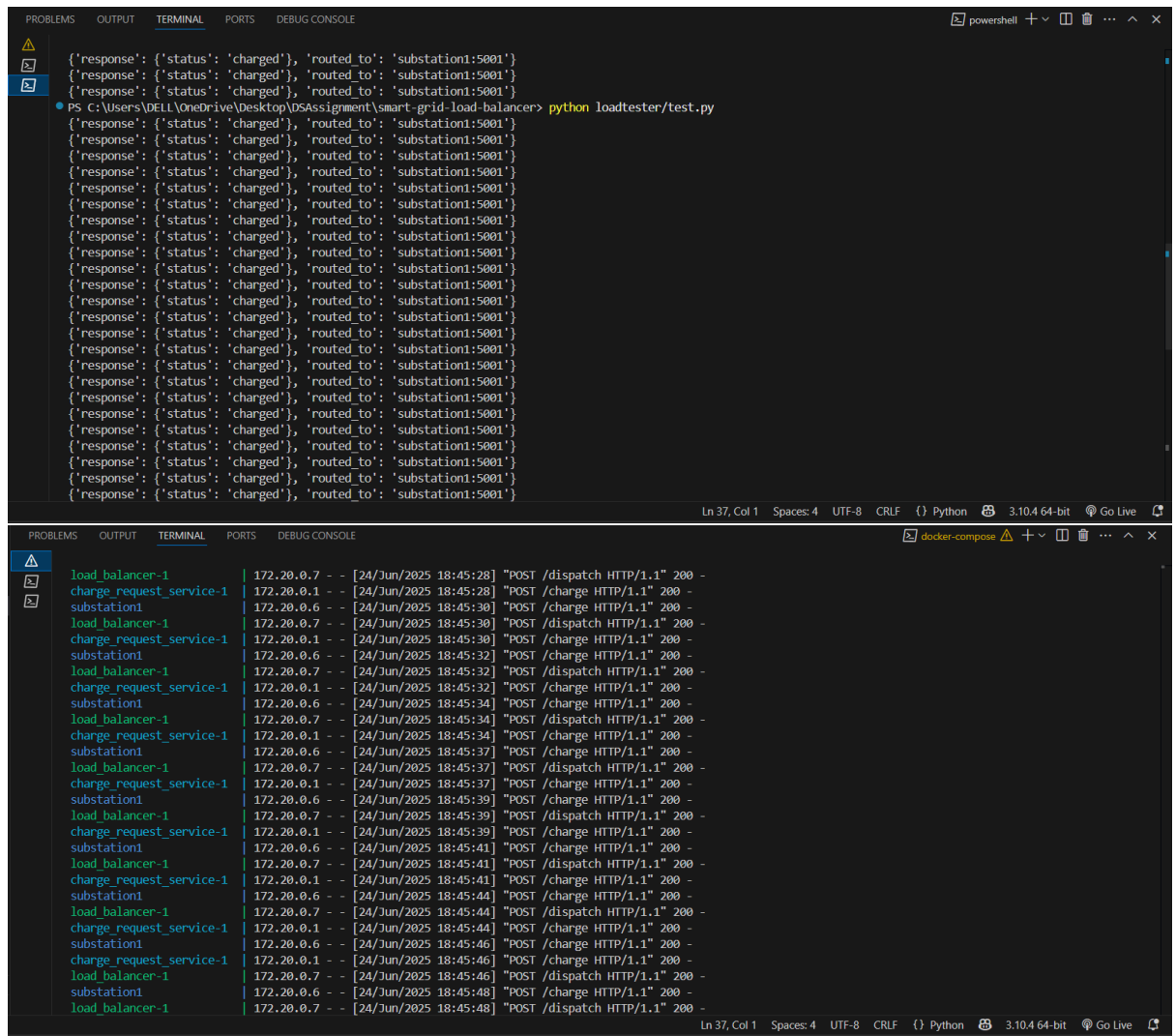
- Dashboard showing live load distribution



- Metric data over time



- Terminal:



The image displays two screenshots of a terminal window. The top screenshot shows a PowerShell prompt where a Python script is executed: `python loadtester/test.py`. The output consists of 50 identical JSON objects, each representing a response with a status of 'charged' and a 'routed_to' value of 'substation1:5001'. The bottom screenshot shows the output of a Docker container, displaying a log of HTTP requests and responses. The log includes timestamps, IP addresses, and the status of various requests, such as `POST /dispatch HTTP/1.1" 200 -` and `POST /charge HTTP/1.1" 200 -`, indicating that the system is handling a high volume of requests.

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. Video Demonstration

Link: https://drive.google.com/file/d/1_F09Ojq408y82cMCI8ox38hus4yNEZsw/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.