A Review of the Code of Practice for Electricity Metering to Regulate Smart Metering and Small Scale Embedded Distributed Generation

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Abstract*— South Africa has a significant number of conventional energy meters installed particularly on residential customers. The use of conventional metering infrastructure causes loss of revenues due to high operational costs, billing errors and illegal use of energy on compromised meters. There is a need to review the effectiveness of the existing metering codes of practice in order to determine whether it will be able to offer regulation of smart metering that is fit for use on small scale embedded distributed generation. A comparative review of the metering codes of practice was conducted for Britain, Singapore, India and South Africa. The area of focus was accuracy, communication, cyber security, compliance, regulation of licensee, regulations to safeguard smart metering implementation and sustainability. The outcome of the study indicated gaps in the metering code of South Africa. It also highlighted the area of improvement in the South African codes of practice for electricity metering. It improvement will provide a firm, sustainable regulatory support that is key to successfully implementation smart metering, small scale embedded distributed generation and subsequently smart grid.

Keywords—smart metering, standards, codes, regulation, compliance, smart grid, energy and distributed energy.

I. INTRODUCTION

Metering is a very important tool that enables the grid operator to do revenue collection, energy planning and load balancing in the grid. Each country has its own metering code of practice that it uses to regulate metering systems that licensees use. This paper provides a sample review of metering code of practice used in both developed and developing countries. Furthermore, it identifies gaps and provides suggestions to improve the metering codes of practice used in South Africa in order to fully regulate smart metering and small scale embedded distributed generators. The outcome of this study will assist in providing requirements that will allow the grid operator or licensor to regulate metering systems and distributed generation. South Africa's smart grid vision 2030 is to implement smart grid as a solution for proactive network management. However, in order to achieve a stable smart grid system, the regulating standards must provide a clear direction that will ensure that all licensee can provide systems that are compatible, compliant, accurate, reliable and secure.

II. SAMPLE SURVEY OF METERING CODE OF PRACTICES FOR DEVELOPED AND DEVELOPING COUNTRIES

A. Electricity Metering Code of Practice - Britain [1]

Britain has ten codes of practice used to regulate metering systems that are used for revenue collection. Each code of practice, except code of practice no 4, which is dedicated to commissioning requirements, provide minimum requirements as per category of customers that is determined by the level of consumption. The metering codes of practice are defined in [1] – [10].

1) Analysis of Code of Practice [1], [2], [3] and [5]

These codes of practice provide minimum and mandatory requirements that must be achieved by the licensee for all metering infrastructure used for the purpose of billing and settlement.

a) Overall Accuracy Requirements for Metering Infrastructure Installation

The minimum accuracy levels required for each category of each code of practice is given in tables 1 - 4 given.

Type of Metering System	Current in per unit	Load Power factor	Overall Accuracy limits
Active Energy	0.1 – 1.2 pu	1	±0.5%
	0.05 – 0.1 pu	1	±0.7%
	0.01– 0.05 pu	1	±1.5%
	0.1 – 1.2 pu	0.5 lagging or 0.866 leading	±1.0%
Reactive Energy	0.1 – 1.2 pu	0	±4%
	0.2 – 1.2 pu	0.5 lagging or 0.866 leading	±5%

Table 1 Code of practice no 1 – balancing and settlement code for load exceeding 100 MVA [1].

Type of Metering System	Current in per unit	Load Power factor	Overall Accuracy limits
Active Energy	0.1 – 1.2 pu	1	±1.0%
	0.05 – 0.1 pu	1	±1.5%
	0.01 – 0.05 pu	1	±2.5%
	0.1 – 1.2 pu	0.5 lagging or 0.866 leading	±2.0%
Reactive Energy	0.1 – 1.2 pu	0	±4%
	0.2 – 1.2 pu	0.5 lagging or 0.866 leading	±5%

Table 2 Code of Practice no 2 – balancing and settlement code for load exceeding 10MVA but less than or equal to 100 MVA [2].

