AN EFFICIENT COMMUNICATION INTERFACE AND PROTOCOL FOR MOTOR PROTECTION RELAYS

A.J.J. MOUTON, C.J. SMITH AND G.E. SMITH

ABSTRACT

A company in South Africa is a three-phase induction motor protection relay manufacturer. The function of the protection relay is to capture running data, to provide protection against possible damage, to control an electric motor and to communicate this data to the System Control and Data Acquisition (SCADA) system in a control room. In the case of remote sites e.g. a pump station, the protection relays are used as standalone units. The protection relays are equipped with communication facilities to be used in an instrumentation environment. If a trip occurs or settings need to be changed a technician has to visit the remote site and address the problem. The ideal cost and time effective solution is to perform these tasks remotely via a reliable wireless network.

A study was conducted to ascertain the viability of using the standard GSM cellular networks in South Africa to effectively control electric motors and to communicate with the Motor Protection Relays (MPRs) controlling the electric motors in order to determine the status of a motor, settings of the motor, trips that occurred and time of occurrence. It was shown that a node controller could be used to store all the data from various electric motors at a single location. It was also shown that the data from the different electric motors could be analysed at the node controller and that communication can then be initiated from the controller to a responsible person via the GSM network. It was further illustrated that, by making use of the GSM networks in South Africa together with the short message service (SMS), communication and control can be effectively established. SMSs proved to be a reliable means of communication between cellular phones, an embedded network and MPRs. It was shown that software protocols, although slower in communication speed, proved to be reliable and effective for the purpose of transferring information between the node controller and the motor protection relays connected to the electric motors.

Keywords: Motor protection relays, Remote GSM node controller, GSM modem, short message service (SMS), Modbus protocol application.

1. INTRODUCTION

Worldwide, electric motors play a very important role whatever their application. Electric motors are used extensively in the mining industry, manufacturing industry and the agricultural sector and can be seen as the workhorses of industry.

Industry requires electric motors to be protected against damage to save money, but also to be monitored and controlled to have maximum production with a minimum of downtime. Repairing or rewinding an electric motor can be a costly affair but downtime could in most cases be even more costly, depending on the function of the motor. Early warning can eliminate the loss of valuable production time and costly motor repair. A company in Pretoria (South Africa) manufactures MPRs. The purpose of the protection relays is to protect motors against a range of possible errors that could damage them. Some of these errors are over- and under-voltages or currents, earth faults, unbalance faults, short circuit faults, amongst others. The protection relay also logs the faults with a time and date stamp at the time of occurrence. Additionally it stores identity information of the relay by storing the relay model, the software revision and the serial number of the protection relay.

The status of contactors on a protection relay, process data and settings data are also stored in the relay. In total each protection relay has nearly 90 bytes of data to control and protects a specific electric motor and keeps track of what is currently the status of a motor or what has occurred over a period of time. The protection relays are standalone units if they are situated at remote locations. This implies that the motor will be protected against faults that occur, but if a motor has tripped it can in some instances not be reset and the monitoring technician will not know of the occurrence. A technician must then physically visit the remote site and the protection relay to reset the unit. If a person needs to investigate the status of a running motor or the causes of a tripped motor he must also be physically at the protection relay and must connect a PC to the unit to perform the required task. The information can then be downloaded via the normal RS232 serial communications port to the PC. Any changes that need to be done must also be done in the same manner. The problem with this approach of changing data, acquiring information and resetting of the units is that it is very time consuming, especially when large distances are involved. It is also costly to a company and costs increase the further the protection relays are located from the department responsible for the maintenance of the motors.

The study had two main objectives: the first objective was to find a method to effectively communicate with a remote site without the need for a person to be physically on site. Control and monitoring were done telemetrically, thus moving away from the traditional approach of connecting to a control room with an operator constantly monitoring the process. The second objective was to find a method to effectively communicate on site with all the motor protection relays, because at remote locations different electric motor and protection relay combinations all function independently. This efficiency is necessary when one communicates with the remote site, making communication to and from a specific protection relay essential.

