

Database System Design for Energy Economization of Smart Home Energy Services

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Abstract—This paper proposes the practical implementation of a balanced electrical supply among the grid, residential units and shared facility controllers for designing future smart home energy services. To achieve energy economization, the project involves design and analysis of a database management system incorporated with different web applications. The main purpose for using these technologies is to inspect, measure and control the energy flow within a specific area. For condition monitoring and long distance work controlling, PostgreSQL version 9.3 for database management and a cloud based platform for website support have been used. The main goal of this project is to process a program by developing a database management system and bring it to the users accessible levels.

Keywords—energy economization; database system design; PostgreSQL; PostGIS; jQuery; web applications

I. OVERVIEW

One of the major concerns of today's electrical grid is to distribute the electric power efficiently and keep track of a balanced supply at all the times. A few variable sources of renewable energy [1] and electro-mobility have become new challenges to this balance [2]. For efficient energy management, we need to keep track of the total generated and consumed power and establish a communication among the electrical grids, Residential Units (RUs) and Shared Facility Controllers (SFCs). The amount of total generated and consumed power can be stored and managed efficiently simply by introducing a database management system.

For distributed resource management of a grid, an economic schedule has been proposed by Bulteel and Capros in [3]. Their work focuses on the identification of heterogeneous and geographically distributed resources to share and aggregate the benefits among the smart grid users. The authors have proposed a distributed computational economy as an effective metaphor to manage and schedule the resources. Based on their scheduling, the proposed architectural framework also supports resource trading. The motivation behind this work is to create a regulation of supply and demand for the resources. This enables the users to establish a trade-off between individual units of energy resources and the grid.

Another cost-efficient integration of Distributed Energy Resources (DERs) has been reported in [4], with an overarching structure of the virtual power plant (VPP). In this work, researchers have mentioned the growing pressure for

generating more electricity from renewables and emphasized on the necessity for integrating the distributed energy resources into the grid. The concept of VPP has been proposed to enhance the visibility and control of DERs to the system operators. Although, over the years, DERs have been used to displace energy from the conventional generating plants, but their capacity are not visible to the system operators. Having a generation system without any database, may reduce the overall system capacity and can eventually increase the electricity cost that needs to be paid by the consumers. So, the practical implementation of this concept needs to share the information through an appropriate interface between the consumers and system operator.

The first database management project, directly addressing a solution for energy economization was done by Pattamavarakun *et al.* [5]. Their project involves luminaire measurement based on the Provincial Electricity Authority (PEA). The outcome of their project reveals the fact that using a DBMS for energy economization of the Highway Department street lamps and the Urban Highways Department public lamps, can save 25-30% of the total energy. In their work, they have proposed a database system design using PostgreSQL along with the features of PostGIS. The initial assumption of their design involved the measurement of control module and the capability of their system. The collected data from any specific area were then sent to the PEA head offices and stored in their database. For selecting the area and achieve geographic information they have used the PostGIS, supporting the spatial or geographical information. To make their database user-accessible, they have employed different web applications along with the JQuery. As the cross-platform JavaScript library, JQuery allowed multiple computing platforms to simplify the client-side scripting of HTML. Using JQuery, they have created a tree-structure representation of all elements of a webpage. Within their project it acted as a DOM (Document Object Model) manipulation library, which provided an accessible way to find, select and manipulate all the elements of a DOM.

In [6], McCormick *et al.* demonstrated how JQuery can be used to find a specific information from a database. As of the core features, JQuery supports DOM (Document Object Model) element selections, traversal and manipulations of data structures and creation of a new programming style. Thus, the

jQuery library can be used to allow the creation of powerful dynamic webpages and web applications, while incorporating JavaScript functionality.

In [7], Piórkowski described the features of MySQL spatial and PostGIS implementations of spatial data standards. PostGIS is an open-source software program that allows to incorporate “light-weight” geometries and indexes for mixed spatial/non-spatial queries. The software added support to locate geographic objects for SQL specification from the Open Geospatial Consortium (OGC). However, this program can also be considered as the database extender for an object relational database, like PostgreSQL.

The rest of this paper proceeds as follows: Section I above provides an overview along with the literature review. Related terminologies and concepts are provided in Section II. Section III illustrates the main idea of the project, and steps required to create a database along with the web applications. Design and analysis of this project are studied in Section IV. At the end, Section V concludes the report with a summary and future possibilities of application.

