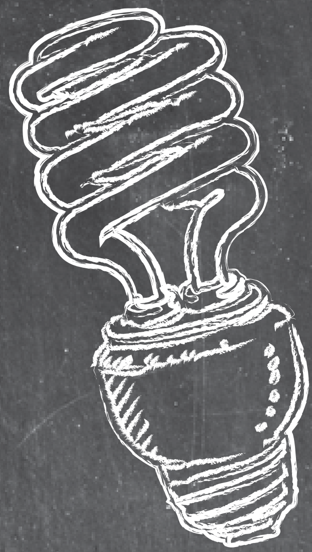
Optimal Metering Plan of Measurement and Verification for energy-efficient lighting Projects



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The Centre for New Energy Systems in the Department of Electrical, Electronic and Computer Engineering devised two models to minimise the metering costs of the measurement and verification of energy-efficient lighting projects. Both models proved to be useful, reliable and flexible. They imply the potential to minimise metering costs, while maintaining expected accuracy in the measurement and verification of other energy-efficiency projects.

In order to evaluate the impact of an energy-efficient (EE) project, the reduction in energy consumption must be determined. Measurement and verification (M&V) is the process of measuring and verifying energy and cost savings due to the implementation of energy conservation measures.

Independent M&V inspection bodies are appointed to evaluate the impact of EE projects. The key objective of the M&V teams is to provide unbiased and reliable information on energy and cost savings to a certain degree of accuracy for the EE projects. The accuracy requirements are typically expressed in terms of precision and confidence, where precision is an assessment of the error margin of the final estimate, and confidence is the likelihood that the sampling results in an estimate within a certain range of the true value. In most M&V projects, the degree of accuracy is regarded as a good way to achieve a minimum requirement of 90% confidence within 10% precision (known as the 90/10 criterion).

There are many M&V guidelines that provide metering and sampling methodologies to achieve the 90/10 criterion. According to these general metering and sampling methodologies, M&V professionals can design specific metering plans for any project. There are usually two components in the metering plan. Firstly, an initial sample size is decided on in order to ensure the measurements can be made in stochastically representative ways, and secondly, specific metering devices and measuring points are recommended and the metering costs are evaluated accordingly.

Cost is an important issue to consider in any M&V metering plan. The average annual M&V costs should be less than 10% of the verified average annual cost savings. It is thus of great interest that the desired accuracy with the lowest metering costs is achieved. Research conducted in this regard proposed a metering cost minimisation model for M&V lighting projects. For a typical M&V lighting project, the entire lighting population was subdivided into different groups according to the uncertainties of the daily energy consumption of the bulbs. By using a proposed optimisation model, the overall accuracy of the project could be maintained by sacrificing the confidence/precision criteria of the groups with high uncertainty, while improving the accuracy in the groups with low uncertainty. The metering costs were then minimised by optimising the sample size of each group. The optimal sample sizes were calculated by the specific confidence and precision levels in each group. The optimal solutions showed that the proposed model largely reduced the metering costs of the sampling, while still maintaining the accuracy requirements of the project.

Lighting characteristics and classification

Lighting characteristics

According to Mills (2002), lighting consumes more than 2000 TWh of electricity globally, which corresponds to about 1 800 million metric tons of carbon emissions per year. Lighting harbours a great potential for energy savings and carbon emission reductions. Energy-efficient lighting can be implemented by either reducing the input wattage or the burning time of the bulb. The wattage and burning hours of the bulbs should therefore be identified, or the energy consumed by the bulbs directly measured. The required metering efforts can be determined by the uncertainties of the metering targets.

Lighting classification

In order to quantify the power and energy savings, measurements are required to characterise the daily energy consumption of the bulbs involved. In practice, the budget for metering is usually limited. Therefore, to achieve the required accuracy with the minimal metering costs, it is wise to perform different metering efforts for different uncertainties of the metering targets. Uncertainties can be quantified by the coefficients of variance (CV), which are defined as the standard deviation of the metering records divided by the mean. The CV value is between zero and one. If the CV is close to zero, it indicates that the uncertainty of measurement is small. If the CV is close to one, the monitored parameter has a large uncertainty. A higher CV indicates more metering efforts, given a certain accuracy requirement.

