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THEORETICAL FRAMEWORK FOR A PROTOTYPE MEASUREMENT AND VERIFICATION (M&V) METER THAT SUPPORTS BASIC M&V 2.0 PRINCIPLES

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***ABSTRACT*:**

A theoretical framework is presented for a prototype Measurement and Verification (M&V) meter. The development of the framework was guided by the regulations, standards, and operating procedures applied in South Africa. The possibility of its further development for other M&V markets, or for more advanced M&V methods than presented here, is not excluded. Longstanding fundamental considerations associated with the classical approach toward M&V, such as process transparency and data integrity, are provided for in the framework as are newer considerations associated with the more recent approaches of M&V 2.0, such as data granularity and real time reporting. The equipment of the industry standard data acquisition path is combined in a single node, and the extent of the quality control path is reduced to one piece of equipment. The framework is supported by the development of Simulink models that provide some basic functionality. Simulation results show that the models perform their intended functions. The models will be interconnected appropriately during prototyping in order to function as the sub-models of a larger model, and additional sub-models will be developed for more complex functions. An introductory overview of the existing and future models is presented. Details will be presented at a more advanced stage of development.

Keywords*: Advanced measurement and verification, M&V meter, Quality control path*

INTRODUCTION

Measurement and Verification (M&V) in South Africa is advanced in its development, having benefited from focused industrial and academic participation in Eskom's demand-side management program, and has been active since the early 2000s [1]. In the period from 2006 to 2013, and among other advancements, M&V calculation processes and reporting procedures were established, the South African National Standard (SANS) 50010 [2] was developed, and a tax incentive scheme for energy efficiency was introduced [3]. Accreditation through the South African National Accreditation System (SANAS) [4] became a prerequisite for performing M&V services for the purposes of consideration in the tax incentive scheme. The South African National Energy Development Institute (SANEDI) took on the role of overseeing the issued savings certificates [3]. Further advancement in the field of M&V depends on developments in the respective areas of the multidisciplinary environment that M&V is practiced in. One of these areas is the technical discipline concerned with measurements and data. Scholarly research in the field of M&V focuses on developments toward M&V 2.0, which is characterized by dense or granular datasets, advanced algorithmic processing, and real time or near real time reporting [5]. The research effort is directed toward the development of advanced mathematical modeling techniques for the establishment of the baseline, and for the automatic detection and handling of non-routine events [6], [7], [8], [9], [10]. It is also directed at the development of technologies for M&V 2.0, which mainly include cloud computing platforms and software applications that need to be supplied with data from advanced metering infrastructure (AMI) systems [9], [11]. The developed technology is proprietary in many cases, and this leads to the contentious issue of open technical documentation for the sake of transparency, which is one of several major considerations in M&V [12] [20] [21], [22], [23]. In the South African context, M&V data servers are supplied with data that follow a path from the physical point of measurement through transducers, data loggers, and data communication channels, all of which are generally not under the direct management of the M&V professional due to practical or contractual limitations, or cost considerations. To ensure the integrity of the data that arrives at the M&V server, the entire data acquisition chain leading up to the server needs to meet the requirements of a quality control path (QCP) that forms part of a quality management plan (QMP) [13]. The QMP forms part of a larger management system that stands under SANAS accreditation. With a specific focus on M&V in South Africa, but not limited to it, and associating the work with the development of M&V 2.0 technology, a theoretical framework for a prototype M&V meter is presented. Although not discussed here in detail, the framework is supported by Simulink models that were developed to show the feasibility of the practical implementation of the basic requirements of the framework.

M&V IN SOUTH AFRICA

M&V in South Africa is considered in terms of 1) the environment within which M&V is practiced, which includes the regulatory environment, the standardization environment, and the operational environment, and 2) the technical approach toward conducting M&V, which includes matters relating to measurement equipment, data communications, data processing calculations and algorithms, data storage, etc.

