Architecture Documentation

Volue Forecast Service
Version: 1.0
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System Overview

High-Level Architecture

```
graph TB
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        PC[PositionsController]
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        HC[HealthController]
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    end

    subgraph Service["Service Layer"]
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    end

    subgraph Repository["Repository Layer"]
        FWR[ForecastWriteRepository]
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    end

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    end

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        RABBIT["RabbitMQ Exchange:<br/>forecast.events"]
        CONSUMERS["Consumers: Trading System,<br/>Analytics, Dashboard"]
    end

    TD -->|REST/HTTP| FC
    PM -->|REST/HTTP| PC
    OA -->|REST/HTTP| PPC

    FC --> MW
    PC --> MW
    PPC --> MW
    HC --> MW

    MW --> FS
    MW --> PS
    MW --> PPS

    FS --> FWR
    FS --> FRR
    FS -->|publishes| EP
    PS --> PRR
    PPS --> PPR

    FWR --> EFCORE
    FRR --> EFCORE
    PRR --> EFCORE
    PPR --> EFCORE

    EFCORE -->|ORM| PG

    EP -->|publishes events| RABBIT
    RABBIT --> CONSUMERS

    style Client fill:#FFF3E0,stroke:#F57C00,stroke-width:2px
    style API fill:#E3F2FD,stroke:#1976D2,stroke-width:2px
    style Service fill:#F3E5F5,stroke:#7B1FA2,stroke-width:2px
    style Repository fill:#E8F5E9,stroke:#388E3C,stroke-width:2px
    style Database fill:#E1F5FE,stroke:#0277BD,stroke-width:2px
    style Messaging fill:#FFF9C4,stroke:#F57F17,stroke-width:2px
```

Design Principles

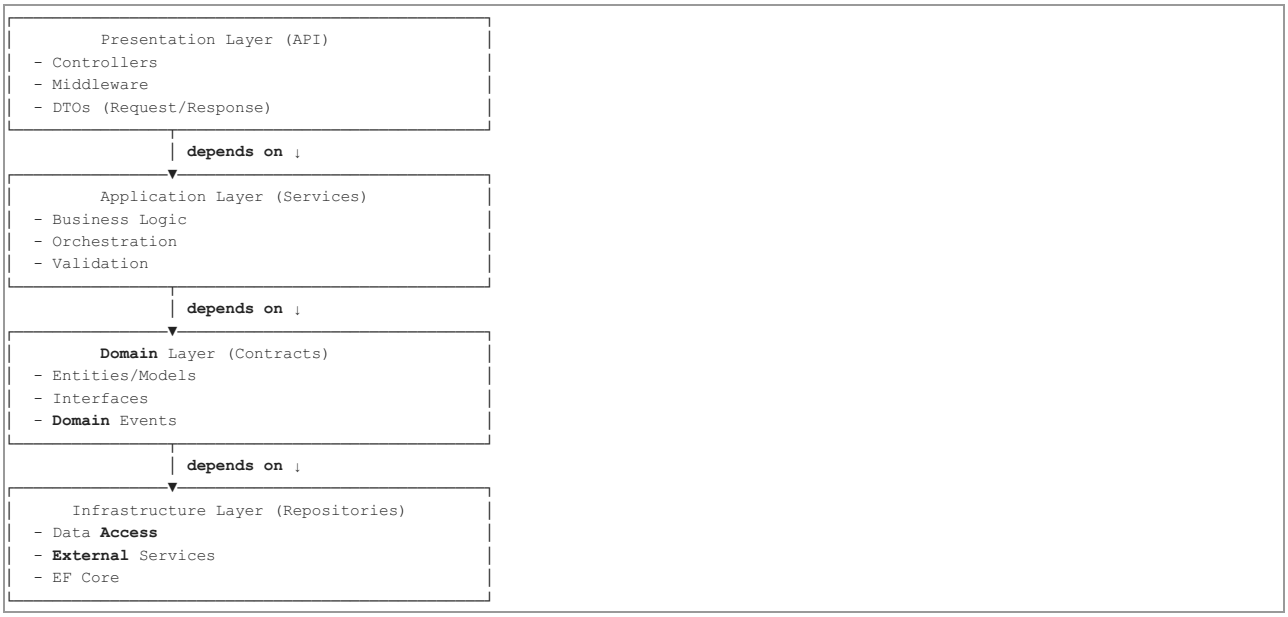
1. **Separation of Concerns**: Clear boundaries between presentation, business logic, and data access
2. **Dependency Inversion**: Depend on abstractions (interfaces), not concrete implementations
3. **Single Responsibility**: Each component has one reason to change
4. **Open/Closed**: Open for extension, closed for modification
5. **DRY (Don't Repeat Yourself)**: Shared logic in reusable components
6. **Fail-Fast**: Validate early and provide clear error messages

