Cellular technology for prevention of "Give and forget" community service projects

Rene Naidoo, Johan Meyer
Department of Electrical and Electronic Engineering Science
University of Johannesburg, P. O. Box 624, Johannesburg 2000
201010199@student.uj.ac.za
johanm@uj.ac.za

Abstract—**This paper describes the use of cellular network technology to monitor installed equipment performance in a rural village as part of a community service project. Monitoring of the equipment enables early detection of performance deviations enabling cost effective preventative maintenance avoiding "give and forget" rural projects. Results are presented for performance data collected at a remote rural village solar installation and communicated through a data radio and the cellular network to a control station in an educational environment.**

Keywords— Community engagement, cellular network, GSM, solar electrification, preventative maintenance

I. INTRODUCTION

Gwakwani is a small, rural village, located in the northern part of the Limpopo province in South Africa, shown in Fig. 1 below. The village contains about 70 to 100 villagers who can be classified as the poorest of the poor making a living from subsistence farming.

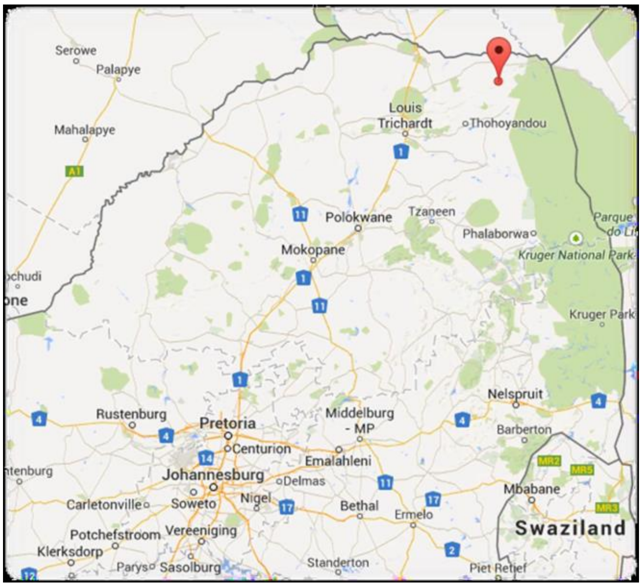

Figure 1: Geographic location of the Gwakwani village in the northern Limpopo province of South Africa.

Many universities and private schools under the Independent Exam Board in South Africa are required to participate in community service projects as part of their curriculums [1]. Private companies are generally keen to support these projects to gain the marketing and product exposure afforded by these engagements. A trend has been observed where community engagement projects especially those in remote rural areas are conducted on the basis of "give and forget". All too often benevolent projects involve a once off donation of equipment with little to none follow-up maintenance conducted during the life cycle of the project leaving the benefactors frustrated and back to square one, once costly maintenance work is required. This situation is intensified when the benefactors are rural and located significant distances away from the sponsor's supply network. Community engagement projects although attractive from a marketing and philanthropist point of view are costly from a maintenance and support point of view resulting in "give and forget" projects. Costly maintenance can in many instances be avoided by performance monitoring of the equipment enabling the application of preventative maintenance. Monitoring of equipment installations in rural areas are difficult given the skill sets of the people involved. Using careful design and the availability of the cellular communication network remote monitoring and operation of equipment in rural areas are possible. In this paper a rural community engagement project is presented where the performance monitoring of the installed equipment is conducted by accessing the cellular network in the area. The work has been undertaken as an endeavor to support Engineering Projects in Community Service (EPICS) in IEEE [2] which seeks vertical academic integration between pre-university and university student members. In the following sections a solution to the "give and forget" community engagement problem is presented using a cellular data communication link. Results from the installation at the Gwakwani village are presented.

II. BACKGROUND

The village of Gwakwani, lacks any source of electricity supply provided by a utility electricity supplier and as result does not have electrical lighting or the ability to use household electrical appliances such as fridges or stoves. The village claims several requests for electricity from service providers have been denied as result of the remote location of the village. Due to the lack of an electricity supply the villagers face the dilemma of a sustainable clean water supply. A diesel operated pump which had been installed over a decade ago is supplying the drinking water to the entire village. The diesel supply for the pump is the responsibility of the villagers who due to the lack of financial support as well as the majority of the individuals being unemployed or lack the means to work due to age, physical transportation to and from work or even education resulting in an intermittent diesel supply and subsequently clean drinking water supply. Although a cellular network signal is available in a particular location in the village the lack of an electricity supply results in the inability to recharge cellular mobile devices. In Gwakwani, the villagers would go about resolving this issue by visiting the neighboring village who has an electricity supply, paying a fee of $0.3 for a single mobile device recharge while having to wait on location for the duration of the recharge.

