Smart Grid Load Balancer Project Report

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GitHub Repo: https://github.com/Harshita217/Harshita-DS-Assignment/tree/main

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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.

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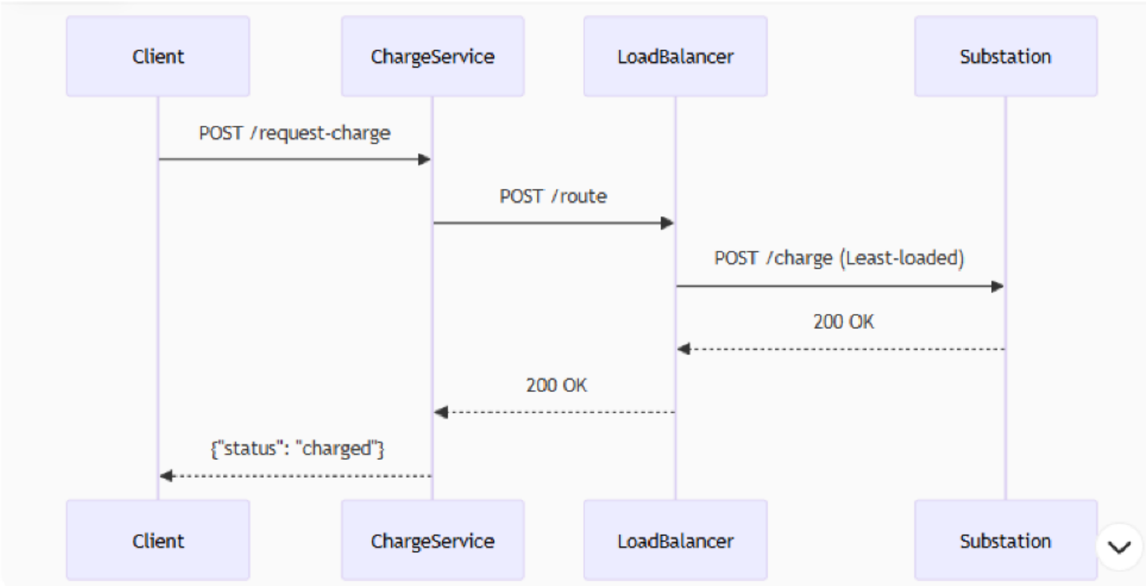
2. System Architecture

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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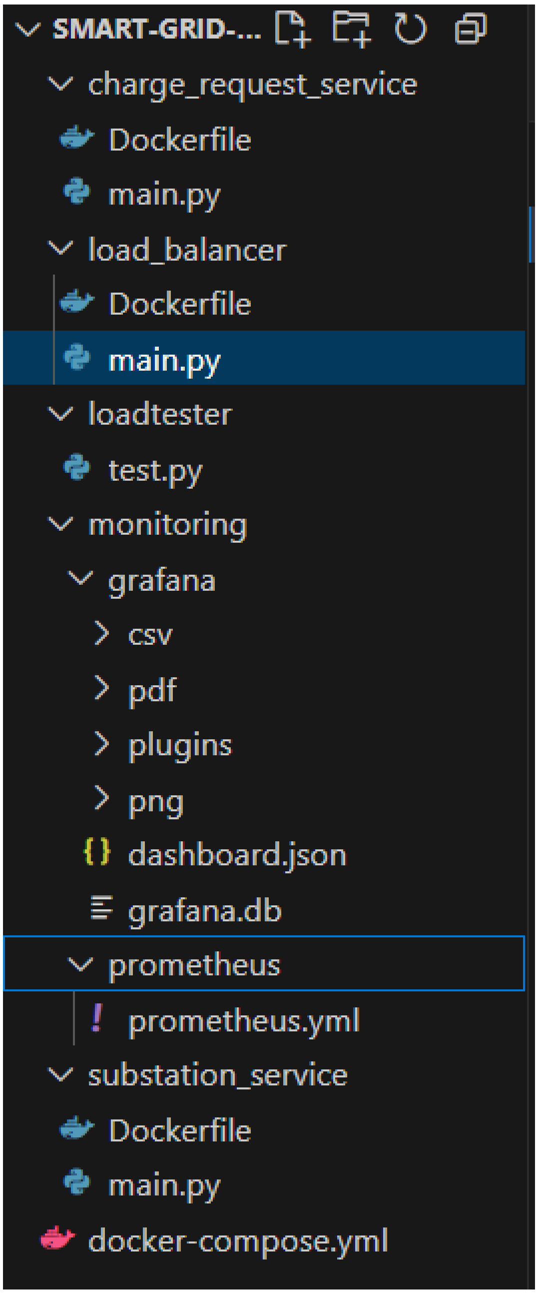
4. File & Folder Structure