Key Architectural Decisions

Decision	Rationale	Trade-offs
Layered Architecture	Clear separation, testability, maintainability	Slight overhead for simple operations
Result Pattern	Type-safe error handling without exceptions	More verbose than exception handling
CQRS-Lite	Separate read/write repositories for optimization	Not full CQRS (no separate read models)
Bulk UPSERT	100x performance improvement	More complex SQL, PostgreSQL-specific
Event-Driven	Decoupled, scalable, async communication	Eventual consistency, debugging complexity
Graceful Degradation	System works without RabbitMQ	Events are lost (not persisted)

Architectural Patterns

1. Clean Architecture (Layered)



Dependencies flow inward:

- API Layer → Service Layer
- Service Layer → Domain Layer (Contracts)
- Repository Layer → Domain Layer (Contracts)

No circular dependencies: Infrastructure (Repository) knows about Domain, but Domain doesn't know about Infrastructure.

2. Repository Pattern

Purpose: Abstract data access logic from business logic.

```
// Interface (in Domain/Contracts)
public interface IForecastWriteRepository
{
    Task<UpsertResult> UpsertForecastsAsync(Guid plantId, IEnumerable<ForecastPoint> forecasts);
}

// Implementation (in Infrastructure/Repositories)
public class ForecastWriteRepository : IForecastWriteRepository
{
    private readonly ForecastDbContext _context;

    public async Task<UpsertResult> UpsertForecastsAsync(Guid plantId, IEnumerable<ForecastPoint> forecasts)
    {
        // PostgreSQL-specific bulk UPSERT
        // Business logic doesn't know about implementation
    }
}
```

Benefits:

- Testability: Mock repositories in unit tests
- Flexibility: Swap implementations (e.g., SQL → NoSQL)
- Separation: Business logic doesn't depend on EF Core

3. Result Pattern

Purpose: Type-safe error handling without exceptions for business logic.

```
public class Result<T>
{
    public bool Success { get; }
    public T? Data { get; }
    public Error? Error { get; }

    public static Result<T> Ok(T data) => new(data);
    public static Result<T> Fail(string code, string message) => new(code, message);
}

// Usage
public async Task<Result<UpsertResponse>> CreateOrUpdateForecastsAsync(...)
{
    // Validation
    if (!IsValidTimeRange(...))
        return Result<UpsertResponse>.Fail("Forecast.InvalidTimeRange", "...");

    // Business logic
    var result = await _writeRepository.UpsertForecastsAsync(...);

    return Result<UpsertResponse>.Ok(result);
}
```

Benefits:

- No try-catch for business validation
- Explicit success/failure handling
- Type-safe error codes
- Clear API contracts

4. CQRS-Lite (Command Query Responsibility Segregation)

Simplified CQRS: Separate repositories for reads and writes, but same database.

```
Commands (Writes)          Queries (Reads)
      ↓                          ↓
ForecastWriteRepository    ForecastReadRepository
      ↓                          ↓
      └──────→ PostgreSQL ←──────┘
```

Write Repository (optimized for UPSERT):

```
public class ForecastWriteRepository
{
    public async Task<UpsertResult> UpsertForecastsAsync(...)
    {
        // Bulk INSERT ... ON CONFLICT DO UPDATE
        // Optimized for write performance
    }
}
```

Read Repository (optimized for queries):

```
public class ForecastReadRepository
{
    public async Task<IEnumerable<Forecast>> GetForecastsAsync(...)
    {
        return await _context.Forecasts
            .AsNoTracking() // Read-only, no change tracking
            .Where(f => f.PlantId == plantId && ...)
            .ToListAsync();
    }
}
```

Benefits:

- Write optimization: Bulk operations, no tracking
- Read optimization: AsNoTracking, compiled queries
- Different scaling strategies (more reads than writes)

