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Cloud Platform Real-time Measurement and Verification Procedure for Energy Efficiency of Washing Machines

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Abstract— **Industrial administrators are promoting approaches to improve energy efficiency and developing smart homes and appliances. Development of green technology requires accurate models. Real-time Measurement and Verification (M&V) procedure is used to quantify energy performance. It is conducted through short-term on-site measurements and engineering calculation. The period of this procedure lasts for several months or up to a year so the failure to immediately detect abnormal energy efficiency decreases energy performance so timely correction of appliances will be unable and the opportunity to adjust or repair them will be missed. In this study, a cloud computing platform is established to measure the washing machine energy consumption parameters and calculate energy savings which consist of load sensors and fuzzy control. Time-series data are transmitted to the cloud environment through the network and saved in databases. On this platform, for constructing accurate models, integration of the particle swarm optimization (PSO), M&V methodologies and multivariate regression analysis are used. After uploading energy consumption data directly, pre-installation energy baseline model is created and post-installation real-time energy performance calculation is obtained. Observing fluctuations of washing machine energy consumptions provides real-time monitoring or correction of the operating performance of the appliance or system and then good energy performance can be obtained. The aim of this study is to gain real-time and long-term energy performance information and automatic calculations of energy savings on washing machines. Using this cloud platform for home appliances could help the manufacturers to promote energy efficiency programs on smart appliances.**

I. Introduction

Energy consumed in buildings consists of residential and commercial end-users and accounts for 20.1% of the total delivered energy consumed worldwide. Energy performance is evaluated through measurement and verification (M&V) procedures under the Tradable White Certificate, Clean Development Mechanism, Demand-Side Management, Energy Service Companies (ESCO) and Energy-Saving Performance Contracting [1]. M&V procedures have become an important key in the energy efficiency policies. Related works were conducted. Bertoldi, et al. [2] standardized contracts and M&V procedures based on the results of reviews and analysis of ESCO industries in the Europe and help end-users understand the M&V procedures. International performance measurement and verification protocol has been used by many countries. This protocol describes M&V concepts and methodologies to determine energy savings for energy conservation measures (ECM) s in residential buildings and industrial processes. For M&V of energy savings in building energy management projects, the American Society of heating, refrigerating an air-conditioning Engineers Guideline 14 is used [3]. This guide contains M&V concepts and methodologies to calculate energy and water savings in residential, commercial and industrial buildings. Different methods are applied to various energy conservation measures to calculate the baseline model and energy saving. Many M&V studies have been conducted. Lee [4] proposed an accurate model for energy savings calculation by long-term monitoring and assumed this model for individual cases because actual lighting conditions may differ from data, which provided by clients, and this difference makes errors in energy saving calculations. Dong, et al. [5] presented a baseline model for energy consumption in buildings by using regression analysis and considered different parameters for the baseline model which included outdoor dry-bulb temperature, relative humidity, and global solar radiation. They used statistical indicators such as coefficient of determination (R2) and the coefficient of variation of the real-time-square error (CVRMSE) to verify the accuracy of the baseline model. Related works show that regression analysis methods are used for constructing M&V baseline models to evaluate the performance of energy conservation measures accurately. PSO algorithm creates more accurate models than the least error squares techniques.

In this study, a cloud computing platform for real-time measurement and verification of energy saving performance is created based on the M&V methodology and integrating of PSO algorithm, java programming language, and cloud computing techniques. While baseline models are applied automatically for pre-installation and real-time energy saving performance is calculated automatically after post-installation, the cloud computing platform reduces the time and cost of M&V and increases the accuracy of energy saving calculations.