Type of Metering System	Current in per unit	Load Power factor	Overall Accuracy limits
Active Energy	0.1 – 1.2 pu	1	±1.5%
	0.05 – 0.1 pu	1	±2.0%
	0.1 – 1.2 pu	0.5 lagging or 0.866 leading	±2.5%
Reactive Energy	0.1 – 1.2 pu	0	±4%
	0.2 – 1.2 pu	0.866 lagging or 0.866 leading	±5%

Table 3 Code of Practice no 3 – balancing and settlement code for load exceeding 1MVA but less than or equal to 10 MVA [3].

Type of Metering System	Current in per unit	Load Power factor Power factor	Overall Accuracy limits
Active Energy	0.2 – 1.0 pu	1	±1.5%
	0.05 – 0.2 pu	1	±2.5%
	0.2 – 1.0 pu	0.5 lagging or 0.866 leading	±2.5%
Reactive Energy	0.1 – 1.2 pu	0	±4%
	0.2 – 1.2 pu	0.866 lagging or 0.866 leading	±5%

Table 4 *Code of Practice no 5 – Metering energy transfer with a Maximum Demand of less than 1MW [5].*

The measurement and verification is done using certified apparatus in either approved facility or onsite. Certificates that proves that the metering installation complies with the error limits as stated in Tables 1-4, are made readily available by the licensee and accessible to the licensor for review and verification. The compensation algorithm used to cater for the voltage transformer (VT), current transformer (CT) and line losses due to length of leads between measuring instruments and electricity meter is clearly defined and available for scrutiny by the licensor or client in case of dispute.

2) *Analysis of Code of Practice defined in [6] – [10]*

The type of meters defined in [6] – [8] only caters for import of active energy. In the event where there is a need to perform metring of reactive energy, code of practice in [5] is adopted for that specific application. Code of practice in [6] sets out the requirements for billing settlement metering equipment and code of practice in [7] specifies the settlement requirements as part of a wider metering and data collection infrastructure providing data to the Data Processing Interface (DPI) [7]. Meters defined in [9] and [10] offers facilities that enable both active energy import and export.

a) *Accuracy Requirements*

The overall in-service accuracy of meters specified in the code of practice defined in [6]-[10] is within a range of -3.5% to +2.5% for any given load that is being metered.

b) *Criteria for Metering Facilities*

All metering equipment including the battery backup supply must be designed for a minimum service life of 10 years maintenance free [6]-[10].

3) *Outstation*

Outstations collect data from all meters and process it for billing and settlement purpose. Metered data have a unique identification to ensure accuracy when handling multiple data acquisition and processing. Duplicate outstations must be provided to enable interrogation of billing data by an authorized third party for verification, audit and/ or settlement purpose [1]-[3], [5]-[10]. Each outstation should have a backup supply either in the form UPS only or a combination of UPS and Diesel generator in order to maintain metering data records and continue collecting data from all meters.

a) *Meter Data Storage*

A minimum storage of 48 periods must be provided for all demand values, where each period is half-hourly. Storage should be able to store data for at least 10 days. Each demand value must be stored as an integer of either MW or MVar as appropriate. In the event of outstation failure, all data must be backed up automatically including the fault duration. Meters should have a battery backup supply that is able to keep the date and clock operational for at least seven days without mains power [1]-[3], and [5].

b) *Communication and security*

Meters can be accessed locally using an opto-port with serial communication. Meters can also be remotely accessed via the following communication protocols:

- Public switched telephone network (PSTN),
- Radio data and network such as Parknet,
- Licensee's own network, and
- Satellite.

All communication protocols are approved by the licensor.

Data security and protection is very important for both licensee and customers. Hence, the meters defined in [1]-[3], [5]-[10] are required to have passwords with various authorization levels as follows:

- Level 1 password – no password required since read-only access rights to metering data has no potential threat to metering data,
- Level 2 password – it offers full read and limited write rights. It can be used to perform time, date correction and resetting of maximum demand,
- Level 3 password – It grants extended write rights where the user has full access to metering setup functionalities, displays, and store data, and

- Level 4 password – offers a full configuration of the meter. It allows setup of transformer ratio and error compensation.