5. Event-Driven Architecture

Pattern: Publish events when company position changes.

```
Forecast Updated
       ↓
Calculate Position Change
       ↓
Publish PositionChangedEvent
       ↓
RabbitMQ (Exchange: forecast.events)
       ↓
Multiple Consumers
  ↓         ↓         ↓
Trading  Analytics  Dashboard
```

Event Publishing (Fire-and-Forget):

```
public interface IEventPublisher
{
    Task PublishAsync<T>(T eventData) where T : class;
}

// RabbitMQ implementation
public class RabbitMqEventPublisher : IEventPublisher
{
    public async Task PublishAsync<T>(T eventData)
    {
        // Publish to RabbitMQ exchange
        // Don't wait for consumers
    }
}

// Null implementation (graceful degradation)
public class NullEventPublisher : IEventPublisher
{
    public Task PublishAsync<T>(T eventData)
    {
        // Do nothing, system still works
        return Task.CompletedTask;
    }
}
```

Dependency Injection (based on config):

```
if (configuration.GetValue<bool>("RabbitMQ:Enabled"))
    services.AddSingleton<IEventPublisher, RabbitMqEventPublisher>();
else
    services.AddSingleton<IEventPublisher, NullEventPublisher>();
```

Layered Architecture

Layer 1: API Layer (Presentation)

Responsibility: HTTP endpoints, request/response handling, middleware.

Components:

- **Controllers**: HTTP endpoints (REST)
- **Middleware**: Cross-cutting concerns (logging, correlation ID, exception handling)
- **DTOs**: Request/Response models

Example Controller:

```
[ApiController]
[Route("api/forecasts")]
public class ForecastsController : ControllerBase
{
    private readonly IForecastService _forecastService;

    [HttpPut("{plantId}")]
    public async Task<IActionResult> CreateOrUpdate(
        Guid plantId,
        [FromBody] CreateOrUpdateForecastRequest request)
    {
        var result = await _forecastService.CreateOrUpdateForecastsAsync(plantId, request.Forecasts);

        return result.Success
            ? Ok(ApiResponse<UpsertResponse>.Success(result.Data))
            : BadRequest(ApiResponse<UpsertResponse>.Failure(result.Error));
    }
}
```

Middleware Pipeline:

```
HTTP Request
    ↓
1. CorrelationIdMiddleware (add X-Correlation-ID)
    ↓
2. ExceptionHandlingMiddleware (catch unhandled exceptions)
    ↓
3. Logging (Serilog structured logging)
    ↓
4. Controller Action
    ↓
HTTP Response
```

Layer 2: Service Layer (Application)

Responsibility: Business logic, validation, orchestration.

Components:

- **ForecastService**: Forecast validation and orchestration
- **PositionService**: Position aggregation logic

- **PowerPlantService**: Metadata operations
- **Event Publisher**: Event publishing abstraction

Example Service:

```
public class ForecastService : IForecastService
{
    private readonly IForecastWriteRepository _writeRepository;
    private readonly IForecastReadRepository _readRepository;
    private readonly IEventPublisher _eventPublisher;
    private readonly ILogger<ForecastService> _logger;

    public async Task<Result<UpsertResponse>> CreateOrUpdateForecastsAsync(
        Guid plantId,
        IEnumerable<ForecastPoint> forecasts)
    {
        // 1. Validate business rules
        if (!IsValidTimeRange(forecasts))
            return Result<UpsertResponse>.Fail("Forecast.InvalidTimeRange", "...");

        // 2. Execute repository operation
        var result = await _writeRepository.UpsertForecastsAsync(plantId, forecasts);

        // 3. Publish event (if position changed)
        if (result.HasChanges)
        {
            var position = await CalculatePositionAsync(plantId);
            await _eventPublisher.PublishAsync(new PositionChangedEvent { ... });
        }

        return Result<UpsertResponse>.Ok(result);
    }
}
```

Layer 3: Domain Layer (Contracts)

Responsibility: Interfaces, models, domain events.

