

National University of Computer and Emerging Sciences

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PROJECT REPORT

Electrolux Energy Management System (EMS)

Group Members:

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1. Introduction

The Electrolux Energy Management System (EMS) is a comprehensive database-driven application designed to modernize energy distribution management for utility companies. This system addresses critical challenges faced by energy providers in managing customer relationships, billing operations, consumption tracking, and operational efficiency.

Built using Next.js 14 with TypeScript for the frontend and backend, and MySQL 8.4 as the database with Drizzle ORM for type-safe queries, the EMS implements role-based access control for three user types: Customers, Employees, and Administrators. The database consists of 16 normalized tables in Boyce-Codd Normal Form (BCNF) connected through 25 foreign key relationships, ensuring data integrity, minimizing redundancy, and maintaining optimal query performance.

This project demonstrates practical application of database design principles, normalization theory, referential integrity constraints, ACID transaction management, and real-world business logic implementation in the context of utility management systems.

2. Target Audience

User Role	Description
Customers	Residential, Commercial, Industrial, and Agricultural electricity consumers who need to view bills, make payments, track consumption, and submit complaints.
Employees	Field staff including meter readers, technicians, and supervisors who submit meter readings, handle work orders, and resolve customer issues.
Administrators	Back-office staff who manage customers, employees, tariffs, approve new connections, generate bills, and schedule power outages.

3. Project Scope

The Electrolux EMS encompasses the complete energy distribution lifecycle with comprehensive functional areas covering all aspects of utility operations.

3.1 Core Operations

- **Customer Relationship Management:** Online and offline customer registration, profile management, categorization (residential/commercial/industrial/agricultural), account status tracking, and legacy meter registration.
- **Meter Reading Management:** Employee meter reading submission, customer reading requests, and admin assignment workflow
- **Tariff Management:** Flexible slab-based pricing, customer category-specific tariffs, time-of-use rates (peak/normal/off-peak), electricity duty, and GST configuration.
- **Billing Operations:** Automated bulk bill generation, individual bill requests, bill calculator tool, preview and printing functionality, due date management.
- **Payment Processing:** Multiple payment methods (credit/debit card, bank transfer, cash, cheque, jazz cash, easy paisa, wallet), payment reconciliation, outstanding balance tracking, receipt generation.

- **Complaint Management:** Customer complaint submission with categorization and priority, admin assignment to employees, real-time status tracking, resolution workflow.
- **Work Order Management:** Admin creates and assigns work orders (meter reading, maintenance, complaint resolution, new connection), employee status updates.
- **Connection Request Management:** Public application submission, admin approval/rejection workflow, employee assignment for installation, application tracking, temporary password generation.
- **Outage Management:** Admin outage scheduling (planned/unplanned) with severity levels, zone-based notifications, customer-visible schedules, restoration tracking.
- **Password Reset Management:** Forgot password request system, admin approval workflow, temporary password generation, request tracking, expiration management.
- **Notification Management:** System-wide notifications for billing, payments, work orders, outages, and alerts, role-based notifications.
- **Usage Analytics & Reporting:** Customer consumption analytics with 5-6 months historical charts (Line and Bar graphs), admin comprehensive dashboard with real-time visualizations (Line, Bar, Doughnut, Radar, Scatter charts), complaint analytics, data export.
- **User Interface & Experience:** Dark/light mode theme toggle with persistent storage, responsive design for all devices, profile and settings management, intuitive navigation.

3.2 Technical Implementation

- 16 normalized tables in BCNF with 25 foreign key relationships
- Strategic denormalization for performance (outstanding_balance in customers table)
- ACID transaction support for data consistency
- Comprehensive constraint enforcement (CHECK, UNIQUE, NOT NULL)
- Real-time data visualizations using Chart.js (Line, Bar, Doughnut, Radar, Scatter charts)
- Database backup and restore functionality, data export capabilities
- Sample data generation for testing, persistent theme management, role-based API route protection

3.3 Limitations and Future Enhancements

Current scope excludes real-time smart meter IoT integration, advanced payment gateway integration (Stripe/PayPal), SMS/email notification delivery, mobile applications (iOS/Android), and GIS mapping for infrastructure management—identified for future enhancement phases.

4. Functional and Non-Functional Requirements

4.1 Functional Requirements

ID	Requirement
FR-01	System authenticates users with email and password using bcrypt hashing.
FR-02	System enforces role-based access control (Admin, Employee, Customer).
FR-03	System auto-generates unique account numbers (ELX-YYYY-XXXXXX) and meter numbers (MTR-CCC-XXXXXX).
FR-04	System calculates bills using slab-based tariff rates with fixed charges, electricity duty, and GST.

