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Wireless Area Telemetry Network for Gas Detection: Indigenous Product Development in the Kingdom of Saudi Arabia

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Abstract

A high-profile VIP compound in Dhahran, Saudi Arabia, required monitoring of methane levels at 102 points due to excessive leaks in their underground natural gas delivery network. A wireless data acquisition and monitoring solution was developed for this purpose with the objective of reducing infrastructure work and cost, and decreasing human dependence for detecting and monitoring gas leaks, while maintaining reliability compared to traditional wired gas detection safety solutions.

To attain this objective, a state-of-the-art wireless data acquisition and monitoring system was designed, developed, and then implemented at the site. A wireless network utilizing VHF band was deployed as the system backbone. The system's advanced wireless detection modules with gas sensors were installed at each monitoring point. These detection modules reported to the fully redundant system controllers which were designed in-house, with information and alarms displayed at strategically placed monitoring stations to alert the trained personnel to take immediate action.

Establishing a stable wireless RF network allowed for a continuous stream of real-time data to the controllers from each gas sensor and an immediate alert of any gas releases. Historical data logs of the sensors allowed for identification of high risk points in the natural gas delivery network. SMS and email notifications were made available to further guarantee a prompt emergency response. Moreover, each advanced wireless detection module also allowed for monitoring of sensor and system diagnostics using proprietary analytics algorithms, thus allowing for timely preventive maintenance personnel to be deployed by the system operator and increasing system reliability and decreasing down-time.

This case study presents an overview of the design of a wireless safety system for the monitoring of a highly dense area installed with gas sensors and analyzes its reliability and performance. The case study outlines how such innovative wireless solutions can be utilized to provide communities with peace of mind while keeping infrastructure requirements relatively low.

Introduction

Saudi Arabia is one of the top producers of crude oil in the world and is reported to possess the world's largest reserves. It is also OPEC's largest producer. Saudi Arabia's economy is largely based on those facts.

According to the IMF, since the 1970s, expansive exploration and production operations have brought 90% of the country's export revenues from oil sales. O&G reports indicate proven oil reserves (2008 est.) to be 264.2 billion barrels, crude oil production average per day (2007 est.) to be 8.82 million bpd, and oil production capacity (2008 est.) to be 10.5-11 million bpd (USSABC, 2009).

The country's major oil reserves are spread across a large area in Ghawar (70 billion barrels), Safania (35 billion barrels), Khurais (27 billion barrels), Abqaiq, Berri, Manifa, Zuluf, Shaybah, Abu Saafa, Khurasaniyah, and more (USSABC, 2009).

Natural gas resources in Saudi Arabia are not as impressive but are estimated to account for 4% of the world's proven reserves (Svoboda & Yue, 2016). Reports indicate reserves (2008 est.) to be 257.8 trillion cubic feet, natural gas production average per day (2007 est.) to be 7.99 billion cubic feet, and natural gas liquids production average per day (2007 est.) to be 1.1 million bpd (USSABC, 2009).

Since 2008, despite the economic recession, Saudi Arabia is pushing forward with its Oil and Gas (O&G) development as necessary for global economy stability. In the period from 2009 to 2014, the upstream and downstream budget allocation included 17 mega-projects (greater than $ 1B), 30 large projects, 17 medium-size projects, and 30 small projects (USSABC, 2009). The O&G sector constantly demonstrates the need for engineering experience, design, and consulting.

Saudi Arabia is intent on expanding the role of the private sector in petroleum and energy support services by adopting new strategies for privatization. High level industry executives and government officials have stated that targets for industry expansion and new production will be met by private investments.

Underground Gas Delivery Worldwide

There are 2.4 million miles of natural gas pipelines in the United States alone with 300 thousand miles dedicated for transmission serving more than 71 million residential, commercial and industrial customers. There have been over 740 incidents associated with gas distribution and 100 incidents associated with gas transmission between 1994 and 2013 in the US alone, resulting in more than 300 deaths and 1,200 casualties. (AGA, 2014)

While underground gas delivery in Saudi Arabia is a rare occurrence, recent development projects have started utilizing such networks. Some examples of such projects are the King Abdullah Economic City, Rabigh, and various closed-gate communities scattered in the Eastern Province.

Currently used systems for detecting leaks in underground gas delivery networks range from the straightforward but unreliable walking, mobile or terrestrial/aerial vehicular surveys where Portable Gas Detection units or Imaging sensors are transported, measuring and reporting concentration levels; to sophisticated and intrusive hydro-testing and similar methods where gas supply must be interrupted. Both, surveys and intrusive tests, can only be performed periodically and do not provide real-time active monitoring and identification of leaks. Wired fixed gas detection systems are also used in underground gas delivery networks. They work in real-time, are highly reliable, but are severely cost prohibitive due to the civil infrastructure requirements.