Components:

- **Interfaces**: Service and repository contracts
- **Models**: Domain entities (Company, PowerPlant, Forecast)
- **DTOs**: Data transfer objects
- **Events**: Domain events (PositionChangedEvent)

Example Interface:

```
public interface IForecastService
{
    Task<Result<UpsertResponse>> CreateOrUpdateForecastsAsync(
        Guid plantId,
        IEnumerable<ForecastPoint> forecasts);

    Task<Result<ForecastQueryResponse>> GetForecastsAsync(
        Guid plantId,
        DateTime fromUtc,
        DateTime toUtc);
}
```

Layer 4: Infrastructure Layer (Repositories)

Responsibility: Data access, external services, EF Core.

Components:

- **Repositories**: Data access implementations
- **DbContext**: EF Core database context
- **Migrations**: Database schema changes
- **Entity Configurations**: Fluent API configurations

Example Repository:

```
public class ForecastWriteRepository : IForecastWriteRepository
{
    private readonly ForecastDbContext _context;

    public async Task<UpsertResult> UpsertForecastsAsync(
        Guid plantId,
        IEnumerable<ForecastPoint> forecasts)
    {
        // PostgreSQL bulk UPSERT using raw SQL
        var sql = @"
            INSERT INTO forecasts (id, plant_id, hour_utc, mwh, created_at, updated_at)
            VALUES (@Id, @PlantId, @HourUtc, @Mwh, @CreatedAt, @UpdatedAt)
            ON CONFLICT (plant_id, hour_utc)
            DO UPDATE SET
                mwh = EXCLUDED.mwh,
                updated_at = EXCLUDED.updated_at
            WHERE forecasts.mwh <> EXCLUDED.mwh;
        ";

        // Execute with parameters
        await _context.Database.ExecuteSqlRawAsync(sql, parameters);

        return new UpsertResult { ... };
    }
}
```

Data Flow

1. Create/Update Forecast Flow

```
sequenceDiagram
    participant Client
    participant Controller
    participant Service
    participant WriteRepo
    participant ReadRepo
    participant EventPub
    participant DB
    participant RabbitMQ

    Client->>Controller: PUT /api/forecasts/{plantId}
    Controller->>Service: CreateOrUpdateForecastsAsync()

    Note over Service: Validate business rules<br/>(hour-aligned, UTC, non-negative)

    Service->>WriteRepo: UpsertForecastsAsync()
    WriteRepo->>DB: Bulk INSERT ... ON CONFLICT
    DB-->>WriteRepo: Rows affected (inserted/updated)
    WriteRepo-->>Service: UpsertResult

    alt HasChanges = true
        Service->>ReadRepo: Calculate position change
        ReadRepo->>DB: SELECT SUM(mwh) GROUP BY hour_utc
        DB-->>ReadRepo: Aggregated positions
        ReadRepo-->>Service: CompanyPosition

        Service->>EventPub: PublishAsync(PositionChangedEvent)
        EventPub->>RabbitMQ: Publish to exchange
        Note over RabbitMQ: Fire-and-forget<br/>Don't wait for consumers
    end

    Service-->>Controller: Result<UpsertResponse>
    Controller-->>Client: 200 OK + ApiResponse
```

2. Get Company Position Flow

```
sequenceDiagram
    participant Client
    participant Controller
    participant Service
    participant PosRepo
    participant DB

    Client->>Controller: GET /api/company/{id}/position?from=...&to=...
    Controller->>Service: GetCompanyPositionAsync()

    Note over Service: Validate time range<br/>(from < to, both hour-aligned)

    Service->>PosRepo: GetCompanyPositionAsync()
    PosRepo->>DB: SELECT plant_id, hour_utc, SUM(mwh)<br/>FROM forecasts<br/>JOIN power_plants<br/>WHERE company_id = @CompanyId<br/>GROUP BY hour_utc

    Note over DB: Database-side aggregation<br/>Efficient for large datasets

    DB-->>PosRepo: Hourly positions
    PosRepo-->>Service: CompanyPosition
    Service-->>Controller: Result<CompanyPosition>
    Controller-->>Client: 200 OK + ApiResponse
```

3. Event Publishing Flow

```
graph LR
    A[Forecast Updated] --> B[Calculate Position]
    B --> C{Position Changed?}
    C -->|Yes| D[Create Event]
    C -->|No| E[Skip Event]
    D --> F[Publish to RabbitMQ]
    F --> G[Exchange: forecast.events]
    G --> H[Routing: position.changed]
    H --> I1[Trading System]
    H --> I2[Analytics Engine]
    H --> I3[Dashboard]
```