A. M&V Environment

The regulatory environment within which M&V is practiced in South Africa, is governed by the regulations concerning sections 12i and 12l of the enabling Act, which is the Income Tax Act of 1962. The 12l regulation was gazetted in December 2013 [3]. Standardization is provided by the South African National Standard (SANS) 50010, which was drafted based on the International Performance Measurement and Verification Protocol (IPMVP). The SANS 50010 was published in September 2011 [2]. Operational processes and procedures developed from the IPMVP, which was adopted as the de facto M&V protocol when it was included in Eskom's guideline on energy efficiency and demand-side management projects in 2005 [14]. To facilitate the M&V of energy savings for the purposes of the tax incentive scheme, accreditation by the SANAS against the relevant technical requirements is a prerequisite [4]. The SANEDI oversees the savings certificates that are issued for the purposes of the tax incentive scheme [3]. The result is that the M&V environment in South Africa is very well defined and highly regulated. Therefore, formal M&V cannot be practiced without using the IPMVP as the basic guideline, and without adhering to the requirements contained in the regulations, the standard, and technical document [5].

B. Technical Approach

The technical approach toward M&V varies in complexity, depending among other things on the nature of the energy saving measure and the expected cost savings [15, 16]. For projects requiring technically advanced measurement systems, a QCP, such as the one shown in Fig. 1, is used [13]. These advanced measurement systems include instrumentation transformers and transducers at the physical point of measurement, data loggers, data communications equipment, data servers, databases, etc, all collectively referred to as an advanced meter reading (AMR) system (alternatively AMI). The purpose of the QCP is to verify that the sections of the data path that are not under the direct management of the M&V professional and operate uncorrupted. This ensures the integrity of the data that reaches the M&V professional.

METER ARCHITECTURE

Fig. 2 shows the meter architecture. The main functions of the meter are grouped in the main modules. Main modules contain sub-modules and/or executable tasks. The architecture is layered and each layer is flat and modular, with increasing detail from the outside inwards. A configuration file is associated with each main module. The configuration files hold values for variables defined for the executable tasks. Interpretive flow is from left to right, which is also the dominant direction of algorithmic flow.

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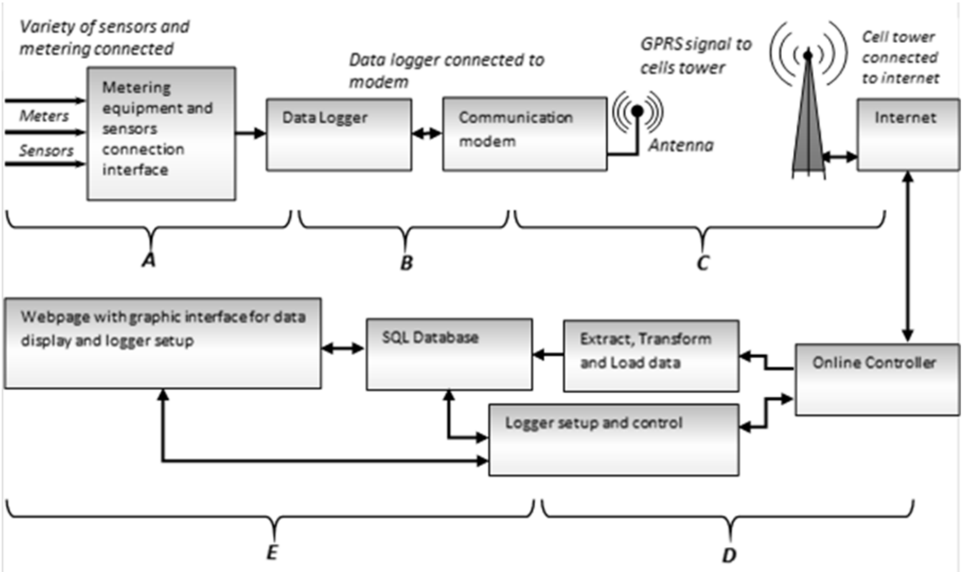