ID	Requirement
FR-05	System allows employees to submit meter readings with current/previous values and photo capture.
FR-06	System processes payments and updates customer outstanding balance atomically using ACID transactions.
FR-07	System allows customers to submit complaints with category, priority, and description.
FR-08	System creates work orders and assigns them to employees with status tracking.
FR-09	System allows public users to apply for new electricity connections online.

FR-10	System enables administrators to approve/reject connection requests and assign employees.
FR-11	System schedules and displays power outages by zone with severity levels.
FR-12	System maintains complete payment transaction and printable bill view
FR-13	System provides bill calculator tool for customers to estimate charges.
FR-14	System supports bulk bill generation for all eligible customers.
FR-15	System implements password reset workflow with admin approval and temporary password generation.
FR-16	System provides real-time notifications for billing, payments, work orders, and outages.
FR-17	System supports dark/light mode theme with persistent storage.
FR-18	System generates usage analytics with 5-6 months consumption charts.

4.2 Non-Functional Requirements

ID	Category	Requirement
NFR-01	Performance	Database queries execute within 2 seconds for 95% of operations with optimized indexing.
NFR-02	Scalability	System supports growth to 100,000+ customer records without architectural changes.
NFR-03	Reliability	System maintains high availability with database backup functionality and transaction rollback.
NFR-04	Security	Passwords use bcrypt hashing; SQL injection prevention through Drizzle ORM parameterized queries.
NFR-05	Maintainability	Database schema normalized to BCNF; migrations version-controlled using Drizzle ORM.
NFR-06	Usability	User interface provides intuitive navigation with clear error messages and responsive feedback.

NFR-07	Data Integrity	All foreign key relationships enforce cascading rules; CHECK constraints validate business rules.
NFR-08	Compatibility	System compatible with MySQL 8.4+, modern browsers (Chrome, Firefox, Edge, Safari), and standard server environments.

NFR-09	Responsiveness	User interface responsive across desktop, tablet, and mobile devices.
NFR-10	Accessibility	System provides dark/light mode themes for user comfort and accessibility.
NFR-11	Data Visualization	Real-time charts render using Chart.js with interactive tooltips and legends.
NFR-12	Session Management	System implements secure session handling with NextAuth.js and automatic timeout.

5. ER Diagram

The Entity-Relationship Diagram illustrates the complete database structure with all 16 entities and their relationships, including 25 foreign key relationships that ensure referential integrity across the system.

Note: The complete ER Diagram is submitted as a separate image file (**Electrolux_ERD.jpg**) as recommended by the instructor.

6. Normalized Schema

The database schema has been normalized to Boyce-Codd Normal Form (BCNF) to ensure data integrity and minimize redundancy. The schema consists of 16 tables organized into 7 logical categories, demonstrating comprehensive coverage of all energy management operations.

6.1 Schema Overview

The normalized schema includes the following table categories:

- **Category 1:** Authentication & User Management (users, password_reset_requests)
- **Category 2:** Customer Management (customers)
- **Category 3:** Employee Management (employees)
- **Category 4:** Billing & Tariffs (tariffs, tariff_slabs, meter_readings, bills, payments)
- **Category 5:** Service Management (complaints, work_orders)
- **Category 6:** Infrastructure (outages, notifications)
- **Category 7:** Workflows & Requests (connection_requests, bill_requests, reading_requests)

Key Notation: Primary keys shown in **bold**, foreign keys indicated with **asterisks*.

6.2 Core Tables Summary

users: (**id**, email, password, user_type, name, phone, is_active, requires_password_change, created_at, updated_at)

customers: (**id**, *user_id, account_number, meter_number, full_name, email, phone, address, city, state, pincode, zone, connection_type, status, connection_date, outstanding_balance, payment_status, created_at, updated_at)

employees: (**id**, employee_number, *user_id, employee_name, email, phone, designation, department, assigned_zone, status, hire_date, created_at)

tariffs: (**id**, category, fixed_charge, time_of_use_peak_rate, time_of_use_normal_rate, time_of_use_offpeak_rate, electricity_duty_percent, gst_percent, effective_date, valid_until, created_at)

tariff_slabs: (**id**, *tariff_id, slab_order, start_units, end_units, rate_per_unit, created_at) —
Extracted from tariffs to achieve BCNF

meter_readings: (id, *customer_id, meter_number, current_reading, previous_reading, units_consumed, reading_date, reading_time, meter_condition, accessibility, *employee_id, photo_path, notes, created_at)

bills: (id, *customer_id, bill_number, billing_month, issue_date, due_date, units_consumed, *meter_reading_id, base_amount, fixed_charges, electricity_duty, gst_amount, total_amount, status, *tariff_id, created_at)