Event Schema:

```
{
  "companyId": "11111111-1111-1111-1111-111111111111",
  "companyName": "Energy Trading Corp",
  "positions": [
    {
      "hourUtc": "2026-01-30T10:00:00Z",
      "totalMwh": 580.0,
      "plantCount": 3
    }
  ],
  "totalMwh": 1176.25,
  "changedAt": "2026-01-30T12:34:56Z",
  "correlationId": "demo-request-001"
}
```

Component Details

ForecastService

Responsibilities:

- Validate forecast business rules
- Orchestrate forecast operations
- Calculate position changes
- Publish position change events

Key Methods:

```
Task<Result<UpsertResponse>> CreateOrUpdateForecastsAsync(Guid plantId, IEnumerable<ForecastPoint> forecasts);
Task<Result<ForecastQueryResponse>> GetForecastsAsync(Guid plantId, DateTime fromUtc, DateTime toUtc);
```

Validation Rules:

- Timestamps must be hour-aligned (minutes and seconds = 0)
- Timestamps must be UTC
- MWh values must be non-negative
- Plant must exist and be active
- Time range must be valid (from < to)

PositionService

Responsibilities:

- Aggregate forecasts across plants
- Calculate company-wide positions
- Provide position analytics

Key Methods:

```
Task<Result<CompanyPosition>> GetCompanyPositionAsync(Guid companyId, DateTime fromUtc, DateTime toUtc);
```

Aggregation Logic:

```
SELECT
    f.hour_utc,
    SUM(f.mwh) as total_mwh,
    COUNT(DISTINCT f.plant_id) as plant_count
FROM forecasts f
JOIN power_plants p ON f.plant_id = p.id
WHERE p.company_id = @CompanyId
  AND f.hour_utc >= @FromUtc
  AND f.hour_utc < @ToUtc
  AND p.is_active = true
GROUP BY f.hour_utc
ORDER BY f.hour_utc;
```

ForecastWriteRepository

Responsibilities:

- Bulk UPSERT operations
- Track inserted/updated/unchanged counts
- Optimize for write performance

Bulk UPSERT Implementation:

```
public async Task<UpsertResult> UpsertForecastsAsync(Guid plantId, IEnumerable<ForecastPoint> forecasts)
{
    var parameters = new List<NpgsqlParameter>();
    var values = new List<string>();

    // Build bulk INSERT with ON CONFLICT
    var sql = $@"
        INSERT INTO forecasts (id, plant_id, hour_utc, mwh, created_at, updated_at)
        VALUES {string.Join(", ", values)}
        ON CONFLICT (plant_id, hour_utc)
        DO UPDATE SET
            mwh = EXCLUDED.mwh,
            updated_at = EXCLUDED.updated_at
        WHERE forecasts.mwh <> EXCLUDED.mwh;
    ";

    await _context.Database.ExecuteSqlRawAsync(sql, parameters.ToArray());

    // Calculate counts
    return new UpsertResult
    {
        InsertedCount = ...,
        UpdatedCount = ...,
        UnchangedCount = ...
    };
}
```

Database Schema

Entity-Relationship Diagram

```
erDiagram
    COMPANIES ||--o{ POWER_PLANTS : "has"
    POWER_PLANTS ||--o{ FORECASTS : "has"

    COMPANIES {
        uuid id PK
        varchar(200) name
        timestamp created_at
    }

    POWER_PLANTS {
        uuid id PK
        uuid company_id FK
        varchar(200) name
        varchar(100) country
        decimal capacity_mwh
        boolean is_active
        timestamp created_at
    }

    FORECASTS {
        uuid id PK
        uuid plant_id FK
        timestamp hour_utc
        decimal mwh
        timestamp created_at
        timestamp updated_at
    }
```