A. Measurement and Verification Procedure

Non-profit Efficiency Valuation Organization (EVO) proposed the International Performance Measurement and Verification Protocol (IPMVP) which explains how to determine baseline data and calculate energy savings. Baseline data should be established because energy consumption in the pre-installation period (i.e., baseline period) cannot be measured by instruments after energy conservation measures (ECM) have been implemented [6]. Therefore, adjustments (A) to the baseline data are required to determine the energy consumption of the equipment and systems during the baseline period (BP) and the energy consumption during the post-installation period (reporting period (RP)) under the same operating conditions [7] The amount of savings (S) can be calculated as shown in (1).

$$S = (BP - RP) \pm A \tag{1}$$

There are four options, A through D, for M&V procedure. In option A, only key parameter will be measured. But in option B all parameters will be measured. A and B options can be used when evaluating the performance of a single conservation measure. Energy consumption parameters will be measured for pre-installation and post-installation. Statistical methods or engineering calculations are used for evaluating the energy performance [8]. In option C, energy conservation measure is calculated by analyzing energy bills and statistical methods. In option D, first energy savings are calculated by specialized software and energy consumption for pre-installation and post-installation in simulated. Then the energy bill data are used to correct the simulation models. C and D options are used for evaluating energy conservation measures in whole buildings or in situations where measurements are difficult.

B. Particle swarm Optimization

PSO is a probability-based optimization technique that was developed by Eberhart and Kennedy [9] and inspired by the social behavior of birds or fish in finding food. It is assumed that a group of birds are randomly searched for food in a region, while food is only available in one part of the search area [10]. In PSO, each answer is a bird in the search area called the particle. Each particle has a fitness value obtained by the objective function. The bird that is closer to food is more desirable [11]. Steps of PSO algorithm and Equation of it are as follow:

$$V_i^{k+1} = W \times V_i^k + L_1 \times r_1\left(Pbest_i^k - X_i^k\right) + L_2 \times r_2\left(Gbest_i^k - X_i^k\right) \tag{2}$$

$$X_i^{k+1} = X_i^k + V_i^{k+1} \tag{3}$$

(1) First, a position and velocity is randomly considered for each particle in N-dimensional space.

(2) Next, an objective function is used to determine the fitness value for each particle.

(3) The fitness value is compared to the current best value for each particle (Pbest) and then the particle velocity is adjusted to improve the fitness value in the next iteration.

(4) A comparison between Pbest and the current best value for group (Gbest) is conducted, if Pbest is greater than the Gbest, then Gbest will be adjusted. The velocity and position of each particle are then adjusted based on Gbest for the next iteration.

(5) Each particle's velocity and position are updated using (2) and (3) as shown in Table II.

II. Cloud Computing Platform for M&V of Real-Time Energy Performance

The architecture of cloud computing platform contains three layers: first is the on-site measurement layer, second is the cloud computing layer and the last one is the user layer.

(1) *On-site measurement layer:* Energy consumption and other energy parameters are stored in storage devices and then all collected data are transmitted to the cloud computing platform via the internet.

(2) *Cloud computing layer:* All calculations are conducted in this layer, including creating files, receiving data, transmitting data, filtering data, sorting data, executing PSO algorithm operations, constructing baseline equations and energy savings calculations. In this cloud computing platform, the Google App Engine (GAE) is used as the cloud-based server. For displaying the results on graphs and curves and calculating energy savings automatically, web pages are created dynamically in hyper markup language (HTML) or JavaScript.

(3) *User layer:* In this layer, users can communicate with the cloud platform via their computers and follow the energy consumption fluctuations of any appliance at any time interval and on the curves, and also finds abnormal patterns, so they become aware of the critical issues of the appliance.

III. Software Architecture

Software architecture of this cloud platform contains PSORun (server), PSORun (client) and the Data Upload Program which are described as follow:

- *PSORun (server):* this program includes four subprograms and established on the GAE platform.
    1) *ProjectServiceImpl.java:* the functions of this program include project creation, project storage, project deletion and PSO operations. Which conducted by this primary program.
    2) *File Upload.java:* when pre-installation baseline data are uploaded and cloud computing results are returned, this program is called and executed.
    3) *DoGet and DoPost are hypertext transfer protocol requests:* DoGet protocol retrieves and

transmit data from the server to users and DoPost transmit data from the user to the server.