payments: (id, *customer_id, *bill_id, payment_amount, payment_method, payment_date, transaction_id, receipt_number, status, created_at)

complaints: (id, *customer_id, *employee_id, category, title, description, status, priority, submitted_at, resolved_at, created_at)

work_orders: (id, *employee_id, *customer_id, work_type, title, description, status, priority, assigned_date, due_date, completion_date, created_at)

outages: (id, area_name, zone, outage_type, severity, scheduled_start_time, scheduled_end_time, status, *created_by, created_at)

notifications: (id, *user_id, notification_type, title, message, priority, is_read, created_at)

connection_requests: (id, application_number, applicant_name, email, phone, id_type, id_number, property_type, connection_type, property_address, city, zone, status, application_date, account_number, temporary_password, created_at)

bill_requests: (id, request_id, *customer_id, billing_month, priority, status, request_date, *created_by, created_at)

reading_requests: (id, request_number, *customer_id, request_date, priority, status, *work_order_id, assigned_date, completed_date, created_at)

password_reset_requests: (id, request_number, *user_id, email, account_number, user_type, status, *processed_by, created_at)

6.3 Normalization Compliance

All tables satisfy BCNF requirements:

- **1NF:** All attributes contain atomic values; no repeating groups.
- **2NF:** No partial dependencies; all non-key attributes fully depend on primary key.
- **3NF:** No transitive dependencies; non-key attributes depend only on primary keys.
- **BCNF:** For every functional dependency $X \rightarrow Y$, X is a superkey.

Strategic Denormalization: The *outstanding_balance* attribute in the *customers* table represents a controlled denormalization to optimize query performance while maintaining consistency through ACID transactions.

Note: For more detailed normalized schema we will attach a separate file.

7. Conclusion

The Electrolux Energy Management System successfully demonstrates the practical application of database design principles in addressing real-world challenges in the energy distribution sector. This fully functional system has been developed and deployed, showcasing comprehensive energy management workflows from connection application to bill payment and analytics.

Through meticulous schema design and adherence to Boyce-Codd Normal Form (BCNF), the system achieves an optimal balance between data integrity, query performance, and operational flexibility. The implementation encompasses 16 normalized database tables connected through 25 foreign key relationships, supporting complex business operations including customer management, meter reading workflows, complaint resolution, work order assignments, and outage scheduling.

7.1 Key Achievements

- **Robust Data Architecture:** 16 interconnected tables in BCNF with 25 foreign key relationships ensuring referential integrity and data consistency.
- **Normalization Excellence:** Complete BCNF compliance achieved through tariff slab extraction, eliminating data redundancy and preventing update anomalies.
- **Security Implementation:** Multi-layered security with bcrypt password hashing, role-based access control, and SQL injection prevention through ORM.
- **Business Logic Integration:** Sophisticated slab-based tariff billing, ACID transaction-based payment processing, and real-time outstanding balance tracking.
- **Technology Integration:** Modern full-stack architecture using Next.js 14, TypeScript, MySQL 8.4, Drizzle ORM, and Chart.js for data visualizations.
- **Advanced Features:** Real-time analytics with 5-6 months consumption charts, notification management, work order tracking, complaint resolution workflow, password reset management, dark/light mode themes.
- **User Experience:** Intuitive dashboards for all three user roles with real-time statistics, interactive charts, and responsive design.

The project demonstrates comprehensive understanding and practical implementation of database management concepts including normalization theory (1NF → 2NF → 3NF → BCNF), constraint design (PRIMARY KEY, FOREIGN KEY, UNIQUE, CHECK), ACID transaction management, and strategic denormalization trade-offs for performance optimization.

7.2 Future Enhancements

Real-time smart meter IoT integration, advanced payment gateway integration (Stripe/PayPal), SMS/email notification delivery, native mobile applications (iOS/Android), and GIS mapping for infrastructure management have been identified for subsequent development phases, building upon the solid architectural foundation established in this implementation.

This database systems project represents a comprehensive, production-ready solution that addresses the complexities of modern energy distribution management while adhering to fundamental principles of database design and best practices in software engineering.

8. References

2. **MySQL 8.4 Documentation** - Oracle Corporation (<https://dev.mysql.com/doc/refman/8.4/en/>)
3. **Drizzle ORM Documentation** (<https://orm.drizzle.team/>)
4. **Next.js 14 Documentation** - Vercel (<https://nextjs.org/docs>)
5. **TypeScript Documentation** - Microsoft (<https://www.typescriptlang.org/docs/>)
6. **Chart.js Documentation** (<https://www.chartjs.org/docs/>)
7. **Database Normalization and Design Techniques** - Ramez Elmasri, Shamkant B. Navathe

Repository: <https://github.com/HuzaifaAbdulRehman/Electrolux-EMS>