Fig. 1 Metering and AMR system layout with QCP sections A to E

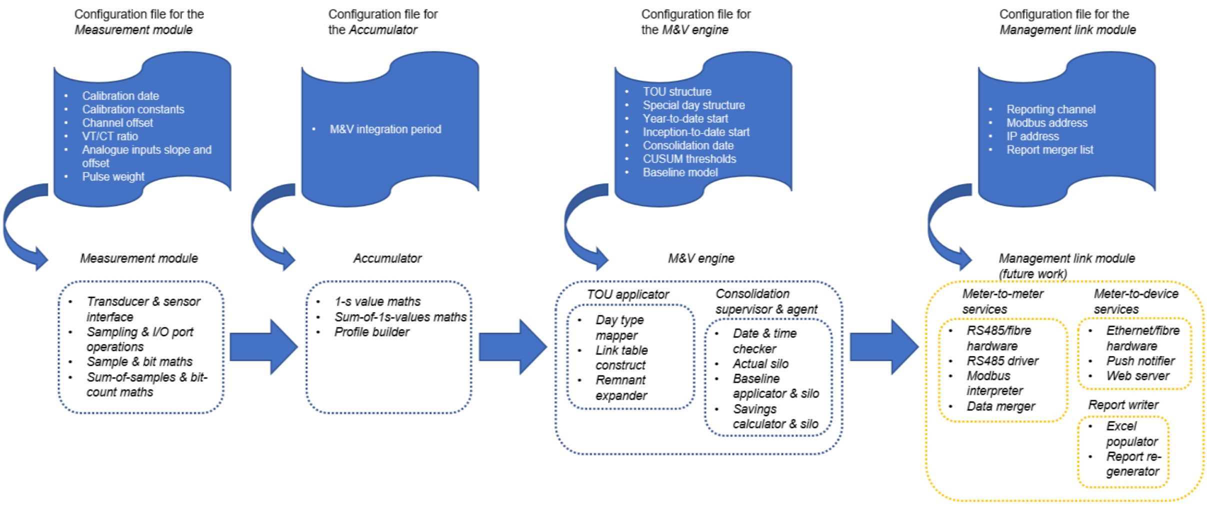

Fig. 2 Meter architecture

B. Accumulator

The executable tasks of the accumulator calculate the 1 second values from the measurement module into values for the M&V integration period (v. Fig. 2), which is set in the configuration file. Shorter M&V integration periods give denser or more granular datasets, while longer periods give less dense or less granular datasets. The default value is 30 minutes.

C. M&V Engine

The executable tasks of the two sub-modules of the M&V engine parse the 30-minute values from the accumulator into reporting values. The reporting values are calculated against a reporting construct that was developed for South African reporting protocols [19].

D. Management Link Module

The purpose of the management link module is to 1) manage communications between meters that are locally connected to each other; 2) generate managerial reports in spreadsheet format and of small size, ideally in the kilobyte range, and 3) manage web sessions between master meters and remote devices such as laptop computers or cellular telephones. The purpose of 3.a) is accessing and/or downloading reports stored locally in on-board memory; 3.b) applying contractual remedies such as marking entries of a data profile as “condonable”, and 3.c) approving such remedies. The reporting construct defines the timespans for which reporting figures are calculated.It also defines set time markers for reporting purposes, data checks and notifications.