The University of Johannesburg (UJ) together with private sponsorship companies and school learners from the King's School West Rand embarked on a community engagement project to alleviate the plight of the Gwakwani villagers. A phased approach was followed where the first phase of the project included the installation of a solar powered water pumping system, a mini cellphone charging station, a small security lighting system and a remote monitoring and communication system. The second phase of the project includes the installation of solar lighting in the village dwellings.

The success of community engagement projects depends not only on the technical solution provided but also on the social and cultural acceptability of the solution and of the solution provider. Fig. 2. Shows a villager handing a baobab seed pod to one of the UJ team members as a token of trust and appreciation. Building a trust relationship was essential for this project as the project work included the removal of existing infrastructure which included the diesel driven borehole pump.

Figure 2: UJ lecturer (on left) engaging with a Gwakwani villager to attain trust.

III. SYSTEM DESCRIPTION

A stand-alone solar powered borehole pumping system using the SQFlex 1.2-2 pump was designed in conjunction with the solar pump supplier Grundfoss [4] capable of fulfilling the watering needs of the Gwakwani villagers. The installation of the solar powered borehole pump system necessitated the installation of the following sub-systems to deliver a system with "giving and not forgetting" characteristics:

- Remote Monitoring System;
- Communication system; and
- Display and Control Station.

A secondary solar electricity supply system was installed to provide the required electrical power supply to the Remote Monitoring station. The availability of a 220 V AC electricity supply, addressed some of the secondary needs of the villagers by enabling the installation of a cellular phone charging point and LED floodlights for area security purposes.

A. *Remote Monitoring System*

The main purpose of the Remote Monitoring System is the collection of operational data from the solar water pumping system. Due to the layout of the Gwakwani village the pump house is located at the bottom of a depression and the water storage tank located at the top of the depression a distance of approximately 500 m away. The separation between the water tank and the pump house resulted in no electricity supply to drive water level sensors at the water storage tank. The water level in the tank is estimated by measuring the tank feed line static water pressure at the pump outlet and compensating for the terrain elevation between the pump house and the water tank. A flow sensor was installed in the tank feed line to verify pump performance. The pressure and flow sensors were interfaced to a Jazz PLC provided by Unitronics [3]. The electrical current between the solar panels and the pump was measured using a DC current sensor interfaced to the PLC. The status of the electrical power supply to the PLC was determined through measurement of the battery voltage V_B, battery temperature T_B and the AC output current A_I of the main inverter. The electrical power supply for the PLC was obtained from a small 300 W inverter with low standby current characteristics. The PLC controlled the timing for switching the LED security floodlights and the 1 kW main inverter supplying the 220 V AC outlet plug. The AC outlet plug was provided as a cellular phone charging station. It was necessary to control the on and off time of the main inverter to reduce the losses caused by the standby current drawn by the main inverter. The system architecture for the Remote Monitoring System is shown in Fig. 3. The data parameters sampled by the PLC is as indicated in Fig. 3.

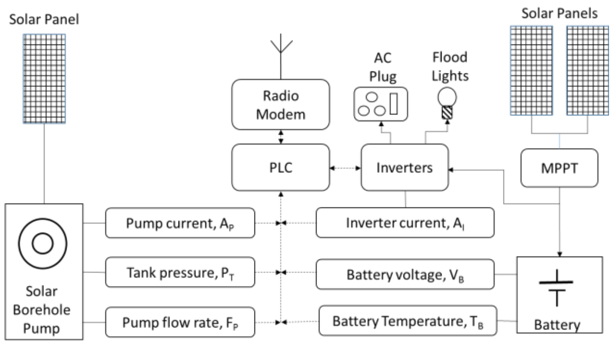

Figure 3: Remote Monitoring System architecture diagram.