The bulb population involved in an M&V project can be classified into groups in terms of CV values. According to the sample size calculation formula, when a CV is assigned to each group, the sample size is determined by the desired precision and the confidence level.

Evidently, more metering efforts are required to achieve a high accuracy level for the group with a high CV value than for the group with a low CV value. If the confidence/precision requirements are sacrificed in the group with a high CV and the accuracy requirements are improved in the group with a small CV value,

Table 1: Details of the EE lighting Project 1

Existing lighting system		Proposed technologies		Operating schedule	Quantity
Type	Wattage	Type	Wattage		
Halogen downlighters	60 W	LED	8 W	0:00–24:00	15 000
Incan-descent	100 W	CFL	20 W	Based on occupancy	5 000
Sampling target	Average daily energy consumption per bulb after the implementation				
Accuracy requirement	90/10 criterion				

Table 2: Initial values of the EE lighting Project 1

Parameters	Group I	Group II
Meter installation costs (R)	a_1=500	a_2=1 000
Maintenance costs (R)	b_1=500	b_2=1 000
Unit price of meter (R)	c_1=500	c_2=5 000
CV values	cv_1=0.15	cv_2=0.5
Estimated mean	E_1=0.19	E_2=0.12
Population size	N_1=15 000	N_2=5 000

then the accuracy requirements of the overall project may still be maintained and the metering costs can be minimised accordingly.

The metering cost minimisation model

In order to calculate the specified confidence and precision levels for each group, a metering cost optimisation model was built.

The proposed optimal metering cost model was adopted to design the metering plan for the first year for two specific M&V energy-efficient lighting projects. Results showed that the model could be used for EE lighting projects with different groups.

Metering cost minimisation for the lighting project with two groups

A number of 20 000 energy-efficient bulbs were installed at a Pretoria hospital. The project aimed to reduce the lighting load in the hospital. An energy audit was conducted to gather the detailed information to help design the metering plan. Details of the project are provided in Table 1.

In order to obtain reliable results of the claimed power and energy savings for this project, the sampling results of the key parameters of the project had to satisfy the 90/10 criterion.

In addition, the hospital expected minimal metering costs for the savings quantification of the overall project. The bulbs could be classified into two groups according to their different operating schedules. It can be assumed that the CV of the sampling target in Group I was under 0.15, since both the rated power and the operating schedule were known. The CV in Group II was assumed to be 0.5.

To calculate the metering costs, the initial values are listed in Table 2, where N_i is the lighting population in the i-th group, and E_i is the estimated sample mean, which is the estimated daily energy consumption at post-implementation stage in the i-th group. After the retrofitting, the

8 W light-emitting diodes (LEDs) were burning 24 hours per day. Based on the known power and burning hours, the estimation of E_1=0.19 kWh with a low CV value as 0.15 could be obtained. However, for the 20 W compact fluorescent lamps (CFLs), the daily burning hours are unknown. An estimation of E_2=0.12 can be made on the assumption that the CFLs were burning six hours per day with a high CV value of 0.5.

Before solving the optimisation problem, the metering costs for the desired sampling accuracy without optimisation were calculated as a benchmark for comparison purposes. Without this optimisation idea, the 90/10 criterion is usually applied to each group.

Table 3: Metering costs without optimisation of Project 1

Parameters	Group I	Group II	Overall
Confidence	90%	90%	95.09%
Precision	10%	10%	9.45%
Meter number	7	67	74
Metering costs (R)	14 000	469 000	483 000

Table 4: Optimal metering cost for Project 1

Parameters	Group I	Group II	Overall
Confidence	89.20%	56.50%	90.23%
Precision	7.77%	20.55%	9.69%
Meter number	10	4	14
Metering costs (R)	20 000	28 000	48 000

Table 3 shows that the overall confidence and precision levels are 95.09% and 9.45%, respectively, given that both groups achieve the 90/10 criterion. For the sampling, if all the bulbs are classified into only one group, a worst possible CV value of 0.5 can be used for the sample size calculation. The obtained sample size is 67, with a metering cost of R469 000, given that the more expensive meters have to be used when the CV is high. For one of the groups' solutions, the 90/10 criterion is achieved without spending unnecessary money on metering to achieve an overall accuracy level that is better than the 90/10 criterion. The results provided in Table 3 indicate that to achieve the 90/10 criterion, it may not be necessary for each group to satisfy the 90/10 criterion. Therefore, different confidence and precision levels can be assigned to individual groups, while the combination of the confidence and precision levels in the entire project still maintains the 90/10 criterion.