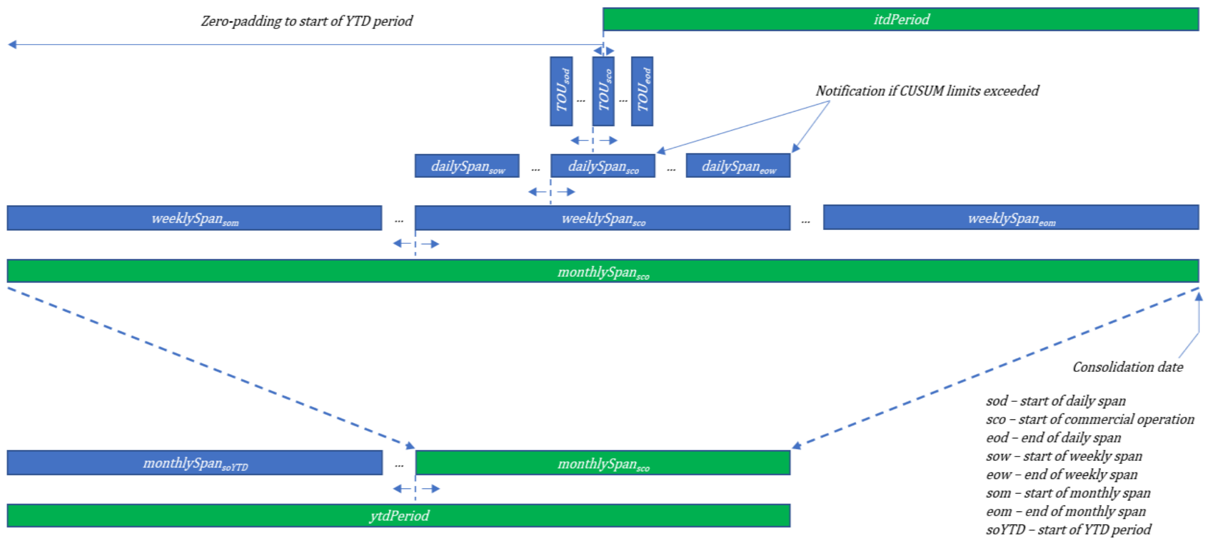

Fig. 3 Reporting construct

REPORTING CONSTRUCTION

Schematically the reporting construct is shown in Fig. 3. The reporting construct is aligned to the standard reporting procedures developed for the national electrical utility company Eskom [18, 19]. The basic premise is to start with a fundamental period or timespan, and to build up larger timespans that are multiples thereof, over which energy savings and other performance indicators are calculated and reported. The fundamental timespan is the M&V integration period (v. Fig. 2), for which the default value is 30 minutes. This is a convenient choice that is equal to the shortest time-of-use (TOU) period defined for differentiated tariffs [18], and also because all TOU periods and other defined timespans can be expressed as multiples of 30 minutes. The start date and time of commercial operation is accurately presented to within +/- 15 minutes, and can fall anywhere in the larger timespans, viz. TOU periods, daily timespans, weekly timespans, monthly timespans, and year-to-date (YTD) timespans, in which case appropriate zero padding of data profiles is applied. CUSUM checks [17] and alarming occur at the end of daily spans. Reporting occurs at the end of monthly spans on the consolidation date (v. Fig. 3), and report values are calculated for the month, the YTD period, and the inception to date period. Generic iterative equations were developed to calculate the reporting values.

ITERATIVE EQUATIONS

Two types of array variables are defined, one for sums in the TOU periods of the day, sum(TOU), and one for averages, avg(TOU), where sum(TOUsod) is the sum for the TOU period at the start of the day, sum(TOUeod) is the sum for the TOU period at the end of the day, and the sequential subscripts in between indicate the same for the remainder of the TOU periods of the day. The elements of the sum-array are indexed with the letter l. The notation is the same for the averages-array.

$$SUM(TOU) = \{sum(TOU_{sod}), sum(TOU_2),\ \cdots,\ sum(TOU_l),\ \cdots,\ sum(TOU_{eod})\}$$

$$AVG(TOU) = \{avg(TOU_{sod}), avg(TOU_2),\ \cdots,\ avg(TOU_l),\ \cdots,\ avg(TOU_{eod})\}$$

The value of the lst element of the sums-array, $sum(TOU_l)$, is given by Eq. 1, where m runs over the number of indexed days in the calculation, starting at sD and ending at eD, and n runs over the number of indexed half hours of the TOU period, starting at sI and ending at eI.

$$sum(TOU_l) = \sum\nolimits_{m=sD}^{eD} \sum\nolimits_{n=sI}^{eI} dS_m \cdot dT_m \cdot val_{m,n} \cdot (1 - eH \cdot eM_{m,n}) \quad \ldots Eq.\ 1$$