2 EFFECTIVE COMMUNICATION WITH A REMOTE SITE

2.1 Options: wireless or wire?

In South Africa it is a well known fact that copper wires, telephone lines and power cables are stolen on a regular basis. Mobile cellular is less prone to vandalism and theft since there are no copper wires to install [1]. It has been estimated that the typical wiring cost in industrial installations is US$130650 per meter and adopting wireless technology would eliminate 20 to 80% of this cost [2]. Wireless technologies are showing an increasing significance, due to their enormous potential [3]. It was evident that for this specific problem the wireless option will be suitable. In rural areas, where the MPRs will be used, the costs to provide wired data transmission will be high compared to wireless mainly due to theft, and costs could increase and data communication could be interrupted. It is also clear that the industry in general is moving towards a wireless data communication system.

2.2 Wireless options

2.2.1 Satellite

The following questions arise with wireless: Should one (i) utilise an existing communication infrastructure or a public network, e.g. public cellular networks, or (ii) install a private wireless network. Utilising an existing communication infrastructure of a public network might enable a cost-effective solution due to the savings in required initial investment for the communication infrastructure. Public networks such as satellite have long been used to reach isolated and remote facilities such as mining and oil companies [4]. In general, the aim of the satellite system is not to support the whole communication infrastructure but to provide or support a particular application or service [5]. Advantages of satellite are global coverage and rapid installation. The disadvantages are long delays, satellite channel characteristics (e.g. characteristics that vary depending on the weather conditions) and high cost [6].

2.2.2 Global Systems Mobile (GSM)

The Global System for Mobile Communications (GSM) (original acronym: Groupe Spécial Mobile) is the most popular standard for mobile phones in the world. GSM service is used by over 2 billion people across more than 212 countries and territories. Cell radius varies depending on antenna height, antenna gain and propagation conditions from a couple of hundred meters to several tens of kilometers. The longest distance the GSM specification supports in practical use is 35 km but with implementations of the concept of an extended cell, the cell radius could be double or even more, depending on the antenna system, the type of terrain and the timing advance [7].

The growth in the Internet industry is immense and along with this trend wireless communication has rapidly gained wide acceptance, especially the cellular systems such as GSM [8]. Mobile terminals, and no longer PCs, will be the major man-machine interface [9]. Mobile telephony, presently superseding wired telephony, has become one of the most convenient information exchange tools since the implementation of the GSM standard in the early 1990s [10].

2.3 GSM coverage in South Africa

A Global System for Mobile Communications (GSM) network is a public network introduced into South Africa in 1995. Population coverage is extremely high and a closer look at the two major South African cellular providers reveals that Vodacom has a 70.9% land area coverage and a population coverage of 97,9% [11]. The second major supplier, MTN, has land area coverage of 87%, and population coverage of 95% [12].

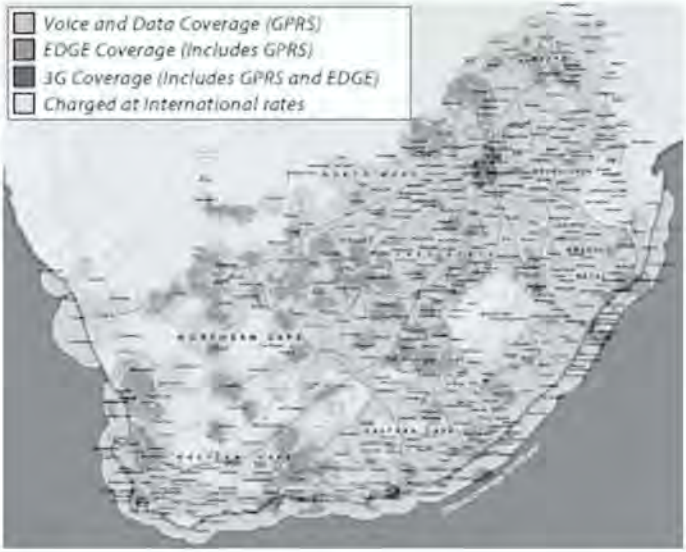

Figure1.1 shows a coverage map from the cellular provider MTN. The communication medium that would be suitable for this application will be the voice/data coverage which includes GPRS and SMS technology.