Table Schemas

companies

```
CREATE TABLE companies (
    id UUID PRIMARY KEY,
    name VARCHAR(200) NOT NULL,
    created_at TIMESTAMP NOT NULL DEFAULT NOW()
);
```

power_plants

```
CREATE TABLE power_plants (
    id UUID PRIMARY KEY,
    company_id UUID NOT NULL REFERENCES companies(id),
    name VARCHAR(200) NOT NULL,
    country VARCHAR(100) NOT NULL,
    capacity_mwh DECIMAL(10, 4) NOT NULL,
    is_active BOOLEAN NOT NULL DEFAULT true,
    created_at TIMESTAMP NOT NULL DEFAULT NOW(),

    CONSTRAINT fk_power_plants_company FOREIGN KEY (company_id)
        REFERENCES companies(id) ON DELETE CASCADE
);

CREATE INDEX idx_power_plants_company ON power_plants(company_id);
CREATE INDEX idx_power_plants_active ON power_plants(is_active);
```

forecasts

```
CREATE TABLE forecasts (
    id UUID PRIMARY KEY,
    plant_id UUID NOT NULL REFERENCES power_plants(id),
    hour_utc TIMESTAMP NOT NULL,
    mwh DECIMAL(10, 4) NOT NULL CHECK (mwh >= 0),
    created_at TIMESTAMP NOT NULL DEFAULT NOW(),
    updated_at TIMESTAMP NOT NULL DEFAULT NOW(),

    CONSTRAINT fk_forecasts_plant FOREIGN KEY (plant_id)
        REFERENCES power_plants(id) ON DELETE CASCADE,
    CONSTRAINT uq_forecasts_plant_hour UNIQUE (plant_id, hour_utc)
);

CREATE INDEX idx_forecasts_plant_time ON forecasts(plant_id, hour_utc);
CREATE INDEX idx_forecasts_time ON forecasts(hour_utc);
```

Index Strategy

Index	Purpose	Usage
`idx_power_plants_company`	Filter by company	Position aggregation
`idx_power_plants_active`	Filter active plants	Validation
`idx_forecasts_plant_time`	Plant + time range queries	Get forecasts by plant
`idx_forecasts_time`	Time range queries	Company position
`uq_forecasts_plant_hour`	UPSERT uniqueness	Idempotency

Event Architecture

RabbitMQ Configuration

Exchange:

- Name: `forecast.events`
- Type: `topic`
- Durable: `true`
- Auto-delete: `false`

Routing Keys:

- `position.changed` - Position change events

Message Format:

```
{
  "companyId": "uuid",
  "companyName": "string",
  "positions": [
    {
      "hourUtc": "ISO-8601 datetime",
      "totalMwh": "decimal",
      "plantCount": "integer"
    }
  ],
  "totalMwh": "decimal",
  "changedAt": "ISO-8601 datetime",
  "correlationId": "string"
}
```

Consumer Example

```
public class PositionChangedConsumer
{
    public async Task HandleAsync(PositionChangedEvent evt)
    {
        // Trading system: update positions
        // Analytics: store for reporting
        // Dashboard: real-time updates
    }
}
```

API Design

RESTful Principles

- **Resource-based URLs**: `/api/forecasts/{plantId}`
- **HTTP verbs**: PUT (upsert), GET (query)
- **Standard status codes**: 200 OK, 400 Bad Request, 404 Not Found, 500 Internal Server Error
- **JSON request/response**: Content-Type: application/json
- **Correlation ID**: X-Correlation-ID header for distributed tracing

Response Wrapper

```
public class ApiResponse<T>
{
    public bool Success { get; set; }
    public T? Data { get; set; }
    public Error? Error { get; set; }

    public static ApiResponse<T> Success(T data) => new() { Success = true, Data = data };
    public static ApiResponse<T> Failure(Error error) => new() { Success = false, Error = error };
}
```

Error Codes

Code	Description	HTTP Status
`Forecast.InvalidHourAlignment`	Timestamp not hour-aligned	400
`Forecast.InvalidTimeRange`	Invalid from/to range	400
`Forecast.NegativeMwh`	Negative MWh value	400
`Plant.NotFound`	Power plant not found	404
`Plant.Inactive`	Power plant inactive	400
`Company.NotFound`	Company not found	404
`Internal.DatabaseError`	Database operation failed	500

Security Considerations

Current Implementation

- **No authentication**: Suitable for internal microservice
- **Input validation**: Strong validation at service layer
- **SQL injection prevention**: Parameterized queries only
- **CORS**: Configured for development (allow all)

Production Recommendations

- **Authentication**: Add JWT bearer tokens
- **Authorization**: Role-based access control (RBAC)
- **Rate limiting**: Prevent abuse
- **HTTPS only**: Enforce TLS
- **API keys**: For external clients
- **Audit logging**: Track all changes

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