Energy savings reporting and uncertainty in Measurement & Verification

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***Abstract* — This paper provides more detailed information on the application of the International Performance Measurement and Verification Protocol (IPMVP) guideline in the determination and reporting of energy savings. It stresses the need, the importance and an approach that can be used to report energy savings accurately in Measurement and Verification (M&V). The paper focusses on the fundamentals and the applications of the IPMVP in the determination and reporting of energy savings that result from energy efficiency intervention. The methodology applied here can be used to ensure complete compliance with the IPMVP guideline.**

***Index Terms* — energy savings, reporting, Measurement & Verification.**

I. INTRODUCTION

The basic principle of the IPMVP is that reported energy savings must be accurate and correct [1]. Reporting accurately and correctly means that a certain level of accuracy is required when doing M&V.

During a case study of an M&V exercise, the energy use of a plant was correlated as a function of the energy governing factors.

It was noted that energy models used to correlate the relationship between the dependent variable and independent variable(s) must adhere to the IPMVP principles. Meeting the accuracy level as specified by the IPMVP alone indicates that the energy model is good enough for energy savings reporting [1].

However, improvements can be made in the reported energy savings by improving the accuracy level of such a model i.e. by the inclusion of the uncertainty level in the values reported.

II. BACKGROUND

Modelling the energy use of a plant is based on data acquired by metering equipment. The metering equipment is affected by harmonics and errors are also introduced in the reported values. These errors are known as instrument errors or measurement errors. Instrument errors are known to be higher for smaller and cheaper power measuring equipment and lower for more expensive or sophisticated equipment. Modelling errors and sampling errors can also play a role when reporting energy savings which lead to either over reporting or under reporting of the energy savings.

III. ACCURACY OF ENERGY SAVINGS REPORTED

Energy savings are not measured. They are computed between two known energy values i.e. the difference between the baseline energy use and actual energy use, or in real applications, the difference between adjusted baseline energy use and actual energy use. The energy use, both baseline and actual or post-implementation energy use, is the result of power measurement over time. As mentioned in the introductory section, power measuring equipment is subjected to effects such as harmonics. Harmonics are not the only factor contributing to the inaccuracy of measured power as the power instruments themselves operate through estimates of the values being measured [1].

Reported energy savings therefore should be reported within certain levels of accuracy as measured values could fall within a certain bracket around the mean values as measured by the metering equipment. The IPMVP provides certain criteria that energy models must conform to. Experience in the analysis of the data collected during the M&V exercise indicates that some analysed data meet certain accuracy levels, but do not meet the others as specified by the IPMVP[1]. More discussion on this is presented in this work.

The energy use of plants is often modelled as functions of the energy driving factors or a combination thereof. Modelling the energy use as a function of the energy driving factors is the simplest when the independent variable is not greater than one. All cases, however, should still adhere to the protocol and the principle of reporting energy savings.

Adherence means that reported energy savings must be correct, accurate, persistent etc. [1]. It was noted that meeting one of the accuracy levels is not sufficient to say that the modelled energy use of plant is correct and accurate enough. The R^2 value is the simplest method of determining whether the energy model correctly predicts the relationship between the dependent and independent variable(s). It assumes that a linear relationship exists between the dependent variable and the independent variable. Sometimes the R^2 value criteria are met, but not in all cases.

IV. CONFIDENCE LEVEL AND PRECISION[1]

Reported energy savings should include statements that describe the confidence that values reported are correct to a certain level of probability and precision level. The probability that energy savings reported are correct is referred to as the confidence. However, having a confidence level is incomplete without a precision level. The IPMVP describes confidence as the likelihood or probability that the estimated savings will fall within a certain precision range [1]. Recall that values measured by power measuring equipment makes use of the sampling at a particular instant from which a value output is given as what was being measured. This output is based on the probability distribution of the sample concerned. To obey the IPMVP principle of accuracy, this probability must be quoted with its associated precision level. Precision level is defined as the measure of the absolute or relative range within which the true value being measured is expected to occur with some specified level of confidence. The expressed confidence level must be accompanied by the precision statement.