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In the practical implementation Eq. 1 is nested in a larger iteration that discerns between the high demand season and the low demand season, as well as between day types (i.e. weekdays, Saturdays and Sundays) and TOU periods. The binary variables dS_m and dT_m in Eq. 1 respectively select zero or one depending on the demand season and the day type. The value of the exception marker binary variable $eM_{m,n}$ is set equal to one if contractual remedies apply, and is equal to zero otherwise. The exception handling binary variable eH is a global variable that is set equal to one or zero to either allow or disallow contractual remedies altogether, i.e. it is not an indexed variable that associates with data entries individually. The binary variables work together to either multiply the value $val_{m,n}$ by one or by zero, depending on whether or not the value should be included in the calculation. Using the same reasoning, the denominator k of the average calculation is given in Eq. 2, and the value for $avg(TOU)_l$ is given in Eq. 3.

$$k = \sum_{m=sD}^{eD} \sum_{n=sI}^{eI} dS_m \cdot dT_m \cdot (1 - eH \cdot eM_{m,n}) \quad \ldots Eq.\ 2$$

$$avg(TOU_l) = \frac{1}{k} \cdot sum(TOU_l) \quad \ldots Eq.\ 3$$

The equations are generic and are applied to the actual energy consumption profile, the adjusted baseline profile, and the savings profile. Calculations done in this manner are suited for implementation as combinational logic on a microcontroller, and will be used to regenerate reports due to contractual remedies or upon archival requests. In order to regenerate reports, certain data profiles need to be stored in memory. A computational model was developed to define the essential data profiles that need to be stored in memory, as well as the data format in which the profiles need to be stored for the efficient use of memory space.

COMPUTATIONAL MODEL

The computational model defines 1) three data profile types, namely “actual”, “baseline”, and “savings”; 2) the format of a data profile entry; 3) the primitive data types and an efficient storage structure for data profile entries. In 4) the calculation of 4.a), the adjusted baseline values for the half hours of the day are done by applying scaling operations to the actual consumption profile; 4.b) the savings profile, and in 5) the essential data profiles to be stored, which translates to the minimum amount of information to be kept on record without compromising on regulatory record keeping requirements.

A. Data Profile Type

The three data profile types are references to whether a data profile is for actual conditions (i.e. real and measurable), baseline conditions (i.e. abstract, but calculable), or whether it refers to the difference between these two types of profiles.

B. Format of a Data Profile Entry

The format of a data profile entry is shown in Table I. The maximum number of days supported by the day index is 1 826 which accommodates a five-year period with two leap years in it. The date format is year-month-day, i.e. the 31st of January 2000 would be stored as “2000/01/31”. Time is stored as hour-minute values and the forward-filling convention is used, meaning that the 30-minute period from 00:00 to 00:30 is stored as “00:00”, which simplifies date- and timestamping a great deal compared to backward-filling. The profile value is stored as a single precision floating point number. Day types are 1 to 7 for Monday to Sunday. The half hours of the day are marked from 0 to 47 under the column heading “indexed T”. The demand season for differentiated tariffs [18] are marked as either high or low. A second field for a single precision floating point number is provided under the column heading “auxiliary value”. The exception marker is a binary variable that is equal to zero if the data entry is valid, and equal to one otherwise. The data fields refer back to Eq. 1 and Eq. 2.

TABLE I
FORMAT OF A GENERIC DATA PROFILE ENTRY

Day index	Date	Time (forward filling)	Value	Day type	Indexed *T*	Demand season	Auxiliary value	Exception marker
0 to 1 826	yyyy/mm/dd	hh:mm	Single precision	1 to 7	0 to 47	High/Low	Single precision	Default = 0

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			floating point number				floating point number	

C. Primitive Data Types and Storage Structure

Only two primitive data types are used in the storage structure shown in Table II, namely nibbles and bytes. Bitwise operations for floating point numbers, combinations of nibbles, and binary coded decimal numbers for date- and timestamping, mask the stored numbers appropriately for the purpose of extracting the information from the respective fields. The benefit of this approach is that memory can be used much more efficiently compared to working with library-defined data types, albeit at the cost of increased complexity in the program code. Appropriate combinations of data fields as shown by the color coding in Table II, lead to a total number of 17 bytes per data entry, which results in a total number of 1 490 832 bytes for a data profile that spans five years.