The optimal results are provided in Table 4. Compared to the metering costs in Table 3, it shows that although the metering costs for Group I increase, the metering costs for Group II decrease sharply. Furthermore, significant metering cost savings are achieved and the 90/10 criterion is met.

Metering cost minimisation for the lighting project with four groups

A number of 24 000 energy-efficient bulbs were installed at a Pretoria office. The project aimed to reduce the lighting load in the office through the new lighting luminaries. An energy audit was conducted to gather the detailed information to help design the sampling plan. Details of the project are provided in Table 5.

An energy audit was conducted to determine whether the introduction of new lighting luminaries would reduce the lighting load at a city hospital.

The bulbs without control devices had fixed operating schedules. Others were controlled by EE devices, such as daylight dim and motion sensors. Therefore, the bulbs could be classified into four groups on the different levels of uncertainties of the wattage and operating schedules. For instance, for the bulbs with fixed wattage and operating schedules, a small CV of 0.05 for the daily energy consumption of the bulbs could be assigned. For the bulbs with daylight dim control and a fixed operating schedule, only the wattage variation contributed to the uncertainty of the daily energy consumption.

Since working power only has two states, it can be expected that a CV value of 0.15 is relevant for the daily energy consumption for these lamps. For the bulbs with motion sensor control, the uncertainty of the daily energy consumption of the bulbs came from the unknown operating schedules. A CV of 0.35 could be assigned to these bulbs.

For the bulbs with two control strategies, a default CV value of 0.5 will apply, given that both the power and operating schedules are unknown. In Table 6, initial values such as the installation costs, maintenance costs, meter unit price, CV values, and estimated sample mean for the sampling target and the population sizes in each group are provided.

Table 5: Details of the energy-efficient lighting Project 2

Existing lighting system		Proposed technologies		Operating schedule	Quantity
Type	Wattage	Type	Wattage		
Halogen down-lighters	60 W	LED	8 W	8:00–16:00	10 000
Incandescent	100 W	CFL	20 W	Daylight dim control (two states: half power and full power), 8:00–16:00	3 000
Incandescent	60 W	CFL	23 W	Motion sensor control	6 000
Incandescent	60 W	CFL	18 W	Daylight dim control and motion sensor control	5 000
Sampling target	Average daily energy consumption per bulb after the implementation				
Accuracy requirement	90/10 criterion				

Table 6: Initial values for Project 2

Parameters	Group I	Group II	Group III	Group IV
Meter installation costs (R)	a_1=500	a_2=500	a_3=1000	a_4=1000
Maintenance costs (R)	b_1=200	b_2=300	b_3=500	b_4=1000
Unit price of meter (R)	c_1=300	c_2=500	c_3=1000	c_4=5000
CV values	cv_1=0.05	cv_2=0.15	cv_3=0.35	cv_4=0.50
Estimated mean	E_1=0.19	E_2=0.12	E_3=0.14	E_4=0.11
Population size	N_1=10 000	N_2=3 000	N_3=6 000	N_4=5 000

Table 7: Metering costs without optimisation for Project 2

Parameters	Group I	Group II	Group III	Group IV	Overall
Confidence	90%	90%	90%	90%	99.59%
Precision	10%	10%	10%	10%	9.02%
Meter number	1	7	33	67	108
Metering costs (R)	1 000	9 100	82 500	469 000	561 600

Table 8: Optimal metering costs for Project 2

Parameters	Group I	Group II	Group III	Group IV	Overall
Confidence	96.45%	52.83%	52.00%	52.00%	89.43%
Precision	6.51%	9.47%	10.95%	20.92%	9.31%
Meter number	3	2	6	3	14
Metering costs (R)	3 000	2 600	15 000	21 000	41 600