Statement of Problem

The client, who is managing over a hundred VIP residences, provides cooking gas in addition to other utilities to the homes it is serving. The problem started when gas was smelled by one of the residents near to a distribution valve in the area. The leak was confirmed using a portable detector. Multiple similar incidents were reported. The client had to assign personnel to scan the area of any leaks daily on a regular basis. This approach was not only inefficient but also very costly. A definitive, on the spot, solution that enables fast emergency response was deemed to be required. No off-the-shelf system was able to meet the client's needs and as such, a custom solution was decided to be pursued.

Challenges and Strategy

The country's high-level, strategic plans for increased exploitations of new oil and gas sources in the coming years will provide further opportunities for more equipment and expertise. But low oil prices are causing budgetary pressures on capital expenditures that will indeed affect foreign investments and, in turn, sharply reduce local companies' share of trade and profitability.

Saudi Arabia is seeking to implement transformative projects focused on advanced manufacturing for long-term economic and social development to enhance sustainable development and create more jobs for citizens in the private sector. But efforts to stimulate innovation and enhance competitiveness at the national level have confronted serious human resources challenges. Although the number of engineers and scientists in the country has increased in the past few years, it remains low for the needs of the private sector. The deficit in engineering design skills and the inability of the labor to produce and manufacture systems and components to specifications as required by projects are among the most challenging difficulties faced by research in the Kingdom. (Wunsch-Vincent, S., 2012)

The Vendor recognized the onset of the economic pressure climate and the country's National Transformation Strategy for a diversified production base as a timely opportunity to test a new business strategy without theorization and interruption in its services to its most important clients. The Vendor's strategic direction was aimed at value creation and maximizing the earned economic value from its contracts through A) national managerial expertise with innovation and development inclination, B) proprietary intellectual property, and C) best-in-class, indigenous engineering skills.

After formally establishing the Engineering, Research & Development Department, the Vendor's immediate task was to recruit engineering resources to undertake the design and development of the gas detection system. In the Middle East region, engineering design, product development, and innovation are not drivers for the local economies. Recruiting local or indigenous engineers with the necessary experience is difficult. In Saudi Arabia's private sector, engineering resources are not abundant; they are modestly educated but unskilled. The insufficient number of engineering graduate students is an impediment for knowledge generation in the country. (Wunsch-Vincent, S., 2012)

The Product Development Approach

To meet the client's specific needs, a product development approach was adopted. In this approach, a project goes through the phases of requirements development, design, development, pilot, scale-up and closing. The design phase typically contains three milestones, known as engineering prototypes. In developing this system, requirements and product features were developed in close collaboration with the client. The client was very hesitant as it was their first time attempting a project involving product development conducted by a local Vendor. The Product Development Process (PDP) was followed to develop hardware for the controller and its operating system, the software for the system monitor and the design of the wireless network. Throughout the project, multiple prototypes for each item, as well as integrations between them, were demonstrated to the client, which in turn increased their confidence in the engineering capabilities of the Vendor.

Undertaking design and product development demands high productivity, high knowledge of theory, and excellent command over physics and mathematics, as well as high capacity for acquiring skill in computer-aided-design (CAD) tools. Engineering resources must possess fresh knowledge. Those are typically fresh or recent graduates. Based on experience, high work productivity is generally associated with high GPA academic performance. High performing fresh engineering grads are typically attracted by large, high-paying, semi-governmental or multinational companies. Therefore, hiring undergraduates seemed to be the best approach.

The Vendor's strategy shifted toward increasing youth participation through engineering design while under internship training supervised by competent and highly experienced product development engineering management. Engineering interns from well-reputed local universities were hired from various disciplines including embedded systems, electronics, electrical, software, and mechanical engineering. Interns were given specific theory, application, or research tasks that resulted in actual designs and proprietary technologies. Post internship, some interns were hired full-time to continue their innovation and creativity work with the Vendor. This strategy helped the Vendor acquire unique core competencies and build engineering capabilities not typical of a private-sector company in the Middle-East region.

Development of Concept

High Level Network & System Architecture

The approach taken in designing the network and system architecture focused on the objective of the delivered system: reliable safety and alarming system. Hence, many factors were accounted for, such as reliability, network availability, and redundancy. After analyzing the requirements, the gas alarms needed to be presented in two different physical locations (1 km apart approximately) simultaneously. The system was designed to consist of two networks: wired and wireless. An overview of the system architecture can be seen in Figure 1.