The literature review on private networks, such as WLAN, ZigBee, and Bluetooth, points out that each one has its own unique place in the market. The disadvantages of these communications systems is that they are all short distance communications devices which have to be connected in a mesh network for longer range data communications that must be achieved.

This implies extreme costs, i.e. maintenance, equipment and installation costs, the further away an MPR site is. Digital mobile cellular technology or GSM in short, provides the most cost effective solution for remote monitoring [13].

3. EFFECTIVE COMMUNICATION BETWEEN MPRs ON SITE

3.1 Electrical specification

RS485 is an OSI model physical layer electrical specification of a two-wire, half-duplex, multipoint serial connection. The standard specifies a differential form of signaling. The difference between the wire voltages is what conveys the data. A logic 1 is between -1.5V and -6V and a logic 0 is between +1.5V and +6V. RS-485 can use up to 32 line drivers and 32 receivers on the same line which can be extended by an additional 31 if an RS-485 repeater is used, making the total nodes 63 [14]. EIA-485 only specifies electrical characteristics of the driver and the receiver. It does not specify or recommend any data protocol. It offers high data transmission speeds (35 Mbit/s up to 10 m and 100 kbit/s at 1200 m), since it uses a differential balanced line over twisted pair. RS-485 has the capability to function up to wire lengths of 5 km at 1200 baud. Baud rates of 56,7 Kbaud can be achieved over 1,2 km. EIA-485 drivers need to be put in transmit mode explicitly by asserting a signal to the driver. This allows EIA-485 to implement linear topologies using only two lines [15].

3.2 Applicable protocols

Although not the only available protocols on the market, three protocols were investigated. They are Modbus (lower transmission rate), Canbus (medium transmission rate), and Profibus (high transmission rate). The core information of the three protocols surveyed is summarised in Table 1.1. Of the three, Profibus has the fastest transmission rate and Modbus the slowest. Due to the RS-485 interface standard the maximum distance is around 1200m. Using Profibus one will have to make use of additional chips making Profibus the most expensive of the three. Modbus is the protocol which will be the fastest to implement due to it being a software protocol only, while the others need software configuration for the hardware. Canbus is implemented on some processors, and if not, a CANBUS driver will need to be connected separately, adding to the cost of the project. Any one of the three protocols surveyed will be able to transmit data from MPRs to a central point.

Table 1.1: A comparison between the three different protocols

Criteria	Profibus	Canbus	Modbus
Additional chip	Yes	No/Yes	No
Maximum distance (with RS-485)	<1200m	1200m	1200m
Software royalty-free	No	Yes	Yes
Max data rates	1,5Mbit/s	1Mbit/s	153.6 kbit/s
Physical layer	RS-485	RS-485	RS-485,422
Error detection	Internal to Profibus-chip	CRC	CRC

The maximum data rates as indicated in Table 1.1 are only achievable with shorter distances and not at the distance of 1200 m. For this study the Modbus protocol was chosen due to the low cost and reliable transmission of data at a reasonable data transmission rate.

3.3 Focus on a central node controller to collect data from the MPRs

In the previous section it was shown that a single cell phone modem could be used for the transfer and reception of data. Each MPR's data should be able to be transmitted to the person in control of the site. With decentralised transmission of data every MPR will need a cell phone modem, which is unnecessary and costly. For this reason the focus of the project was on a centralised node controller with intelligence to receive messages from the site controller, analyse the message, get the required data and report back to the originator of a message. The greatest advantage of such a system is that the node controller will be very low cost when compared to the total cost of the site setup but will have massive communication advantages and capabilities. The disadvantage of a centralised system is that a total communication block out will be experienced when either the cell phone modem or the intelligent microprocessor fails. This could cause a communications delay of a few hours. A microprocessor was used for the intelligence of the node controller. The aim was to use a microprocessor that would be able to perform the required tasks and not to simply use the quickest and most advanced microprocessor. The basic requirements were that the processor must have at least 100 K program memory, at least 3 K of RAM memory and most importantly it must have at least 2 UARTs for communication to the MPRs and to the cell phone modem respectively. On further investigation and for various reasons it was decided to use the PIC 18F8720® microprocessor from Microchip.