The PLC was programmed to allow receiving of switching commands for the main inverter from the Display and Control Station. The PLC was configured as slave device in a MODBUS communication architecture. Data parameters sampled by the PLC were transmitted by the radio modem to the nearby Radio to Cellular Interface Station. Fig. 4 shows a photograph of the installed equipment in the Remote monitoring System.

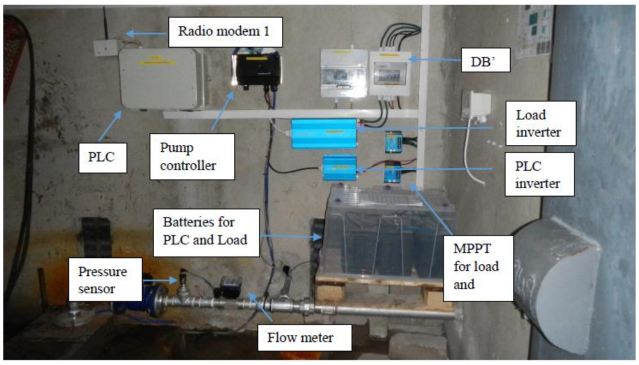

Figure 4: A photograph depicting the equipment installation in the pump house.

B. *Communication System*

The word Gwakwani means "armpit" in the local language of Venda. This is an apt description of the geography of the village situated in a depression next to a bend in the Mutale river. This depression resulted in no cellular signal availability at the location of the borehole pump house which housed the equipment of the Remote Monitoring System. The position of the cellular masts around the Gwakwani village is shown in Fig. 5. The absence of a cellular signal at the pump house necessitated the installation of a radio link to the Radio to Cellular Interface station which was positioned approximately 1 km away on a nearby hill side within the cellular signal range from cellular mast A. The cellular signal from the two additional cellular masts B and C were shaded by the hill and therefore not available.

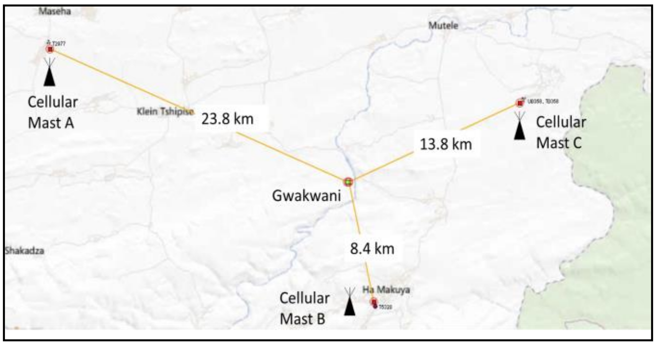

Figure 5: Geographic locations of the cellular masts around Gwakwani rural village. Cellular mast B and C were not within line of sight from the Radio to Cellular Interface station due to signal shading by the hill side.

The schematic diagram of the communication link from the Remote Monitoring Station at the pump house to the Radio to Cellular Interface Station on the hill side which is connected via the Global System for Mobile communication (GSM) signal to the internet cloud from where the Display and Control station interfaced with the pump monitoring equipment is shown in Fig. 6.

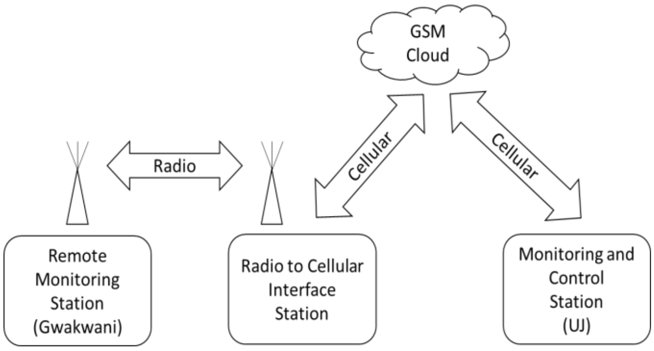

Figure 6: Schematic diagram of the radio relay link from the Remote Monitoring Station at the pump house to the Radio to Cellular Interface station on the hill side which is connected via GSM signal to the internet cloud from where the Display and Control Station interfaced with the pump monitoring equipment.