II. FUNDAMENTAL TERMINOLOGIES & CONCEPTS

This section attempts to familiarize the readers with the fundamental terminologies and concepts required to realize and implement the project. These definitions are based on the resources provided by Clifford [3], Momjian [8], Heninger [9], Kirda [10], and Kaur [11].

A. Database Management System (DBMS)

A database is an organised collection of data, consisting of schemas, tables, queries or other objects. According to Clifford, “A database system configures a storage model in accordance with a hierarchical tree-like structure to enable fast and comprehensive data extraction functions” [3]. A database management system corresponds to a system software to create and efficient management of databases. The DBMS essentially serves as an interface between the database and end users or application programs. Efficient use of a DBMS enables the end users to create, update or delete data in a database.

B. PostgreSQL

PostgreSQL, also known as the Postgres, is an open source, object relational database management system. More often it is considered as the relational database system with additional object-oriented features. This additional features may emphasize on extensibility and standards-compliance. As a database server, PostgreSQL provides better support for multiprocessor environment. The primary function of this database server is to store data and allow secure retrieval in terms of software applications. In a database management system, logical operation performed on a single data is called transaction. PostgreSQL is ACID (Atomicity, Consistency, Isolation, Durability) compliant for all the database transaction. This results in a support for foreign keys, joins, views, triggers and stored procedures in multiple languages [10]-[11].

C. Client-side Scripting

Client-side scripting can be classified as a class of computer program, that is executed in the client-side by different web browser. As an important part of dynamic HTML (DHTML) this enables webpages to be scripted from the user platform [12].

D. Server-side Scripting

A server-side scripting language is designed to use for web development. This is more likely used as an interpreter or an executable common gateway interface. The main advantage of using a server-side scripting language lies on the fact that, it can be used in combination with various web template systems to build a framework. Some examples of server-side scripting languages include PHP, Perl, and Ruby [9].

E. Web Applications

In the field of computing, a web application is considered as a software application of client-server. With the help of a web app, the client or user interface runs a web browser. Generally, websites are most likely referred as the web applications since they have similar functionality to a desktop software application. Per [11], “web is highly programmable environment, which allows the immediate deployment of large and diverse range of applications”. However, in contrast to the websites, web applications use web documents. These web documents are usually written in a standard format, e.g. HTML/Javascript and are supported by the web browsers. As the computer programs, web applications allow client to submit and retrieve data to/from database over the internet using a preferred web browser.

III. PROJECT IDEA

To facilitate the modern residential communities, it is necessary to study the energy demand and keep a track of the total power consumption of all the equipment. Creating a database of power consumption, for all these different elements, will enable us to determine the total power consumed by a specific area. The records can also provide an idea of the cost for total electricity purchase for each RU or SFC within the area. Based on the energy demand provided by the database server, electrical grids can sell its energy to the SFCs and the RUs in a controlled manner [13]. That is how the system may prove to be efficient to create a revenue among RUs, SFCs and the grid. Additionally, we can also use the same database to keep track of the generated electricity by the available Distributed Energy Resources (DERs).

For achieving the energy economization, we propose to construct a database system using the PostgreSQL for tracking the power generation, distribution and consumption. PostgreSQL is an open source object-relational database system. The system architecture of this database, provides data integrity as well as system reliability. As a database system, PostgreSQL can be run on all major operating systems. It can support most of the SQL data types and is enable to store large binary objects. It also provides native programming interfaces

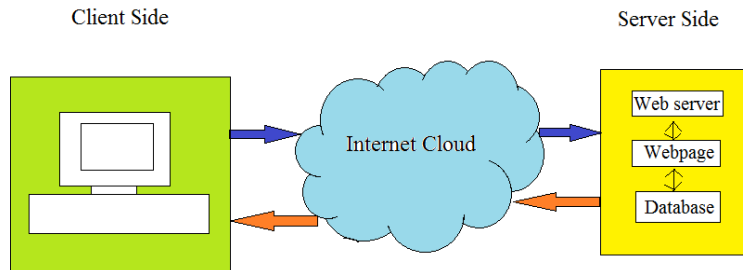


Figure 1. Web application model.

for C/C++, Java, Net, Perl, Python, Ruby, Tel, ODBC and exceptional documentation [5]. This helps to proactively manage the server from a single common interface. Availability and easy accessibility of Linux or Windows, equipped with modern technology of web application framework can provide a pathway towards an efficient energy management system. Adapting web application framework, PHP, Javascript, CSS, and HTML we can also create an accessible database server to measure the total power demand for a specific area. This allows users to access and retrieve proper information of total power consumption and helps to ensure a balanced distribution of power.