This device has 128K-program memory, 3840 bytes of RAM. 1K EEPROM data, two Addressable Universal Synchronous Asynchronous Receiver Transmitter (AUSARTs), Serial Peripheral Interface (SPI) and Inter-Integrated Circuit Bus, (I^2C), communication ports that can be used for expansion. A further advantage of the Microchip microprocessor is the fact that Microchip produces an integrated product range.

Figure 1.2 graphically indicates the connection from the node controller USARTs to the MPRs and the GPS module. Using Modbus protocol and USART 1 as the communications port, connection is made to the different MPRs via an RS485 interface chip. USART 2 is used to connect to the GSM modem via an RS232 chip.

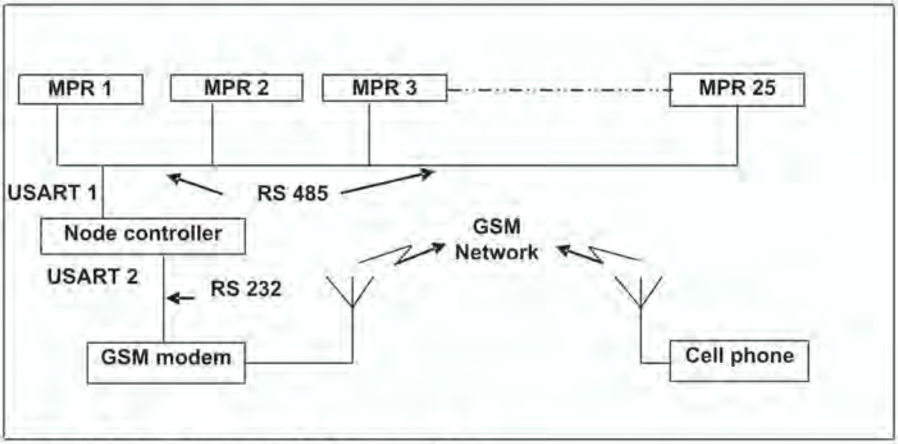

Figure 1.2: Node controller connections

4. THE GSM-SMS PERFORMANCE

The use of a Wavecom modem and a cell phone to implement the communication started in January 2003 and continued until October 2006. The aim was not to evaluate the performance of the MTN GSM-SMS network but rather the overall performance of the node controller/GSM combination. During this period SMSs were sent over a period of almost 4 years. Around 854 SMSs were sent from the node controller and around 934 SMSs were sent from a cell phone to the Wavecom modem. The difference between the two numbers is due to the fact that the Wavecom modem mainly responded to the SMSs from the cell phone, but a lot of programming and tests had to be done on messages received from the cell phone before the Wavecom and node controller started to respond correctly to the messages.

Figure 1.3 shows the performance of the system over a period of 5 different days. The same message was used and the message was sent 20 times on selected days.

The minimum response time during these days was a time of 42 seconds on day 1 and the maximum response time was 70 seconds on day 2. The average response during these 5 days was 51.79 seconds. Response times will never be the same on two different days, but this is an indication that response times for this specific request will be around 1 minute.