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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.

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6. Observability and Monitoring

- Each substation exposes a substation_load metric.
- Prometheus scrapes these metrics at regular intervals.

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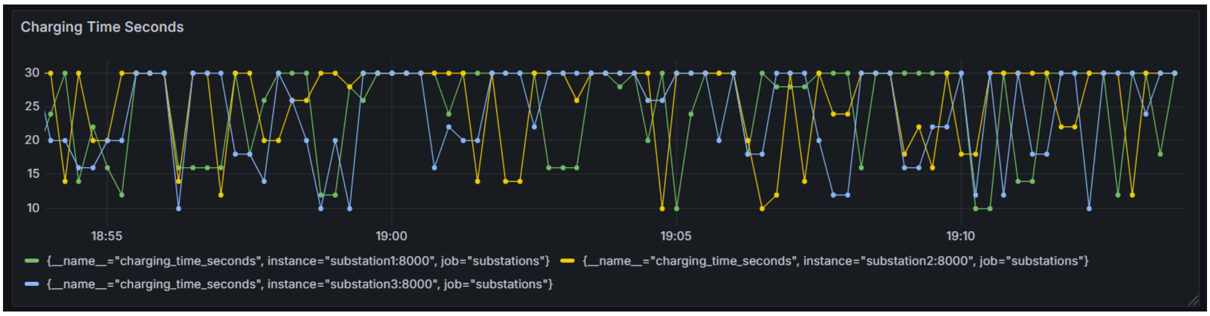
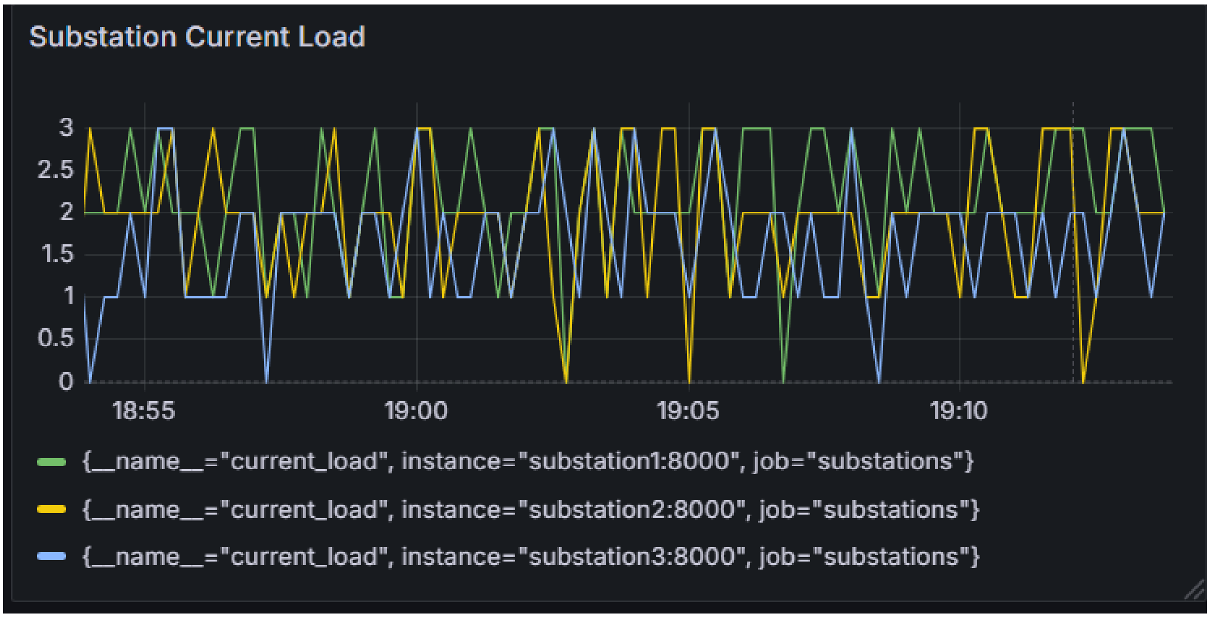
- Grafana displays a time-series graph showing load on each substation.