All meters must be sealed with a unique seal to show when the meter has been tempered with. Furthermore, they should have a monitoring system that will send an alarm to the outstation in the event where tampering is detected.

B. Electricity Metering Code of Practice – Singapore [2]

The minimum requirements that form the foundation of the code of practice on metering infrastructure in Singapore is defined by the Metering code [11].

1) *Technical Requirements and Accuracy requirements*

The metering code of practice of Singapore requires that all metering infrastructure be certified by an accredited metering equipment test laboratory that is recognized by Singapore Accreditation Council - Singapore Laboratory Accreditation Scheme (SAC-SINGLAS).

a) Accuracy Requirements

The accuracy requirements of metering infrastructure are given in Table 5.

Metered Facility	Accuracy Class				
	Active Energy Meter	Reactive Energy Meter	CT	VT	Overall Accuracy
Generation Facility	0.2S	1	0.2	0.5	±0.5%
Intertie Meters	0.2S	2	0.2	0.5	±0.5%
Pool Meters	0.5	2	0.5	1	±1.3%
High Voltage Installation Meters	0.5	2	0.5	1	±1.3%
Low Voltage installation meters	2	-	0.5 (where applicable)	-	±2.5%

Table 5 Calibration intervals for Metering Infrastructure in Singapore [12].

C. Electricity Metering Code of Practice – India [13]

The code of practice for India is very similar to the code of practice used in South Africa. However, there are slight differences on the requirements highlighted in the sections to follow.

1) Accuracy Requirements of Meters

The Table 6 gives the in-service limits of errors for various classes of metering infrastructure under various operating conditions.

SI No	Accuracy Class	Type of Connection	Test Points	P.F	Overall Uncertainty of meter Test Equipment Percent	Limits of Error Percent
i)	2.0	Direct Connected/ with CTs	10% I_b to I_{max}	1.0	±0.4	±2.0
				0.5 lag	±0.6	±2.0
				0.8 lead	±0.6	±2.0
ii)	1.0/ 1.0S	Direct Connected/ with CTs	5% I_b to I_{max}	1.0	±0.4	±1.0
			10% I_b	0.5 lag	±0.6	±1.0
			10% I_b	0.8 lead	±0.6	±1.0
iii)	0.5S	For CT/VTs	5% I_b to I_{max}	1.0	±0.1	±0.5
			10% I_b to I_{max}	0.5 lag	±0.12	±0.6
			10% I_b to I_{max}	0.8 lead	±0.12	±0.6

Table 6 In-Service Limits of Errors for Metering Infrastructure [13].

2) Calibration Interval for Metering Infrastructure Using Fixed Acceptable Quality Levels

The code of practice used in [13], determines the calibration period based on the prototype performance results in the lab. Upon expiration of this period, further determination to extend the period can be done if there is sufficient sample data to support the decision [13].

a) Acceptable Quality Level (AQL)

The sample data is obtained using the concept of Acceptable Quality Level (AQL). AQL "is the maximum percentage of defects of a given characteristic in a population, which can be considered satisfactory for the purpose of sampling inspection" [13]. In the event that sample data is not adequate, the following methods are used in a chronological order as stated, in order to determine the calibration interval. Table 7 gives the "deemed compliance period" which then become the calibration interval.

SI No	Accuracy Class	Deemed Initial Compliance Period (Years)
i)	2.0 S	10
ii)	1.0/1.0 S	8
iii)	0.5 S	5

Table 7 Initial Calibration interval for Metering Equipment using fixed AQL [13].

b) Variable error-band method (constant Acceptable Quality Level (AQL))

This method defines an on-going compliance period that is allocated based on variable error-bands at constant AQL see Table 8.