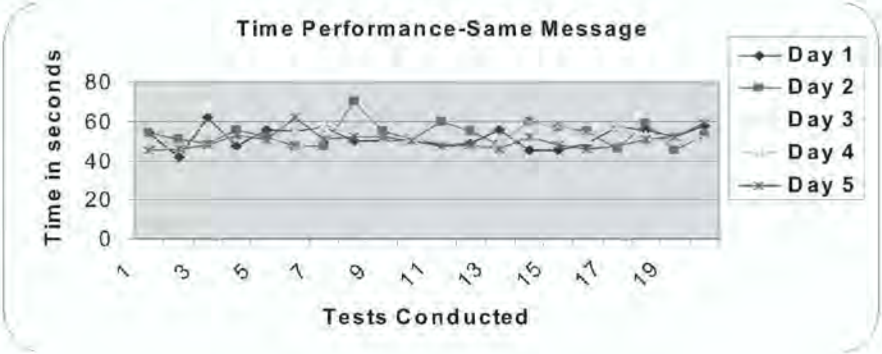

Figure 1.3: Report-back times on different days

Table 1.2: Data transmission from node controller to cell phone

Tested data transmission from node controller to cell phone					
Test period	**Sent out**	**Errors count**	**Correctness of SMS at cell phone**	**Re-sent count**	**Re-sent %**
9/1/2003-24/11/2003	239	0	100%	0	0 %
13/2/2004-14/11/2004	134	0	100%	0	0 %
8/1/2005-25/11/2005	275	0	100%	0	0 %
18/3/2006-12/10/2006	206	0	100%	0	0 %
Total	**854**	0	100 %	0	0 %

Table 1.2 indicates the number of SMS transmissions that occurred during the 4 year period. During the development period it never happened that a distorted message was received on the cell phone from the node controller/ Wavecom combination.

The correctness of SMS messages was thus 100%. The node controller was programmed in such a way that if a message was sent from the Wavecom modem and a failure occurred, i.e. no "OK" message was received from the modem, there would be a further two attempts to resend the message. This ensured that all messages were sent from the Wavecom modem, making it impossible to determine the retransmission rate. For this reason the retransmission rate was 0% from the node controller/Wavecom combination to the cell phone. A retransmission is seen as an SMS that has to be transmitted again due to a previous failure of transmission.

Table 1.3: Data transmission from cell phone to the node controller

Test period	Sent out	Errors count	Correctness of SMS at controller	Re-sent count	Re-sent %
9/1/2003-24/11/2003	229	0	100%	3	1.3 %
13/2/2004-14/11/2004	233	0	100%	2	1.5 %
8/1/2005-25/11/2005	305	0	100%	4	1.5 %
18/3/2006-12/10/2006	167	1	99.5%	3	1.5 %
Total	**934**	**0**	**99.99%**	**12**	**1.4 %**

Table 1.3 shows a transmission of 934 SMSs during the 4 year period. During this period one error was picked up. The received message at the node controller indicated that some text in the SMS was missing. The SMS message could not be decoded but was not lost in the process. The node controller responded back to the cell phone with an "Invalid Command". Retransmissions from the cell phone were 12 out of the 934 or 1.4% and had to be re-transmitted due to a first time failure. In the 4-year time period there were 2 days which had SMS transmission problems from MTN, giving problem-free transmission days of more than 99%.

Table 1.4: Average response times for mixed messages over different days

Supplier MTN	Sent count	Minimum response time (Sec)	Maximum response time (Sec)	Average response time (Sec)
Day 1	47	47	60	55.4
Day 2	35	46	56	50.3
Day 3	42	48	59	53.6
Day 4	57	45	62	56.3
Day 5	40	50	65	58.6
Total	**221**	**45**	**65**	**54.8**

In order to measure the average response time of the system, tests were performed to determine how long it would take to receive feedback once a message was transmitted to the node controller. A total of 221 different messages with different requests were sent to the node controller during 5 different days. The five testing days in this experiment were not the same as the five testing days of Figure 1.3 Some messages were not included as their response time was a lot longer than the rest and would have given a distorted response time. From Table 1.4 it is evident that the minimum response time was 45 seconds and that the maximum response time was 65 seconds. The average response time from 221 messages was 54.8 seconds.

5. OVERALL SYSTEM PERFORMANCE

5.1 GSM/node controller

All commands or requests were sent from a cell phone to the node controller. Controlled adjustments were done on a demo unit and the results were then compared. A demo unit is a unit that emulates different parameters on a MPR. All tests then compared 100% with the controlled values thus giving a 0% error. Report-back times were also measured and the average time for the system to report back on the different messages was 57.1 seconds. Report-back time for a request to receive the MENU was 95.7 seconds and this was also the longest for a response to a request. This is due to the fact that three messages have to be transmitted from the node controller. Analysing the report back times globally, one can derive that except for the MENU request, the majority of report back times will be less than one minute or close to one minute. Different motor trips were initiated and a 100% correlation was achieved between the trip initiated and the report-back data.