- *PSORun (client):* web page creation

Projectlist.java: this program is an interface which can be divided into two subprograms:

1) projectList-Savingview.java: is the interface for energy savings calculations
2) ProjectList-Manage.java: is the interface for managing projects.

- *Data Upload Program*: this program uploads post-installation data in a fixed format to the cloud platform for calculating energy savings.

IV. Constructing the Baseline Model Using PSO

Users can determine the number of independent variables in baseline regression model using cloud computing platform. In this study four energy consumption parameters (i.e. four independent variables) are used in the baseline regression model. The pre-installation energy consumption is assumed as P and the measurement of the four independent variables are considered as X, Y, V and Z. the PSO algorithm is applied to determine the coefficient of each independent variable (C_0- C_{14}) [1].

$$P = f(X,Y,V,Z) \tag{4}$$

$$P = C_0 + C_1 \times X + C_2 \times X^2 + C_3 \times Y + C_4 \times Y^2 + C_5 \times V + C_6 \times V^2 + C_7 \times Z + C_8 \times Z^2 + C_9 \times X \times Y + C_{10} \times Y \times V + C_{11} \times V \times Z + C_{12} \times X \times Z + C_{13} \times X \times V + C_{14} \times Y \times Z \tag{5}$$

In this process, the cloud computing platform first filters the pre-installation data using a regression analysis while retains data with less than 10% errors for dependent variables. Then, PSO regression analysis is used to determine the coefficients of independent variables to complete the baseline model. Further, the filtered independent variable data can be used as the upper and lower limits for post-installation data filtering, therefore users can be assured that the ranges of the baseline model and uploaded data are matched and the energy savings are calculated accurately. PSO algorithm includes the number of particles, number of iterations, inertia weight (w), cognitive learning factor (L_1), social learning factor (L_2), maximum particle velocity (Vmax), minimum particle velocity (Vmin), maximum particle position (Xmax), minimum particle position (Xmin), random numbers (r_1 and r_2) and convergence condition (Z_minAvg) which can be defined by the user. When the PSO algorithm determines that the convergence condition has been satisfied, the calculations will be determined. The convergence condition in this study is the relative error of dependent variable in (6).

$$Z = \sum_1^n \frac{depend\ variable - depend\ variable\ pso}{depend\ variable} \times 100 \tag{6}$$

V. Energy Saving Calculations

Energy saving calculations require uploading post-installation data to the cloud platform and a corresponding pre-installation project ID and URL should be entered like a data file name and file path. Inputting post-installation energy consumption values to the pre-installation baseline model yields the pre-installation energy consumption with the same conditions. Energy performance is obtained by subtracting the post-installation value from the pre-installation value (1).

While the post-installation data are uploaded to the cloud platform, a data filtering function is used to allow the appropriate data range to be set, so energy savings will be calculated accurately. In this cloud computing platform, energy performance information including average energy savings (KW), total kilowatt-hours savings (KWh), average percentage of energy savings, and energy cost saving are calculated.

In addition, constructing a time interval calculating function allow users to set a time interval so they can monitor fluctuations in the pre-installation energy consumption (Padjusted) and post-installation energy consumption (Pmeasured) on a graph and users can select a time point over the curve to see the associated data record and gain the results online.