The Radio to Cellular Interface Station consists of a small 50 W solar panel connected through a maximum power point tracker (MPPT) to a 12 V battery. The MPPT also acts as charge controller for the battery. A radio modem RM848500D is connected to a Wavecom Q2303A GSM modem using a serial RS-232 connection. Electrical power supply for the modems are derived from the battery through DC-DC converters. The power consumption of the modems are less than 10 W. A schematic diagram for the Radio to Cellular Interface Station is shown in Fig. 7.

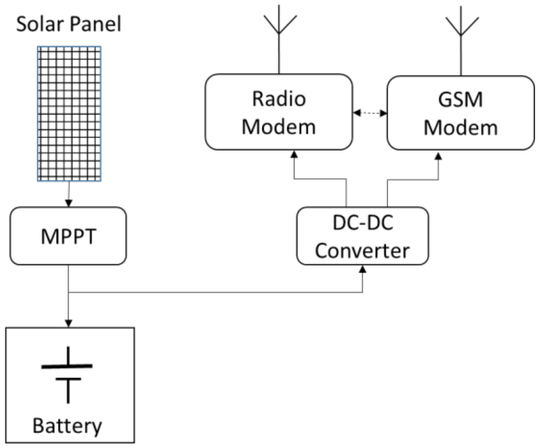

Figure 7: Schematic diagram of the radio relay link from the Remote Monitoring Station at the pump house to the Radio to Cellular Interface station

The MODBUS communication protocol is used between the slave PLC in the Remote monitoring System and the master PLC of the Display and Control Station. The equipment was installed in a steel cabinet which was mounted on a 2 m aluminium mast. The solar panel was mounted on the top of the mast. A position with clear cellular reception from cellular mast A was located on a nearby hill side also within radio line of sight of the radio modem located in the Remote Monitoring Station at the pump house. Fig. 8 shows a photograph of the installed equipment of the Radio to Cellular Interface Station.

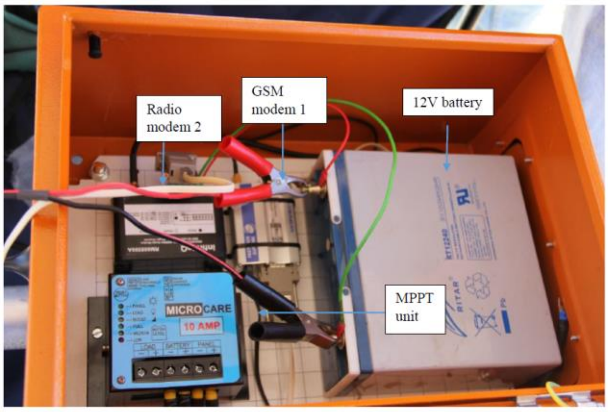

Figure 8: Photograph showing the installed equipment of the Radio to Cellular Interface Station.

C. *Display and Control Station*

The purpose of the Display and Control Station was to display the data parameters of the solar pumping system at UJ from where the performance of the pumping system could be monitored. The schematic diagram of the Display and Control Station is shown in Fig. 9. The Display and Control Station consisted of a Unitronics V1210 PLC with built in human machine interface [3] connected to a Wavecom Q2303A GSM modem. The PLC received and displayed the solar pump performance parameters from the Radio to Cellular Station.

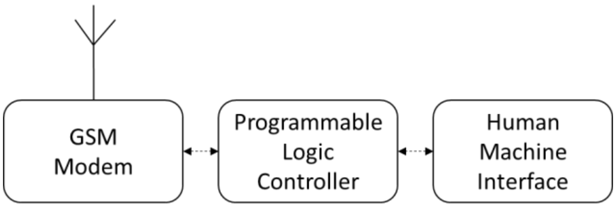

Figure 9: Display and Control Station architecture diagram.

The display of the solar pump operational parameters allows the monitoring of the pump performance enabling evaluation of solar water pumping system and early detection of possible problems.