5.2 Modbus protocol and the node controller

Efficiency tests were performed on the different Modbus functions. The report-back times to the node controller of Function 4 with the development MPRs was around 100 mS. Function 16, which is used to implement changes from the node controller, had report-back times per MPU of less than 30mS. Function 17, which is used to determine if communication exists between the node controller and the MPRs, also had report-back times per MPU of less than 30mS. Detailed measurements for average report-back times were not taken due to the fact that these times had no real effect on the system performance. The report-back performance was determined by the GSM delays.

6. COST ANALYSIS DONE ON SYSTEM

The aim was to develop a system that would be a low cost solution. For this analysis real life economic values were used. The top part of Table 1.5 indicates some assumptions to do a comparison between a company with a node controller and one without a controller. The middle part of the table indicates the monthly costs if no node controller is fitted and the MPRs have to be physically inspected once a week (four times per month) on site. The last part of the table indicates the monthly costs if a node controller is fitted on site and an inspection is conducted once a month.

Table 1.5: Cost analysis of no system compared to an installed unit

Assumptions	Values
Distance (50 km X2)	100 km
Fuel cost / km	R 5-00
Salary / hour	R 100
Travel + work time in hours	2 hrs
Without unit	
Visits / month	4
Total kms / month	400 km's
Travel cost / month	R2000
Monthly salary cost	R 800
Total monthly cost	R 2800
Node controller installed	
Unit cost	R 6000
Visits / month	1
Total kms / month	100 km's
Travel cost / month	R 500
Monthly salary cost	R 200
Monthly SIM card cost	R 130
Total monthly cost	R830

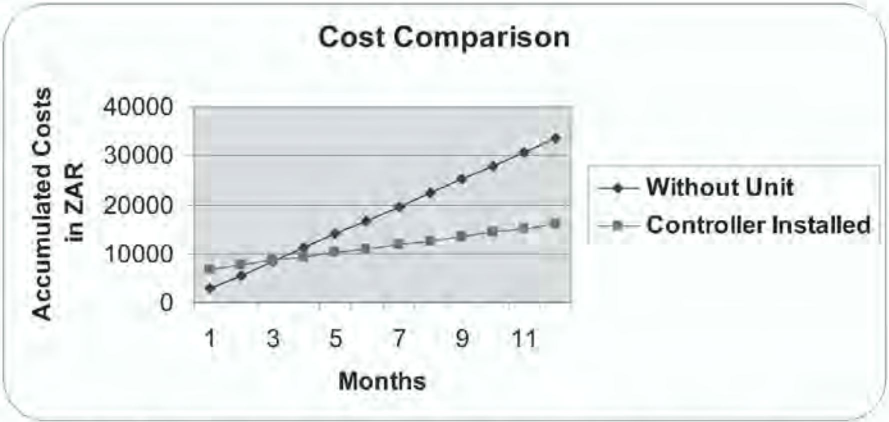

Figure 1.4: Cost comparison between an installed unit and no unit

Figure 1.4 indicates that initially the cost of an installed node controller will be higher than doing regular visits at a remote site. During month three the break-even point will be reached and after one year the saving in costs could be more than R17 000.

7 SUMMARY

The purpose of this study was to investigate and analyse the feasibility of a low cost communications network to transfer measured data and to accurately control the transmission of information from one or more remote motor protection relays bi-directionally to a technical person that is responsible for the effective operation of a remote site. A plan was implemented, problem areas identified, solved, experimental tests performed, and finally the prototype with the different technologies was built and tested.