V. ERROR AND UNCERTAINTY[1]

Electrical energy savings to be reported must have a reasonable level of uncertainty that must be managed by controlling random errors and possible bias in the data being used. The quality of the measuring equipment, the sampling approach chosen, the assumptions made and method of analysis all come into play and may result in the introduction of errors and uncertainty in reported energy savings. The result of this is a statistical estimate of the expected values that includes some statistical variations using measures of central tendencies (mean, median, mode etc.). The use of the statistical mean, range, standard deviation etc. helps to quantity the level of uncertainty in the reported values. Sources of errors that lead to over/under reporting of energy savings can be classified as

- modelling errors,
- sampling errors and
- measurement errors.

As the name suggests, modelling errors are associated with modelling the energy use as functions of the energy governing factors. Sampling errors are associated with sampling of the parameters to be measured, i.e. using the wrong population size or using a biased method of sampling. Measurement errors are linked to the errors introduced by the measuring equipment themselves e.g. errors due to inaccurate sensors, drift of the measuring equipment etc. Measurement errors are mostly noticeable when wrong sized metering equipment is used for measurement in ranges that it is not recommended for.

To be accurate and complete, electrical energy savings must be expressed with their associated confidence and precision levels. The confidence in a reported value is defined as the likelihood that the reported energy savings will fall within a certain precision range i.e. the probability that the metered target will fall within a specified range. Precision in reported energy saving is the assessment of the error margin in the values reported. Various methods of analysis can be used to check the accuracy of a model. Some of the most common ones are discussed here. It is also important to note that some methods of checking the accuracy of models are sometimes more suitable than others. For illustration and application purposes the ones often used in M&V applications are

- coefficient of determination;
- standard error of the estimate;
- t-statistic;
- uncertainty.

A. Coefficient of Determination

The preceding section discussed the precision and the uncertainty that must be expressed when energy savings are reported. This method of assessing the accuracy of a model makes use of the R^2 value based on using the least square as a tool to express the relationship between a dependent variable (energy use) as function of the independent variable.

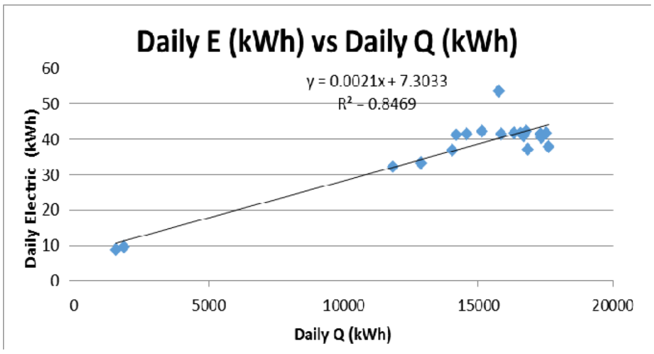

Figure 1: Daily electrical energy use against daily thermal energy use

When the energy use of plant or facility is modelled as a function of the independent variable, the R^2 value is an indication of how the model correctly matches the actual values. This is known as linear regression. The IPMVP dictates that adherence to the protocol requires that the R^2 value of 0.75 or better is acceptable to pronounce that a model is correctly representing the energy use of that plant [1]. The simplest form of the linear regression is the single variable function where the energy use is a function of one variable. Complex forms of the regression analysis results when the energy use is a function of more than one independent variable.

To express the energy use as a function of more than one independent variable involves the use of Excel or a similar package to do the regression. In Excel, the *LINEST* function is used to correlate the energy use as a function of the independent variables when the energy use to be modelled is dependent on more than one variable. By developing a multivariable function, the energy use of the plant is modelled with an associated R^2 value similar to a single variable function. Meanwhile, the model still needs to conform to the IPMVP requirements. The R^2 value must still be greater than 75%. A typical energy model is that uses the regression method shown in Figure 1. The model is for a change house where the existing electrical geyser is to the retrofitted with a heat-pump system.

As can be seen the model meets the IPMVP R^2 value criterion of 75% (i.e. 85%). This means the 85% variation in the thermal energy of the change house is explained by the model for the period concerned.