SI No	Accuracy Class	Error-Band in Class Index Load and P.F. Range	In-Service Compliance Period (years)	
			Initial (AQL=1)	On-going(AQL-4)
i)	2.0	±2.0	10	5
ii)		±2.5	7	4
iii)		±3.0	4	2
iv)		±4.0	To remove within 2 years	To remove within 2 years
v)	1.0/ 1.0 S	±1.0	8	4
vi)		±1.5	5	3
vii)		±2.0	3	2
viii)		±3.0	To remove within 2 years	To remove within 2 years
ix)	0.5 S	±0.5	6	3
x)		±0.75	4	2
xi)		±1.0	2	1
xii)		±1.5	To remove within 2 years	To remove within 2 years

Table 8 Compliance Period determination using Fixed Error Band Method (After Implementation of Fixed AQL Method) [13]

c) *Variable AQL method (constant error-band)*

Table 9 provide accuracy class wise determination of compliance periods based on variable AQL for class-index error-bands.

SI No	Accuracy Class	AQL for the Class Index Error Band	In-Service Compliance Period (years)	
			Initial	On-going
i)	2.0	1.0	10	----
ii)		2.5	7	5
iii)		4.0	4	4
iv)		6.5	To remove within 2 years	2
v)		10	----	To remove within 2 years
vi)	1.0/ 1.0 S	1.0	8	----
vii)		2.5	5	4
viii)		4.0	3	3
ix)		6.5	To remove within 2 years	2
x)		10	----	To remove within 2 years
xi)	0.5 S	1.0	6	----
xii)		2.5	4	3
xiii)		4.0	2	2
xiv)		6.5	To remove within 1 years	1
xv)		10	----	To remove within 1 years

Table 9 Accuracy Class Wise Compliance Perion of Meters in-service (After Implementation of Fixed Error Band Method) [13]

D. *Review of electricity metering code of practice – South Africa*

1) *Technical Performance Requirements for Metering Systems*

a) *Accuracy*

The code of practice used in South Africa for metering infrastructure verification is defined in [14]. It is one of the key standards that complement the metering code, which is an integral part of the South African Grid Code. The requirement for accuracy class of electricity metering equipment is shown in Table 10.

Load Category	Accuracy Class			
	Active Energy Meter	Reactive Energy Meter	Current Transformer	Voltage Transformer
>100 MVA	0.2S	1	0.2	0.2
10 MVA to < 100 MVA	0.5S	2	0.2	0.2
1 MVA to < 10 MVA	1	2	0.5	0.5
100 KVA to < 1 MVA	1	3	0.5	0.5
< 100kVA and Whole Current	2	3	1 (where applicable)	-

Table 10 Accuracy Class requirements for Meters and Instrument Transformers [14]

2) *Advanced Metering Infrastructure for Residential and Commercial Customers*

a) *Communication*

The communication network requirement for meters, concentrators and master stations is defined in [15]. Numerous communication protocols can be used to communicate between remote metering infrastructure and the master station as stated in [15]. However, such protocol must be discussed and approved by the licensor.

b) *Security*

Adequate security measures are required to give assurance to end users and licensee on the integrity and validity of collected data. It must ensure data security by providing sub-level passwords with accesses as stipulated in [15]. A secure third party access to the master station should be provided for the purpose of auditing or raw data collection in case of a dispute. Access to raw meter data is important to ensure unbiased analysis and helps in resolving settlement dispute

c) *Calibration and Certification*

The calibration of metering infrastructure is given in Table 11.

Load Category	Calibration Interval (years)
>100 MVA	5
10 MVA to < 100 MVA	5
1 MVA to < 10 MVA	10
100 KVA to < 1 MVA	10
< 100kVA and Whole Current	20

Table 11 Calibration interval for Metering Infrastructure in South Africa [14]

III. DISCUSSION ON METERING CODE OF PRACTICES USED IN VARIOUS COUNTRIES

The comparison of the metering code of practice in developed and developing countries was limited to Britain, Singapore, India and South Africa. The summary of best practices for the metering code of practice is given sections below.