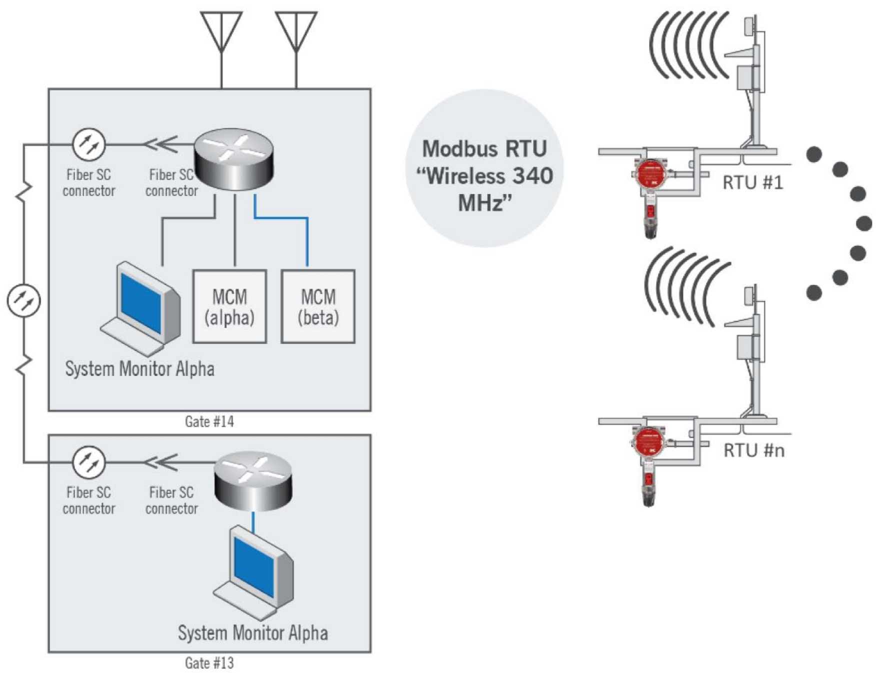

Figure 1—High-level architecture of the gas detection system

The wired network links the system monitors and the controllers over a high speed local area network. The system monitors are the users' interface to the entire system. The controllers (MCM) are responsible for acquiring all the information from the sensors (the RTUs) including gas readings as well as sensor diagnostic information. The controllers will also collect information about the status and the health of the network. System monitors and controllers can be installed in different physical locations.

The wireless network is established between the controllers and the RTUs. For maximum reliability, proprietary Very High Frequency (VHF) wireless links are utilized to avoid interference and to offer maximum availability and security. Directional antennas are installed on the RTUs to maximize the link-budget. This allows installation of the antennas at relatively low heights satisfying the client's preference for each RTU location.

System Communication and Redundancy

The wireless network is based on star to peer-to-peer topology to avoid disruption of the network if one or more link fails. The controllers poll the RTUs in a round robin manner for the gas reading and the diagnostics information. Once the RTU is polled, the information is collected, aggregated and stored on the controller and can be viewed on the system monitors within few seconds. Interrogation timeouts and delay between polls were optimized for the network size, maximizing the throughput, which contributes to enhancing the detection-to-alarm duration. Calibration and troubleshooting modes were designed such that no disruption in operation occurs.

A unique approach for redundancy is utilized in this wireless gas detection system. It starts with doubling the hardware for the controllers and system monitors while having the option to install each in a different location. With the star topology, only one controller can oversee the system at a time. Despite that, both controllers maintain the same level of "*authority*". In other words, the controller with better conditions (network connectivity and controller health) will take charge and the other controller will be on standby. In this proprietary redundancy algorithm, the controllers can switch control between them without the need for system monitors. Having one system monitor or more installed will further enhance the redundancy switching in terms of speed and reliability.

There are four states in which the controller can be in terms of redundancy: Autonomous In-Control, Autonomous On-Standby, Forced In-Control and Forced On-Standby. The controllers will determine the states that they should be in with the assistance of the system monitors. Conditions that are accounted for while determining the state include hardware failure(s), network failure(s), and weak wireless link(s).

System Description

RTUs

The RTUs in the system are responsible for measuring gas leaks underground, converting the measurement into a digital electrical signal and then making it available, along with diagnostic information, to the controller wirelessly. The RTUs can be line or solar powered. The sensors are in underground manholes, enabling a gas leak to be detected from pipelines and valves before it escapes to the environment.

Although the wireless frequency for the system was selected to be at the VHF (Very High Frequency) band for the reasons mentioned previously, the wireless module is not tightly integrated into the system. In other words, depending on the client or contract needs, the wireless communication can be at virtually any frequency.

Controllers

At the core of this wireless system are the robustly designed controllers. The controllers use the Modbus protocol to wirelessly interrogate RTUs. Standard Modbus is limited to 240 RTUs; however, the proprietary architecture of the designed system allows a maximum of 720 RTUs. The controllers also can interface with a SCADA or DCS system, allowing the wireless gas detection system to be one of many client systems at a location. Furthermore, the controller is equipped with a 7-inch display which is used to view valuable system and RTU information.