Grafana Dashboard for monitoring load:

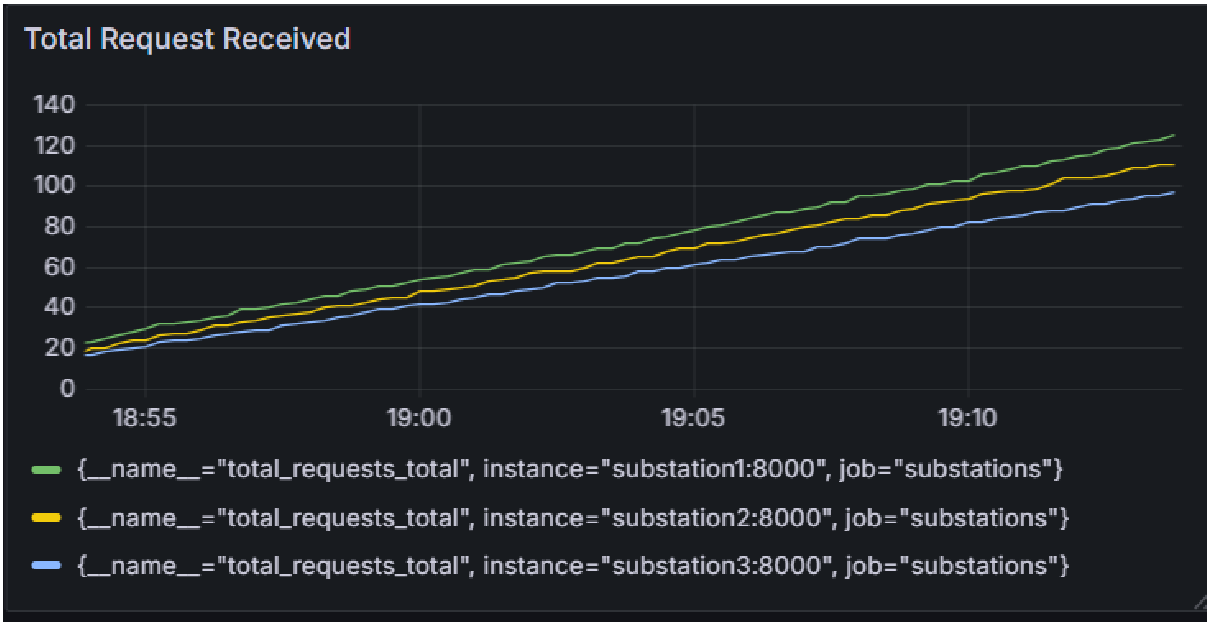
Charging Time (in secs)



Substation Load



Total Request Received per Substation



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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.

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8. Video Demonstration

Link: https://drive.google.com/file/d/1HvCeG8pFkTIx8zvNbamacuMSc2k7c_1Q/view?usp=sharing

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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.