A. Accuracy Requirements

The British metering code of practice has clear requirements on overall accuracy error limits for metering systems for all active and reactive energy meters as indicated in in table 1 - table 4. This information can be used to assess the entire metering infrastructure for overall compliance for both active and reactive in all operating modes. The code of practice used in India, Singapore, and South Africa does not provide a clear overall accuracy limits for all foreseeable operating conditions but an umbrella compliance. The South African code of practice in [14] has to be revised to include overall accuracy requirement of the complete metering infrastructure taking into consideration the accuracy requirements of data processing of the AMI for both active and reactive energy meters for all modes of operation. Furthermore, it must be indicated in the standard that these requirements are mandatory in order to ensure that it can be used as a regulatory tool.

B. Metering Infrastructure Calibration and Supplier Certification

The British metering code of practice [1]-[10] provide minimum details required for certification of metering infrastructure with the relevant code of practice depending on the metering categories. Certifications for each equipment and on overall metering infrastructure is carried out by a certified measurement and verification laboratory and/ or using certified measurement and verification equipment on-site. It also provides the frequency at which calibration of metering infrastructure as shown in table 8. The British code of practice requires a 10 yearly calibration for all metering systems for load exceeding 10MVA. Whereas all meters for load below 10MVA have an initial calibration of 15 years, followed by a 5 yearly calibration.

South African code of practice requires a 5 yearly calibration interval for high energy consumers. Calibration of domestic meters which are mainly direct meters is 20 yearly.

The code of practice in Britain, Singapore, India except South Africa, have a mandatory requirement to have all metering infrastructure certified by the accredited certification body prior installation. Metering infrastructure is expected to comply with the applicable code of practice throughout its operational life. The South African code of practice [14] must be revised to include a mandatory requirement that requires certification of complete metering infrastructure by the South African Accredited Services (SANAS) prior installation. Compliance with the code of practice must be a prerequisite for granting permission to install metering infrastructure for billing and settlement purpose.

The code of practice used in [13] use unique methods to determine calibration interval of each type of meter. These methods are lab based and are implemented in chronological order as discussed in [13]. These methods are the best assessment matrix to assess a need to calibrate meters over time. They provide quantitative results that can be used to make a decision on calibration frequency during the useful life of the meter. The population of South Africa is quite big and with the continued electrification of residents, a strict adherence to the metering code will result in enormous human and capital resources investment required to carry out calibration of meters. Hence, the South Africa metering code of practice for electricity metering can be revised to implement calibration interval using methods defined in [13] for all residential metering systems.

C. Communication, Data Security and Storage

Various communication protocols are allowed for use in all metering code of practice considered in this paper. However, the Licensee must obtain approval of such protocol from Licensor and relevant communication regulation body. Data security and accessibility is an issue of concern due to lack of a governing standard. There is a gap on cyber security requirements to provide confidence on the confidentiality of metered data.

The metering code assessed in this report requires a minimum of 5 years raw meter data storage. As more energy users migrate to smart metering, the database for metering data increases a lot such that it cannot be supported through the use of historians and conventional backups. Secure Cloud backup platforms need to be used with great care to ensure tamper proof on the collected data. In order to achieve this requirement, data storage has to adopt the use of secure cloud backup.

The South African code of practice defined in [14] and [15] should be updated to include minimum data security considerations. Cyber security requirements should be clearly defined to cover the use of cloud for backup.

IV. Improvements Required for Electricity Metering Code of Practice to Provide Effective Regulation

A. Metering Infrastructure

All meters used for the purpose of billing settlement in South Africa must be accredited by SANAS. The criteria for accreditation must be in accordance with performance requirements such as such as accuracy, security, communication protocols, calibration intervals and storage as defined in [14] and [15]. A list of all accredited meters should be published and made readily available to licensor or licensees that wishes to install metering infrastructure. This measure will ensure that all smart meters are regulated and make it feasible to implement smart grid.

B. Smart Metering for Embedded Small Scale Distributed Generation

Distributed generation is becoming popular to commercial and residential customers who wish to minimise expenditure on electricity. The solution that is mostly considered by customers is roof top solar PV. The metering standards in their current state do not cater for metering requirements to back feed into the grid from residentially generated energy except for commercial customers whom can obtain a generation license and enter into a Power Purchase Agreement (PPA) with the grid operator where the point of connection will be located.