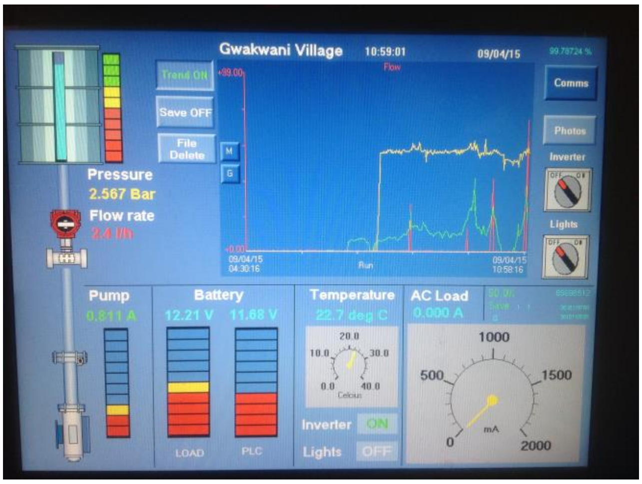

Figure 10: Picture showing the Display and Control Station interface.

The PLC was programmed to allow an operator to intervene by the switching off the main inverter which would disable the AC outlet plug and the LED security flood lights preserve battery power. Fig. 10 shows a picture of the Display and Control Station PLC display.

IV. System Results

The solar pump performance parameters are captured and displayed by the Control and Display System at UJ. Fig. 11 depicts the static water pressure as indication of the water level in the tank. At a pressure level of 256 kPa the tank is full and overflowing. An empty tank is indicated by a pressure level of 240 kPa as result of the pressure difference created by the elevation of the tank above the pressure sensor. Pressure sensor quantization noise of 1.7 kPa can be seen on the plot. The large pressure drops and spikes are caused by villagers opening and closing water taps in the water supply line. By monitoring the tank water levels a watering needs estimation for the Gwakwani village can be determined. The data storage capacity of the PLC allow long time trend analysis which could be useful in the seasonal watering needs estimation. From the graph it can be seen the tank can be filled from near empty to overflowing in one day, subject to good solar radiation conditions.

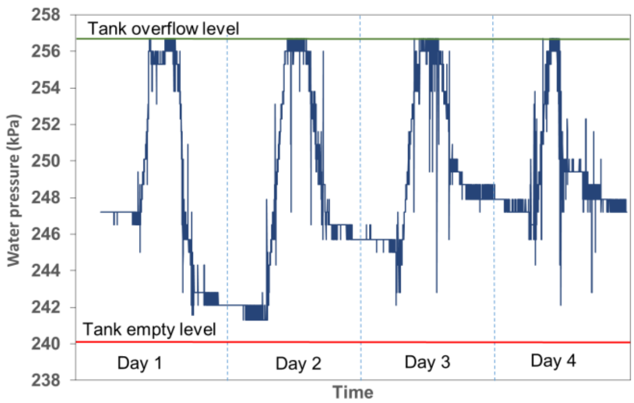

Figure 11: The output of the water static pressure senor over a period of four days. The water pressure when the tank overflows is 256 kPa and 240 kPa when empty as result of the elevation of the tank above the pressure sensor level.

The water flow rate as function of the solar pump current is shown in Fig. 12. The normal operational zone for the pump is indicated. When the flow rate is below the operational zone it is an indication of the onset of pump failure or clogging of the pump filters which would require maintenance. The graph shown in Fig. 12 is essential for pump health detection and early failure prevention.

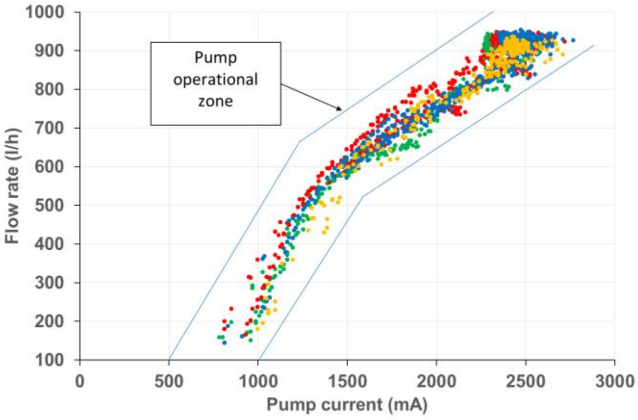

Figure 12: Water flow rate as function of the solar pump current. The operational zone of the solar pump is as indicated.

The health of the batteries supplying power to the Remote Monitoring System is determined from the battery voltage plot shown in Fig. 13. A number of events can be detected in the data plot labeled A to E and explained in the figure caption of Fig. 13. Additional data spikes are an indication of the main inverter switching in and out of stand-by mode when villagers load the system by using the cellular phone charging point. Monitoring the battery voltage over a longer period of time would provide an indication of the battery health status.