TABLE II
PRIMITIVE DATA TYPES USED FOR A DATA PROFILE ENTRY

Field / Prim*	Day index	Date	Time (forward filling)	Value	Day type	Indexed *T*	Demand season	Auxiliary value	Exception marker
Nibble	3	3/1/2	2:2	8	1	2	1	8	1
Byte	**1.5**	3	2	4	**0.5**	1	**0.5**	4	**0.5**

**Primitive data type*

D. Adjustable Baseline and Savings Profile

From the actual values for the energy driver, the adjusted baseline is calculated with the stored baseline equation. Using daily aggregates for the adjusted baseline and the actual energy consumption, either offset scaling or factor scaling is applied for the purpose of determining the adjusted baseline profile and the savings profile, which is the industry standard when required to quantify impacts in the TOU periods of differentiated tariffs [18] in the absence of baseline data with high TOU specificity. The day-value of the adjusted baseline is applied over the 48 half hours of the day by either 1) appropriately adding the daily difference between the adjusted baseline and the actual energy consumption as an offset to the actual energy consumption profile, or 2) by appropriately multiplying the actual energy consumption profile by the quotient of the day-values of the adjusted baseline and the actual energy consumption. It follows that the savings profile is then calculated as the difference between the constructed profile for the adjusted baseline and the actual energy consumption profile. It also follows that the adjusted baseline profile and the savings profile do not need to be stored in memory.

E. Stored Data Profiles

The essential data profiles that need to be stored, which constitute the minimum amount of information necessary for the regeneration of reports, only include the values for the actual energy consumption and the actual values for the energy driver. The format of a stored data entry therefore becomes specific to actual values only, and the two fields for floating point numbers (v. Table I) are reserved for the values of the actual energy consumption and the actual values of the energy driver. With this approach the entire dataset required to keep record over a five-year period is 1 490 832 bytes (v. 6.3), using the primitive data types and the storage structure in Table II and the format for a data entry in Table I, and storing only the half-hourly values for the actual energy consumption and the actual half-hourly values for the energy driver.

SIMULINK MODELS

With reference to the meter architecture in Fig. 2, executable tasks are implemented in the form of Simulink models. Conceptually speaking, all the Simulink models together represent a real-time sequential logic implementation of the iterative equations, and execute collectively on the basis of the reporting construct and the computational model discussed above. This means that collectively the output of the Simulink models is equivalent to that which one expects from the combinational logic. While the combinational logic is suited for implementation on a microcontroller, the sequential logic is suited for implementation on a field programmable gate array. While the combinational logic is meant to regenerate reports from stored data profiles when needed, the sequential logic provided by the Simulink models are meant to generate first-time reports in real time.

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A. Current Status

The Simulink models exist as separate models at this time. Each model was tested individually for functionality with positive results in each case. The models will be interconnected appropriately during prototyping to form a larger model that represents the meter in its entirety, with further development as required. The detailed Simulink models and simulation results will be discussed when the prototype meter is under development. An introductory overview of the Simulink models is presented here for each of the modules and sub-modules in the meter architecture of Fig. 2.

B. Measurement Module

Simulink models were developed for 1) analog-to-digital conversion with a 16 -bit successive approximation register, 2) pulse counting, and 3) parsing analog-to-digital converted values and pulse counts into 1-second values.

C. Accumulator

Simulink models were developed that average and aggregate the 1-second values from the measurement module appropriately over 30-minute intervals. The 30-minute values are passed on to the M&V engine for further averaging and aggregation. Functionality to store the 30-minute values as data profiles in on-board memory will be developed during prototyping.