B. Standard error of the estimate[1]

The standard error of the estimate is used to check the accuracy of a model that is used to predict the energy value for a given independent variable in the energy model. To use the standard error of the estimate, the root mean square error (RMSE), the coefficient of variation RMSE or CV(RMSE) and a similar measure known as the mean bias error (MBE) are calculated to check possible bias in the regression[1]. An example of how to apply this on a model is presented here. The baseline model of Figure 1 is used for illustration purposes. The IPMVP recommends that the CV(RMSE) and MBE must fall within ±15% and ±7.5% respectively.

C. T-statistic[1]

The t-statistic is used to determine the statistical significance of an estimate. A comparison is made between certain critical t-values from a t-table and the value obtained through the statistical test of the estimate. This test is used because the coefficients as determined through regression models are subjected to some variations of the estimate from the true relationships.

D. Uncertainty

In [2] the power measurements when harmonics are present in a single phase system were discussed. Using the total power to calculate the energy savings gave different results to when the fundamental power is used. The results also indicated that the energy savings calculation based on the total power can be misleading as the harmonics in the system can lead to under/over reporting of the energy savings. However, ignoring the harmonic components of the system yields better and more accurate results. Emanuel indicated in his book [3] that the harmonic components of the power measured constitute what was referred to as distortion power. This can have various consequences in energy efficiency projects where the energy (MWh) or the demand (MW) savings reported have a monetary value.

A comparison of the two cases when harmonic components are ignored and when harmonic components are included in the energy savings calculation were shown in [2]. A difference of 10.9% for example is very serious when a comparison is drawn from the energy savings reported when the harmonic component is included in the calculation as opposed to when harmonics are excluded when determining the energy savings. This can also become more serious when such data is to be used to model the energy use as functions of the energy drivers, bearing in mind that modelling and sampling also introduce more errors in the values to be reported as the energy savings.

The linear model in Figure1 further indicates the relationship between the daily energy usage and functions of the daily thermal energy. The model is written as;

$$Daily\ Electric\ Energy = 0.0021 * Daily\ Thermal\ Energy + 7.3033 \quad \ldots\ldots (1)$$

The method used to determine the uncertainty is now discussed. Following the IPMVP criteria, the errors and uncertainty in the model are computed using the measured and calculated values. The following are measured:

- Inlet and outlet water temperature;
- Electricity demand (kW) used to heat the water over the period;
- Volume of water used by the occupants of the change house.

The above data were recorded at 5 minute intervals. These measured values were then converted from 5 minute to daily values. The daily electricity data was then plotted against the thermal energy calculated by using the relationship;

$Q = mc\Delta\theta$ [kWh] .... (2)

Where;

Q is the thermal energy,

m is the mass of the water used in kg,

c is specific heat capacity of water and

$\Delta\theta$ is the change in temperature of the water used by the occupants.

The result of the daily thermal and electric energy is shown in Columns 2 and 3 of Table 1. The uncertainty in the above model is determined as follows:

Table 1: Daily thermal and electric energy

	Daily Q (kWh)	Daily E (kWh)	Model Daily E (kWh)	%error
Day 1	14 021	37	37	-1%
Day 2	15 865	41	41	-2%
Day 3	17 332	41	44	7%
Day 4	16 556	42	42	0%
Day 5	16 764	42	43	1%
Day 6	11 816	32	32	-1%
Day 7	1 830	10	11	16%
Day 8	16 844	37	43	15%
Day 9	16 698	41	42	3%
Day 10	14 558	42	38	-9%
Day 11	16 341	42	42	0%
Day 12	15 139	42	39	-8%
Day 13	14 170	41	37	-11%
Day 14	1 542	9	11	20%
Day 15	17 613	38	44	17%
Day 16	17 321	42	44	5%
Day 17	17 517	42	44	5%
Day 18	17 307	41	44	5%
Day 19	15 762	54	40	-25%
Day 20	12 880	33	34	3%
SUM	287 877	750	751	
AVERAGE	14 394	37	38	