Smart metering provides the following advantages, which are instrumental to embedded small-scale distributed energy generation:

- A tool for energy balancing and grid load management,
- Revenue protection through anti-tampering technology,
- Service improvement due to automatic fault location, diagnostic and reporting,
- Reduced administrative costs required to manage and process raw data for billing,
- Load management and protection during network downtime period as a result of either faults or maintenance,
- Revenue protection by eliminating errors in conventional metering data processing methods used for billing purpose,
- Minimize outages due to a timely notification of faults using a smart metering system,
- A better understanding of the load model for low voltage networks, which then improves electrical grid planning and management, and
- Enable Smart Grid implementation.

It is an inevitable fact that both net metering tariff schemes and renewable energy feed in tariff (REFIT) schemes will cause the grid operator to lose its revenue. Revenue losses are already occurring because most customers have started to minimise energy consumption by avoiding the use of energy intensive loads such as electrical geysers and use solar geysers and heat pumps. However, net metering tariff scheme still stands less chances of being accepted by the grid operator because tariffs charged by grid operators are generally higher than the tariff that customer can charge the operator. Thus, it results in higher revenue losses suffered by the grid operator when compared to REFIT. REFIT allow the grid operator to buy and sell electricity to customers with reduced revenue losses due to difference in tariff charged. Billing settlement for both net metering tariff scheme and REFIT are defined in the equations below. Equation (1) defines the tariff structure for time of use as well seasonal related tariff that is used to charge customers.

$$Summer:\ 1 \le j < 6 \ \& \ 9 \le j \le 12$$
$$u_{ji} = \begin{cases} u1, & 0h00 < t \le 06h00 \ \& \ 22h00 < t \le 24h00 \\ u2, & 06h00 < t \le 07h00 \ \& \ 10h00 < t \le 18h00 \\ u3, & 07h00 < t \le 10h00 \ \& \ 18h00 < t \le 20h00 \end{cases} \tag{1}$$
$$Winter: 6 \le j \le 8$$
$$u_{ji} = \begin{cases} u1, & 0h00 < t \le 06h00 \ \& \ 22h00 < t \le 24h00 \\ u2, & 06h00 < t \le 09h00 \ \& \ 17h00 < t \le 19h00 \\ u3, & 10h00 < t \le 17h00 \ \& \ 19h00 < t \le 22h00 \end{cases}$$

Where: j is the number of the month in a year, i is the number of 30 minutes time intervals in a day and u is the tariff at a specific time of use (TOU) period and season.

Equation (2) defines the tariff structure for time of use as well seasonal related tariff that is used for REFIT

$$Summer:\ 1 \le j < 6 \ \& \ 9 \le j \le 12$$
$$v_{ji} = \begin{cases} v1, & 0h00 < t \le 06h00 \ \& \ 22h00 < t \le 24h00 \\ v2, & 06h00 < t \le 07h00 \ \& \ 10h00 < t \le 18h00 \\ v3, & 07h00 < t \le 10h00 \ \& \ 18h00 < t \le 20h00 \end{cases} \tag{2}$$
$$Winter: 6 \le j \le 8$$
$$uv_{ji} = \begin{cases} v1, & 0h00 < t \le 06h00 \ \& \ 22h00 < t \le 24h00 \\ v2, & 06h00 < t \le 09h00 \ \& \ 17h00 < t \le 19h00 \\ v3, & 10h00 < t \le 17h00 \ \& \ 19h00 < t \le 22h00 \end{cases}$$

Where: v is the REFIT tariff at a specific TOU period and season.

Equation (3) defines the billing settlement for each month when using net metering tariff structure.

$$C_j = \Delta T \times \sum_{i=1}^{K} P_{ji} u_{ji} - R_{ji} u_{ji} \tag{3}$$

Where: C is the billable cost for energy for a specific month, ΔT is a fixed 30 minutes interval in each hour, P is the average power supplied to the customer by the grid operator at each 30 minutes time interval, R is the average power supplied to the grid by the customer at each 30 minutes time interval.