D. M&V Engine

For the *TOU applicator*, Simulink models were developed to 1) check and change the day type (weekday, Saturday or Sunday) if necessary, i.e. for special or alternative billing days in differentiated billing tariffs [18], and 2) for linking 30-minute values appropriately to TOU periods in differentiated billing tariffs [18]. Functionality to add remnant information to an entry of a data profile before storing it in on-board memory, will be developed during prototyping. Remnant information includes the changed day type (if applicable), the TOU period that the entry is linked to, and whether or not the entry should be considered for reporting (i.e. whether or not the entry should be handled as an exception, which might be provided contractually under terms such as “condonable days”, etc). For the *consolidation supervisor & agent*, Simulink models were developed to 1) check the date and time against the *consolidation date* (v. Fig. 2), which is an array variable of 12 elements for which values are assigned in the configuration file, and for which the default values are the ends of the 12 calendar months; 2) update the running averages and aggregates of the actual energy consumption for the various reporting periods of the reporting construct; 3) apply the baseline model and update the running averages and aggregates of the adjusted baseline energy consumption for the various reporting periods of the reporting construct; 4) calculate the savings and update the running averages and aggregates for the various reporting periods of the reporting construct, and 5) check the savings against CUSUM thresholds [17] that are set in the configuration file.

E. Management Link Module

The development of Simulink models and microcontroller functions will be done during prototyping.

CONCLUSION

The objectives of the research were to 1) develop a theoretical framework for a prototype M&V meter that meets South African requirements, and which 2) supports some basic principles of M&V 2.0. These objectives were met successfully. The meter architecture was established, which separates the M&V process into functionally manageable blocks. The reporting construct was developed and iterative equations were defined for the required calculations. The computational model was developed in which 1) the types of data profiles are defined as well as the format of the data entries and an efficient storage structure using primitive data types; 2) the calculation of the adjusted baseline and scaling techniques for TOU applications, as well as the calculation of the savings profile, are described, and 3) the minimum requirements for the types and instances of profiles to be stored in on-board memory are determined. Simulink models were developed to implement the iterative equations as sequential logic circuits and to provide the basic functionality required by the reporting construct. The work serves as the basis for the development of a prototype M&V meter and illustrates the feasibility of such a meter. The research was done with the requirements of the South African M&V market in mind. The suitability of such a meter will ultimately need to be evaluated through use in real projects in South Africa, but this does not necessarily exclude wider application.