For creating an accessible database server, we have adopted the structure technology of web application development. It can employ advantages of flexibility and extensibility for the database management system. These data can be presented to the user using the web browsers. Usually, information is generated dynamically in a specific format in HTML through the web server. Web applications query the content repository database and dynamically generate web documents to serve the clients. The client side script is on form of Java Script that permits dynamic elements on each page. The proposed system architecture is shown in Fig. 1.

IV. DATA BASE SYSTEM DESIGN

This section aims to provide an overview of the design steps required to bring this project to the users accessible level. Necessary steps are specified within the sub-sections, starting from the database design to the user accessible webpage.

A. Database Design for Total Power Consumption

As a case study, we considered the City of Lethbridge, Alberta. We illustrated the power consumption scenario within a specific area code, which contains twelve houses¹. To provide a power consumption record for five major electrical equipment for each of these houses, first we need to create a database. The power consumption measurement can be collected either from the meter side or from the head office of the electricity distribution centre. To create the database, we have used PostgreSQL (version 9.3). This version of PostgreSQL

¹information obtained from the Canada Post database

benefits the users in terms of having the materialized view of a query. This also enables the query to be executed and used to populate the view, when a command is issued. A materialized view of a query has many of the same properties as of a table, except the automatic generation of OIDs. Using the software, we have created a table consisting of: SFC equipment list, consumed power by the SFC equipment, equipment list for the total of 12 residential units and the consumed power for each of the equipment of these residential units. One efficient way to search for data within the database is to open the Query tool, select Graphical Query Builder and select the column of information that a customer want to retrieve from the database. The steps are shown in Fig. 2.

B. Introduction of the Web Applications and Webpage

Introduction of such a DBMS can help to create a record of power consumption within the residential units and associated shared facility controllers, categorized by their postal code. These records can usually be kept within the system administration of the power distribution centres. Now, for efficient energy economization, customers purchasing the electricity from the grid need to know the records of power consumption and the total generated power by the DERs. So, to make the database user accessible I have incorporated different web applications to create a website. The functional layout of the proposed webpage is illustrated in Fig. 3.

This project also utilizes a cloud based platform, Caspio, for providing information within the webpage. The information for a specific postal code may include:

- 1) The total generated power of the nearest power plant
- 2) The total generated power by the DERs, and
- 3) The total consumed power by the RUs and SFCs within that specific area.

The webpage can be designed in such a way so that when a consumer enters the required fields of information (e.g. City and Postal Code), the page will direct to the result that are embedded within the HTML code generated by Caspio. Caspio works in a way of raising the bar for cloud data management and provides the information through a