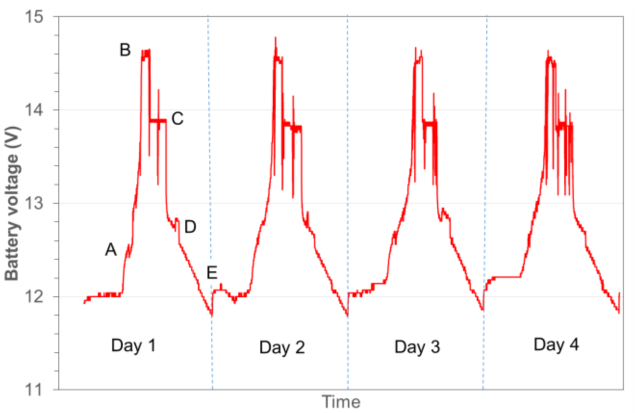

Figure 13: Battery voltage over a four day period. The following events can be identified:
A. Main inverter switched on at 10:00 AM.
B. Battery charger at maximum charge voltage of 14.6 V.
C. Battery charger voltage drops to 13.7 V for trickle charge.
D. Battery voltage change as result of LED security lights switched on at 18:00.
E. Battery voltage returns to 12 V after main inverter switch off at 12:00 PM.

The second parameter affecting battery health is the temperature of the batteries [5]. Gwakwani village is located in an area where the ambient temperature can reach as high as 45 °C. The batteries of the Remote Monitoring System are housed in the pump house. Fig. 14 shows a plot of the ambient temperature of the batteries. The graph shows the day rise and night fall of the temperature. A long term weather dependent rise of the temperature is evident in the rising trend of the graph.

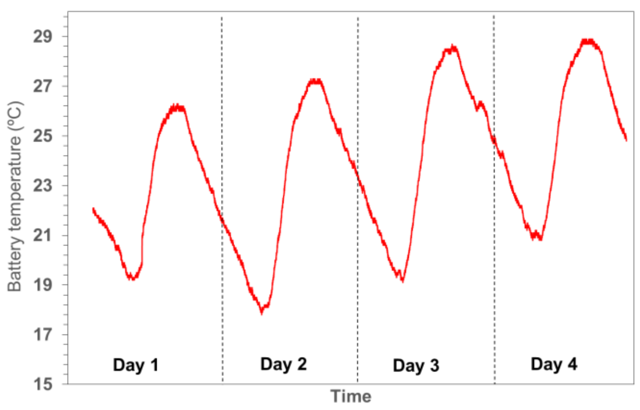

Figure 14: Battery temperature over a four day period.

V. Conclusion

The installation of a data link consisting of a radio link and a cellular network link between the rural village of Gwakwani and the University of Johannesburg enabled the implementation of a "giving and not forgetting" community service project. The availability of system performance parameters from the remote installation allows performance monitoring for the purpose of system health determination and preventative maintenance as shown by the data plots of the performance data received from the Remote monitoring System. Early detection of system performance deviation allows for preventative maintenance avoiding costly equipment replacement. This project provided broad range exposure from school learners to university students and lecturing staff to the plight of South Africans living in remote rural areas and brought the application of cellular technology to these rural people.

Acknowledgement

The contributions to this project from Grundfos, Vision Automation, Clever Devices and Aventura Tshipse are acknowledged.

References

[1] (2015) The Independent Examination Board Website. [Online] Available: http://www.ieb.co.za
[2] (2015) The IEEE Foundation Website. [Online] Available: http://www.ieeefoundation.org/epics
[3] (2015) The Vision Automation Website. [Online]. Available: http://www.visionautomation.co.za
[4] (2015) The Grundfos Website. [Online]. Available: http://www.za.grundfos.com
[5] IEEE Std 450-2010, *IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications*, IEEE Standards Association, IEEE Energy and Power Society

Rene Naidoo is a final year undergraduate electrical and electronic engineering student at the University of Johannesburg. She will be completing her undergraduate engineering studies in 2015.

Johan Meyer is an associate professor in the Faculty of Engineering and the Built Environment at the University of Johannesburg and appointed as Head of School for Electrical Engineering.