7.1 GSM-SMS technology

From the literature survey it was clear that GSM technology is the best solution for the present-day scenarios of remote MPRs. The main reasons were the low cost of getting access to the technology and the huge coverage of GSM networks in South Africa. GSM is also a maintenance free environment when it comes to the communications network. Both GSM-SMS and GPRS will be able to perform the desired communications transfer but this project focused on the use of SMSs because of the fast implementation time, low volumes of data transfer and low cost of SMSs, especially if bought in bundles. SMSs are relatively fast, efficient and reliable as the tests performed during this project and tests by others proved.

The experimental tests performed on GSM and SMS during the four-year period proved that this technology is extremely reliable, robust and had a resend percentage of only 1.4% mainly due to the GSM network that was busy at the time. A single error occurred where the SMS was transmitted incorrectly.

7.2 Report back times of node controller-GSM combination

The experimental tests performed showed that the majority of requests or commands would respond back in a time of approximately one minute. Compared to a site visit, which will take at least 1 hour for return if situated 50 kms away from the operator site, this is extremely quick. The tests further showed that the report-back time of around one minute is applicable on different days of the year, making the report-back time of the Node Controller relatively fast, reliable, and consistent.

8. BIBLIOGRAPHY

[1]MINGES, M. 1999. Mobile cellular communications in the Southern African region. *Telecommunications Policy.* 23:585-593(586).

[2] WANG, N., ZHANG, N. & WANG, M. 2006. Wireless sensors in agriculture and food industryRecent development and future perspective. *Computers and Electronics in Agriculture.* 50:114(2)

[3] EGEA-LOPEZ, E., MARTINEZ-SALA, A., VALES-ALONSO, J., GARCIA-HARO, J. & MALGOSA- SANAHUJA, J. 2005. Wireless communications deployment in industry: a review of issues, options and technologies. *Computers in Industry.* 56:2953(31).

[4] GUNGOR, V.C. & LAMBERT, F.C. 2006. A survey on communication networks for electric system automation. *Computer Networks.* 50:877897(885-886).

[5] EGEA-LOPEZ, E., MARTINEZ-SALA, A., VALES-ALONSO, J., GARCIA-HARO, J. & MALGOSA- SANAHUJA, J. 2005. Wireless communications deployment in industry: a review of issues, options and technologies. *Computers in Industry.* 56:2953(34).

[6] TSENG, C.L., JIANG, J.A., LEE, R.G., LUB, F.M., OUYANG, C.S., CHEN, Y.S. & CHANG. C.H. 2006. Feasibility study on application of GSMSMS technology to field data acquisition. *Computers and Electronics in Agriculture.* 53:4559(46).

[7] Wikipedia encyclopedia (GSM: 1-5)

[8] HÄNNIKÄINEN, M., HÄMÄLÄINEN, T.D., NIEMI, M. & SAARINEN, J. 2002. Trends in personal wireless data communications. *Computer communications.* 25:84-99(84).

[9] ARETZ, K., HAARDT, M., KONHÄUSER, W. & MOHR, W. 2001. The future of wireless communications beyond the third generation. *Computer Networks.* 37:83-92(85).

[10] SCHARNHORST, W., HILTY, L.M. & JOLLIET, O. 2006. Life cycle assessment of second generation (2G) and third generation (3G) mobile phone networks. *Environment International.* 32:656675(656).

[11] GSM COVERAGE-VODACOM [Online]. Available from: http://www.vodacom.co.za [Accessed: 11/11/2005].

[12] GSM COVERAGE-MTN [Online]. Available from: http://www.MTN.co.za [Accessed: 11/11/2005].

[13] Ozkul, T. & Al Homoud, A.2003. Communication protocol for monitoring a large number of remotely distributed hazardous material detection devices. *Computer Standards & Interfaces.* 25: 553561(553-554)

[14] (Practical Fieldbus & Device Networks for Engineers & Technicians, Chapter 2:2.22). *Practical Fieldbus & Device Networks for Engineers & Technicians.* Instrument Data Communications Pty Ltd.

[15] Wikipedia encyclopedia (RS-485:1-3) WIRELESS Networks [Online]. Available from: http://en.wikipedia.org/wiki/Wireless_networks [Accessed: 10/11/2005].