VI. Case Study

The M&V cloud computing platform is used to assess the energy conservation for the washing machine. This platform automatically calculates the energy consumption, energy savings, and the energy cost savings. In addition, this system displays the results on the web pages and allows users to monitor the energy savings and energy performance and whenever the efficiency of the washing machine comes down, it warns the users, for example, washing their laundries in proper time or change the filter of machine. According to (4) and (5) five parameters, wash load (L_w), the amount of water (W_q), the temperature to be reached (T_f), energy consumption (P_e) and spin speed (V_s), are selected and shown in (7). First, the project ID, project name, and PSO parameters Table II were entered into the real-time energy performance M&V cloud computing platform. Next, pre-installation energy consumption data are uploaded for calculations. Cognitive Learning Factor is a broad theory that explains thinking and differing mental processes and how they are influenced by internal and external factors in order to produce learning in individuals. Social Learning Factor (Bandura) Bandura's Social Learning Theory posits that people learn from one another, via observation, imitation, and modeling. The theory has often been called a bridge between behaviorist and cognitive learning theories because it encompasses attention, memory, and motivation. Then the PSO algorithm is applied to determine the coefficients of these independent variables (C_0-C_{14}) and the construction of the baseline model is complete and the message ‘‘true” was displayed for the field ‘‘computations completed”.

$$P_e = C_0 + C_1 \times L_w + C_2 \times L_w^2 + C_3 \times W_q + C_4 \times W_q^2 + C_5 \times T_f + C_6 \times T_f^2 + C_7 \times V_s + C_8 \times V_s^2 + C_9 \times L_w \times W_q + C_{10} \times W_q \times T_f + C_{11} \times T_f \times V_s + C_{12} \times L_w \times V_s + C_{13} \times L_w \times T_f + C_{14} \times W_q \times V_s \quad (7)$$

After the post-installation data for energy consumption and other energy parameters are uploaded to the cloud computing platform for the real-time M&V of the energy performance, the calculations indicates the energy savings accumulated over 11.5 h. Specifically, the average energy savings is 20.3 KW, the total kilowatt-hours saved is 2.8 KWh, the average percentage of energy savings is 25%, and energy cost savings was $523 as shown in Table I.

TABLE I.
THE POST-INSTALLATION ENERGY SAVINGS FOR THE WASHING MACHINE

Average energy savings(KW)	20.3KW
Total kilowatt-hours savings	2.8 KWh
Average percentage of energy savings	25%
Energy cost saving	523$

TABLE II.
PSO PARAMETERS VALUE

Interia weight (W)	0.4
Social learning factor (L2)	2
Minimum particle velocity (Vmin)	-5
Minimum particle position (Xmin)	-20
Maximum number of iterations	10,000
Cognitive learning factor(L1)	2
Maximum particle velocity (Vmax)	5
Maximum particle position (Xmax)	20
Number of particles	300
Convergence condition (Z_minAVG)	0.1

VII. CONCLUSION

Over the past few years, the energy efficiency and the market penetration of efficient washing machines has increased. Key parameters of washing machines are their energy and water consumption (full and partial loads), spin-drying efficiency and supply for hot fill. There are many washing machine features which make sense concerning energy efficiency containing load-auto sensor, automatic temperature control, automatic dispensers, spin speeds, fuzzy control and all water washing machines. The key parameters of washing machines can be achieved by these features. Observing fluctuations of the washing machine energy consumptions on a curve can help the users monitor the appliance operations and gain information about the energy consumption, a view of calculating energy savings and detect abnormal functioning. In this study a washing machine is considered with four independent variables including wash load, the amount of water, temperature to be reached, speed of spin and energy consumption for heating, mechanical actions, and pumping. A cloud computing platform for the M&V of the real-time energy performance that integrates the M&V methodology, PSO, and multivariate regression analysis modeling is conducted on the GAE cloud platform. The M&V cloud platform use uploaded real-time energy consumption data and create pre-installation baseline model and post-installation real-time energy performance calculation. When independent variables are uploaded onto the platform, a baseline regression model can be established and the energy performance can be calculated then the results will be displayed on the web page. Therefore, whenever energy consumption rises or energy savings decrease, the system alerts and suggests that the relevant problem be corrected for example the system suggests that the filter should be changed or declares the time inappropriate. This procedure can be used for evaluating energy performance accurately.

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