Equation (4) defines the billing settlement for each month when using REFIT.

$$C_j = \Delta T \times \sum_{i=1}^{K} P_{ji} u_{ji} - R_{ji} v_{ji} \tag{4}$$

V. CONCLUSION

The metering standards used for electricity metering in South Africa should be revised to match best practice that was identified in metering code of practice from Britain, India and Singapore. Furthermore, the metering standards should be revised to ensure regulation of smart meters that are used in South Africa. It should ensure that SANAS accredited meters are mandatory for settlement billing purpose. Revised standards will ensure that standardisation on security, data acquisition format and communication is achieved, thus paving a way for a successful implementation of smart grid.

Small scale embedded distributed generation is considered by most customers to reduce energy consumption. Smart metering can play a vital role to improve safety of the distribution network. It can be used as an isolation point, to open solid state switch and prevent energy back feed into the grid during faulty network or maintenance on the distribution system feeding the consumer. This will mitigate the risk of electric shock to personnel. The energy generated using solar PV cannot be despatched. Hence, a thorough network analysis should be used to determine the quota of renewable energy generation that is acceptable per customer.

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VII. Biographies

[1]Morris Sibiya received the Bachelor's degree in 2009 and an Honours degree in 2013 and he is currently pursuing Master's degree at the University of Pretoria, Gauteng, South Africa. He worked in manufacturing plant from 2010 to 2012. He then worked in Eskom generation plant, Petrochemical Plant and Renewable Energy Company, where he specialises in wind energy generation. His area of interests include smart grid, smart metering, power system protection and power quality in embedded generation systems. He is currently a consultant for power systems, automation and process control. Mr. Sibiya is a registered professional engineer with the Engineering Council of South Africa.

[2]Raj Naidoo, (M'04), received the Bachelor's degree from the University of Kwa-Zulu Natal, Durban, South Africa, in 1995, the M.Sc. degree from the University of Witwatersrand, Gauteng, South Africa, in 2000, and a Ph.D. degree in electrical engineering at the University of Cape Town, Rondebosch, South Africa. From 1995 to 1997, he worked at a manufacturing plant. From 1997 to 2002, he was with the utility Eskom in the fields of power quality and network planning. His specialist interests include waveform-processing techniques for power-quality assessment and power system stability. He is currently a faculty member at the University of Pretoria, Pretoria, South Africa. Dr. R.M. Naidoo is a member of the IEEE and SAIEE. He is a registered professional engineer with the Engineering Council of South Africa.

[3]Ramesh Bansal, (SM'03), received the M.E. degree from Delhi College of Engineering, Delhi, India, in 1996 and the Ph. D. degree from Indian Institute of Technology (IIT), Delhi, India in 2003. Professor Ramesh Bansal, who has more than 25 years' experience in teaching, research and industry, is a professor and Group Head (Power) in the Department of Electrical, Electronic and Computer Engineering in the School of Engineering. Prior to his appointment at UP he was employed by the University of Queensland in Australia, the University of the South Pacific in Fiji, the Birla Institute of Technology and Science in Pilani, India, and the Civil Construction Wing of All-India Radio. He has worked with Powerlink, an Australian government-owned corporation responsible for Queensland's high-voltage electricity transmission network.

Professor Bansal has published more than 250 journal articles, presented papers at conferences, and has contributed to books and chapters in books. He has supervised 18 PhD students and currently supervising 10 PhDs students. His diversified research interests in the areas of renewable energy and conventional power systems include wind, photovoltaics (PV), hybrid power systems, distributed generation, grid integration of renewable energy, power systems analysis, smart grid, flexible ac transmission systems (FACTS) and power quality. Professor Bansal is an editor of the highly regarded journals, *IET-Renewable Power Generation* (regional editor for Africa) and *Electric Power Components and Systems*. He is a fellow and a chartered engineer of the Institution of Engineering and Technology, UK, a fellow of Engineers Australia, a fellow of the Institution of Engineers (India) and a senior member of the Institute of Electrical and Electronics Engineers (IEEE).