Table 9: Metering costs without optimisation over two years

Parameters	Year 1	Year 2	Overall
Confidence	90%	90%	97.61%
Precision	10%	10%	10%
Meter number	68	67	68
Metering costs (R)	102 000	13 900	115 900

Table 10: Optimal metering costs 1

Parameters	Year 1	Year 2	Overall
Confidence	80.02%	69.80%	90%
Precision	9.94%	10.04%	9.91%
Meter number	42	27	42
Metering costs (R)	63 000	12 900	75 900

In tables 7 and 8, metering costs and sample sizes with or without optimisation are also given. By comparing tables 7 and 8, it is clear that by applying the metering cost minimisation model, overall metering costs are minimised and the overall accuracy requirements are maintained.

Long-term optimal metering plan

In order to capture the sustainability of the achieved savings, a long-term performance assessment is conducted for the lighting M&V project to continuously report the savings in five or up to ten years after the implementation. When considering the long-term metering plan, the proposed metering cost minimisation model can be generalised to achieve minimal metering costs for a project over a certain number of years.

The preliminary results of an optimal metering plan over two years for one group are provided as an example to illustrate the ideas of designing the optimal metering plan.

Suppose the project window is 10 years and the required reporting interval is two years. This means that during the reporting years, the 90/10 criterion must be upheld. For the first reporting interval (after two years), an accuracy requirement for an M&V EE lighting project is to satisfy the 90/10 criterion over two years of the achieved savings.

Metering cost minimisation over two years

The metering cost minimisation model is generalised and applied to the optimal metering plan design over two years. Assume that there are 10 000 CFLs installed in the first year and only 6 000 bulbs survive in the second year. The CV and the estimated sample mean do not change over the two years.

Table 9 shows the metering costs without the optimisation. The number of required meters in the first year is 68, and 67 for the second year because of the decrease in the lighting population. In addition, all these meters are purchased in the

Table 11: Optimal metering costs 2

Parameters	Year 1	Year 2	Overall
Confidence	74.89%	83.78%	90%
Precision	10.01%	9.91%	9.95%
Meter number	33	50	50
Metering costs (R)	49 500	32 100	81 600

Table 12: Optimal metering costs 3

Parameters	Year 1	Year 2	Overall
Confidence	57.91%	93.65%	90%
Precision	6.70%	15.43%	9.99%
Meter number	36	36	36
Metering costs (R)	54 000	7 200	61 200

first year, and only maintenance costs are required in the second year. If the 90/10 criterion is achieved in each year, the overall accuracy is very high and a large amount of money is spent without awareness.

In Table 10, 42 meters are installed in the first year and a higher accuracy is achieved. To guarantee the 90/10 criterion over the two years, only 27 meters are required in the second year. Compared to the results shown in Table 9, additional meter removal costs are spent although metering costs are less.

Table 11 indicates that to maintain the 90/10 criterion over the two years, 33 meters are required for the first year and 50 for the second year. However, since more meters are installed in the second year to achieve a higher accuracy, the 90/10 criterion over the two years is still maintained.

In Table 12, the number of meters remains unchanged over the two years, while the overall 90/10 criterion over the two years is maintained. Minimal metering costs are also incurred, compared to the results in tables 10 and 11.

Application

Both the models developed imply the potential to minimise metering costs while maintaining expected accuracy in other M&V energy-efficient lighting projects. These models can also help with the metering plan for a project with different numbers of groups. In addition, when long-term metering plans are designed by the proposed model, the project developer will be able to make the optimal arrangement of the budget more easily. The proposed optimisation models can also be applied to projects with accuracy requirements other than the 90/10 criterion.

References

Mills, E. 2002. Why we're here: The $230-billion global lighting energy bill. *Proceedings of the Right Light 5, Nice, France, 2002.*

The University of Pretoria houses the South African National Energy Research Institute (SANERI) National Hub for Energy Efficiency and Demand-side Management.

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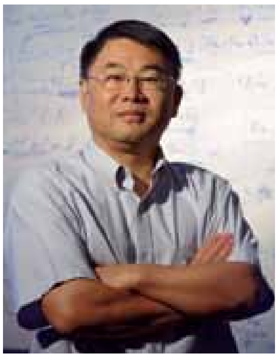

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