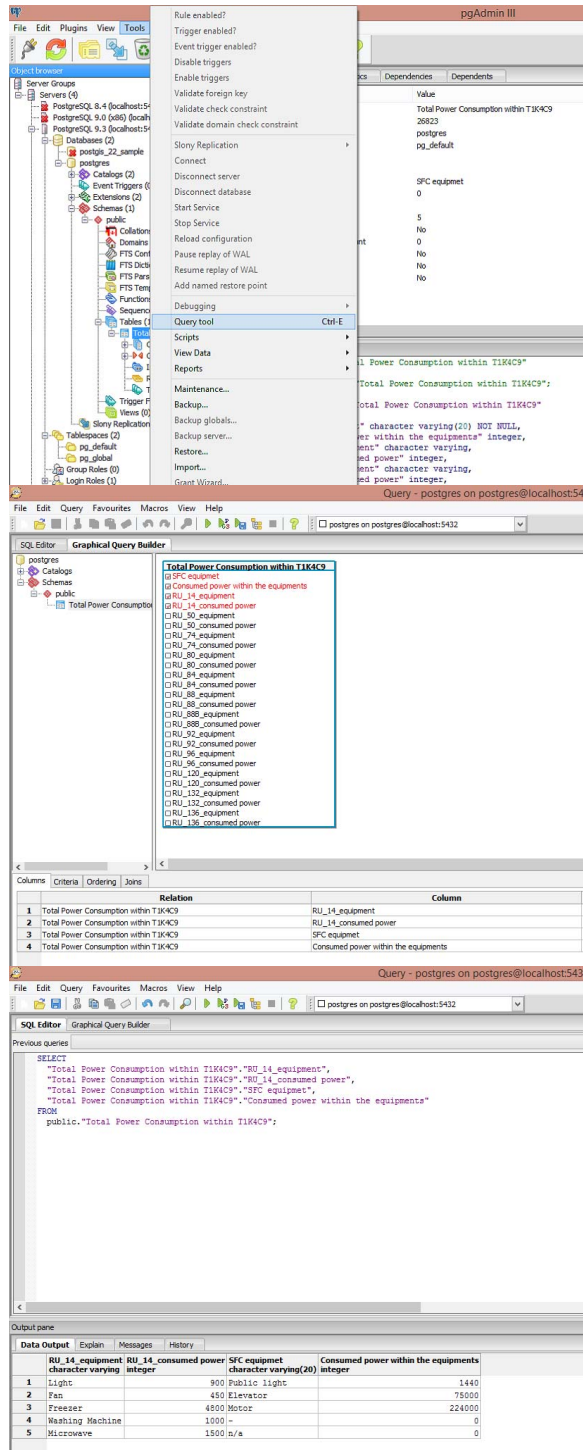


Figure 2. Searching data from the database.

web-based interface. It does not require any installation within the operating system and is designed to centralize cloud database and external database and programs.

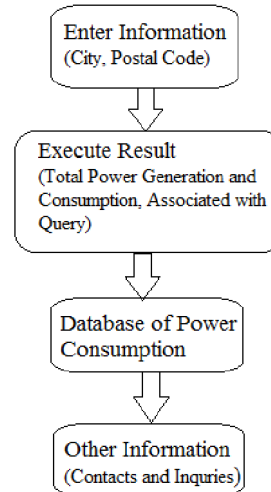


Figure 3. Functional flow chart of the proposed webpage.

```

//start HTML table for displaying
//results from query
<head>
<title>Power Consumption data</title>
</head>
<body>
<table width="600" border="1"
cellpadding="1" cellspacing="1">
<tr><th>Electrical equipment for
Location X </th>
<th> Consumed power
within the equipment </th></tr>

```

Figure 4. Sketch of PHP Form Handler and HTML header.

C. Displaying the Data

To display the items that can be fetched from the database on the webpage we have illustrated a PHP form handler for fetching and displaying data directly from the database. An example sketch of a PHP form handler is shown in Fig. 4 and Fig. 5.

For displaying the information directly from the database, we can build a HTML table and create a header row (shown in Fig. 4). To direct the query and fetching data directly from the database we need to specify locations associated with the query. Fig. 5 shows the sketch of the PHP form handler needed to fetch and display info directly from the database. Energy consumption information for location X is then provided by a form connected to this form handler. The second portion of the code shown in Fig. 5 can be used to fetch each record directly from the database. This portion can also be used to format the HTML table row for information, before closing the table.

```

//connect to database and fetch data
//using mysql and php
<?php
server_connect
    ("postgres" "username" "password");
select_db ("power_consumption");

//Query for total Power Consumption
//for Location X
$sql="SELECT * FROM consumption_table
    where Location='X' "
$records= exec_query($sql)

//Fetch each record and add to HTML table
while ($power_consumption
    =fetch_record($records))
{
    echo"<tr><td>"
        $power_consumption[Equipment]
        "</td><td>"
        $power_consumption
        [Consumed_Power_Within_Equipment]
        "</td></tr>";
} //end while
</table>

```

Figure 5. Sketch of PHP form handler fetching and displaying info from location X.

V. CONCLUSION AND FUTURE WORKS

For efficient energy economization, it is necessary to create a balanced system and share the real-time data among all the units. Creating a database for each of the postal codes within a city can essentially help to provide a record of the total power generation and consumption. Although the project considered a specific area of one postal code but the idea can be implemented to create a database for the entire city. With the advanced versions of different web applications, it is possible to access data categorized by the postal codes where the website visitors can submit and retrieve data over the internet.

Additionally, to make the database more users accessible, QR codes can be introduced as a trademark for the resulting webpage. The concept of including a QR code benefits customers to access the database, simply by using a QR Code Scanner app installed within their smart phone. For any individual without an iPhone or Android, few sites offer the option of downloading a software via PC. A QR code scanning software enables a person to visit the website with his smartphone through its browser and allows the direct download of information.

As for the future possibilities, practical implementation of this project can contribute as follows: a) introduce a system model which provides a stable energy management scheme for a specific community, b) keep a track of total produced and consumed power for a specific area, and c) can create a good balance of energy flow among the electrical grid, distributed energy resources, residential units and shared facility controller for designing smart home energy services.

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