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REFERENCES

1. Xia, X. 2012. *EEDSM, M&V in South Africa.* Presentation prepared for the University of Pretoria.
2. SABS. 2018. *SANS 50010:2018 Measurement and verification of energy and demand savings*. South Africa: South African Bureau of Standards.
3. Government gazette No 37136. December 2013. *Regulations in terms of section 12l of the Income Tax Act, 1962, on the allowance for energy efficiency savings*. South Africa: Parliament.
4. SANAS. 2019. *Technical requirements for the application of ISO/IEC 17020:2012 in the assessment of Inspection Bodies' application of SANS 50010:2018 measurement and verification of energy savings*. South Africa: South African National Accreditation System.
5. E. Franconi, E., M. Gee, M. Goldberg, J. Granderson, T. Guiterman, M. Li, and B. A. Smith, 2017. *The status and promise of advanced M&V: an overview of M&V 2.0 methods, tools, and applications*. Unites States: N. p. Web. Doi:10.2172/1350974.
6. C. V. Gallagher, P., O'Donovan, K. Leahy, K. Bruton, and D. T. J. O'Sullivan, *From M&V to M&T: An artificial intelligence-based framework for real-time performance verification of demand-side energy savings*. International Conference on Smart Energy Systems and Technologies (SEST), 2018, pp. 1-6, doi: 10.1109/SEST.2018.8495711.
7. H. Carstens, X. Xia, and S. Yadavalli, *Bayesian Energy Measurement and Verification Analysis*. Energies. 2018; vol. 11, no. 2, pp. 380, https://doi.org/10.3390/en11020380.
8. J. Maritz, F. Lubbe, and L. Lagrange, *A Practical Guide to Gaussian Process Regression for Energy Measurement and Verification within the Bayesian Framework*. Energies. 2018; vol. 11, no 4, pp. 935, https://doi.org/10.3390/en11040935.
9. C. V. Gallagher, K. Leahy, P. O'Donovan, K. Bruton, and D. T. J. O'Sullivan, 2019. *IntelliMaV: A cloud computing measurement and verification 2.0 application for automated, near real-time energy savings quantification and performance deviation detection*. Energy and Buildings, vol. 185, 2019, pp. 26–38, ISSN 0378-7788, https://doi.org/10.1016/j.enbuild.2018.12.034.
10. C. V. Gallagher, K. Bruton, K. Leahy, D. T. J. O'Sullivan, 2018. *The suitability of machine learning to minimise uncertainty in the measurement and verification of energy savings*. Energy and Buildings, vol. 158, 2018, pp. 647–655, ISSN 0378-7788, https://doi.org/10.1016/j.enbuild.2017.10.041.
11. P. Memari, S. S. Mohammadi, and S. F. Ghaderi, *Cloud Platform Real-Time Measurement and Verification Procedure for Energy Efficiency of Washing Machines*. 2018 Federated Conference on Computer Science and Information Systems (FedCSIS), 2018, pp. 697–700.
12. J. Granderson, and S. Fernandes, *The state of advanced measurement and verification technology and industry application*. The Electricity Journal., vol. 30, no. 8, 2017, pp. 8-16, ISSN 1040-6190, https://doi.org/10.1016/j.tej.2017.08.005.
13. J. J. Steyn, and M. E. Storm, *Managing meters and ensuring quality data*. MVCSA newsletter, 10 February 2021
14. Information published on the website of the Energy Valuation Organisation https://evo-world.org/en/?option=com_content&view= article&id=230&Itemid=1029&lang=pl
15. J. J. Steyn, and C. A. van der Merwe, *Why bother with SABS: 50 010: 2018 and IPMVP when considering that an ISO 50 015 exists?* MVCSA newsletter, 04 February 2021.

16. J. J. Steyn, 2021. *M&V; 'wrong'…, but correct?* MVCSA newsletter, 03 March 2021.
17. W. Booysen, J. F. Van Rensburg, and M. Kleingeld, 2014. *A holistic approach to presenting DSM project results*. 2014 International Conference on the Eleventh industrial and Commercial Use of Energy, 2014, pp. 1-8, doi: 10.1109/ICUE.2014.6904163.
18. Eskom. 2020. *Tariffs and charges booklet 2020/2021*. South Africa: state-owned power utility company.
19. H. J. Vermeulen, *Reporting protocols for performance assessment of demand side management projects.* 2011, Stellenbosch University. Version 1, revision 0, working document developed for Eskom
20. P. S. P. Eboule, B. Mokoena, and J. H. C. Pretorius, 2022. *Financial Investment Impacts in the Renewable Energy Sector: Case Study of a Micro-Grid PV System*. International Review of Electrical Engineering, vol. 17, no. 5, pp. 523–535, doi: 10.15866/iree.v17i5.22709
21. S. Abdurahman, and A. Moncef Krarti, Measurement and Verification Building Energy Prediction (MVBEP): An interpretable data-driven model development and analysis framework, Energy and Buildings, vol. 295, 2023.
22. S. Sukarti, M. F. Sulaima, A. F. Abdul Kadir, N. I. Zulkafli, M. L. Othman, and P. Dziwiński, 2025. Enhancing energy savings verification in industrial settings using deep learning and anomaly detection within the IPMVP framework. Energy and Buildings, 327, 115096. https://doi.org/10.1016/j.enbuild.2024.115096
23. T. Cerbelaud, B. Duplessis, and P. Stabat, Hybrid method for automatic fault detection and diagnosis in buildings with limited monitoring data, Energy and Buildings, vol. 352, 2026, 116648,ISSN 0378-7788,