1) *Mean* $\bar{Y}$

$$\bar{Y} = \frac{\sum Y_i^2}{n} = \frac{750}{20} = 37.5\ kWh$$

2) *Variance* S^2

$$S^2 = \frac{\sum(Y_i - \bar{Y})^2}{n-1} = \frac{2118.60}{20-1} = 111.5\ kWh$$

3) *Standard Deviation* s

$$s = \sqrt{S^2} = \sqrt{111.5} = 10.6kWh$$

4) *Standard Error SE*

$$SE = \frac{s}{n} = \frac{10.6\ kWh}{20} = 0.53$$

5) *Value* R^2

$$R^2 = \frac{\sum(\hat{Y}_i - \bar{Y})^2}{\sum(Y_i - \bar{Y})^2} = \frac{1799.13}{2118.60} = 0.85$$

6) *Mean Bias Error* (MBE)

$$MBE = \frac{\sum(\hat{Y}_i - \bar{Y})^2}{n} = \frac{0.82}{20} = 4.1\%$$

7) *Root Mean Square Error* $(RMSE)$

$$RMSE = \sqrt{\frac{\sum(\hat{Y}_i - Y_i)^2}{n - P - 1}} = 4.3$$

8) *Coefficient of Variation of Root Mean Square Error* (CV)

$$CV(RMSE) = \frac{RMSE}{\bar{Y}} = \frac{4.3}{37} = 11.6\%$$

From the statistical tables, t-values for 20 entries is 2.09, given that the confidence level expected is 95%, the precision of the model is calculated as follows:

9) *Absolute Precision:*

$$t * SE = 2.09 * 0.53 = 1.11$$

10) *Relative Precision:*

$$\frac{t * SE}{\bar{Y}} = 0.029$$

The precision is a measure of the expectation. The reported values in every saving reported in M&V must carry the accuracy or precision level in the values being reported. To be complete, the mean value of the daily electric data in the above example must read 95% confidence that the true mean-daily electric energy consumption lies in the range between 36.4 and 38.6 i.e. there is 95% confidence that the mean value of the daily energy consumption for the 20 day period is 37.5±2.9%.

VI. DISCUSSION

It was shown that for an energy model to be accurate enough, it must meet the IPMVP criterion which includes R^2 square value of ≥ 75%, CV (RMSE) of ±15 and MBE of ±5 among others. Case studies on the heating, ventilation and air conditioning (HVAC) system show that a model can meet the R^2 value criteria but not the CV and MBEs. Therefore, for a model to be deemed accurate and correct enough, other IPMVP accuracy criteria should be applied.

Power due to the harmonic component does not contribute to energy savings when a retrofit is used to replace an existing technology that is less energy efficient [2]. Emanuel indicated this in his book [3]. This distortion power, also does not contribute to energy saving. Moreover, this power may lead to the over/under reporting of power measurements which in turn result in incorrect energy calculations. This can have various consequences in energy efficiency projects where the energy (MWh) or the demand (MW) savings reported has a monetary value.

Energy savings should be reported to a certain level of accuracy. Measured active power quantities are estimates of the expected values. Therefore reported energy values should include a certain level of accuracy/precision i.e. the likelihood that reported energy values (or MW values) fall within a certain range since there is no certainty that an exact value will be obtained if the measurements are repeated. Reporting energy values (i.e. savings) in M&V can be become expensive depending on the nature and accuracy level to be reported. This is so as a designer will have to consider factors like metering selection, methodology, sample size etc. and the cost of doing this should be factored into the budget at the initial design stage.

For a multifaceted energy efficiency intervention, uncertainty and accuracy calculations will result in extremely complex mathematical calculations, a larger budget and more time spent. Different criteria regarding confidence and precision levels apply, depending on applications and what is acceptable to stake holders. From the international view point, the confidence and precision levels differ depending on application and the standard being applied [4, 5, 6]. No requirement was set by the IPMVP [1, 5].

VII. CONCLUSION

The paper discussed the need and methods for reporting energy savings more accurately. To comply with the IPMVP principles, energy savings reported should include the accuracy level of the values being reported. Error analysis, methods of quantifying the uncertainties in energy models presented above and applicable standard can be applied when energy savings are to be reported.

Although, more time and funds are needed when error analysis is to be done for energy projects, it might be worth the effort. Using the correct sample size reduces sampling errors, using the correct metering equipment improves the confidence levels and modelling errors are reduced by choosing the correct energy governing parameter as the independent variable and checking for the variation with the dependent variables i.e. the energy use.

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