Two controllers are installed in any system, however only one is needed to wirelessly collect information from the scattered RTUs. The role of the second controller is to continuously monitor the wireless communication between the active controller and the RTUs. Should an interruption in communication be detected, the second controller automatically takes control of the network. Additionally, the second controller can be forced to take control if the active controller is unable to communicate with any of the system monitors. This redundancy feature is what gives this designed wireless telemetry system its exceptional robustness.

Inside of a controller are the following key components: an RF modem, a communication gateway, and a processing unit. The RF modem is the device that is used to communicate wirelessly over a specific frequency with the RTUs. The communication gateway is used to interface with the system monitor over a high-speed local area network. Lastly, the processing unit ties all the components together. It receives the data from the RTUs via the RF modem, processes them, displays them on the controller display, and responds to the system monitors data request to forward the information through the communication gateway.

The indigenously designed processing unit contains state-of-the-art technology. It is based around an eight-core microcontroller which processes data in parallel. This allows the processing unit to receive data over the RF modem while communicating with the system monitor, all in real-time. Due to the criticality of most applications, a watchdog timer circuit is used to recover the controller from any malfunctions.

System Monitors and Software

Two touch-screen enabled system monitors were deployed in the target residential district as part of the gas detection system. Operators and Engineers situated at two separate points use a developed proprietary SCADA software running on these system monitors to continuously supervise the underground gas delivery system for releases. The software can communicate with the controllers to display real-time sensor data. This data is represented in both map and tabular forms. Reports from the system can also be exported.

Color-coded critical and non-critical alarms appear on an "*Attention Panel*". This provides a summarized view of any system event requiring action. In case of a gas leak critical alarm, localized warning alarms also get triggered by the system monitors to alert all nearby personnel. These personnel then follow their set Emergency Response Plan immediately to minimize risk and thus reduce possible casualties. The layout of the software can be seen in Figure 2.

Figure 2—View of the SCADA software running on the system monitors

Results and Data

Network Bring Up, Stability and Availability

Theoretical and simulated RF studies were performed to verify network design parameters including the antenna locations, heights, gains, RF power output and feeder losses. A sample of the link budget simulation can be seen in Figure 3. The studies showed good to excellent fade margins for all wireless links (10 to 20 dB). All links were tested in the field and showed comparable results (±2 dB).

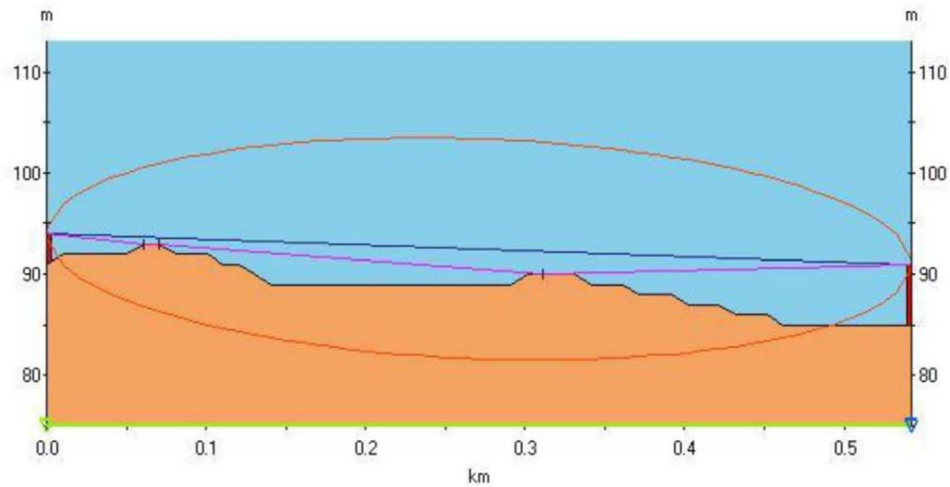

Figure 3—Sample of the link budget simulations between the controller and a RTU

At the first stage of the pilot, only 10 RTUs were powered up to test the stability of the network parameters. The RTUs were monitored closely for a month and reported a wireless availability of 98%. For the second stage, more RTUs were powered up and joined the network until full scale-up was achieved. The wired local area network achieved an availability of 99.9%.

Detection of Gas Leaks

The system has been in operation at full scale since mid-2015. On an average, 3-5 gas releases are detected per quarter. One such release can be seen in Figure 4. The figure shows the gas slowly accumulating at the RTU placed in House #32. The LEL reading finally exceeded the configured alarm level of 50% around 3 pm. Within seconds after the limit was exceeded, authorities were alerted as per the client's emergency response procedure, the service valve was shut to stop the leak, and emergency personnel were dispatched to the location; all within the next 15 minutes. Fortunately, no causalities occurred throughout this incident and crisis was averted. Examination of the data logs revealed the slow accumulation of methane. Note that the installed gas detectors have a maximum range of 100 % LEL, hence the saturation of the gas reading at that value.

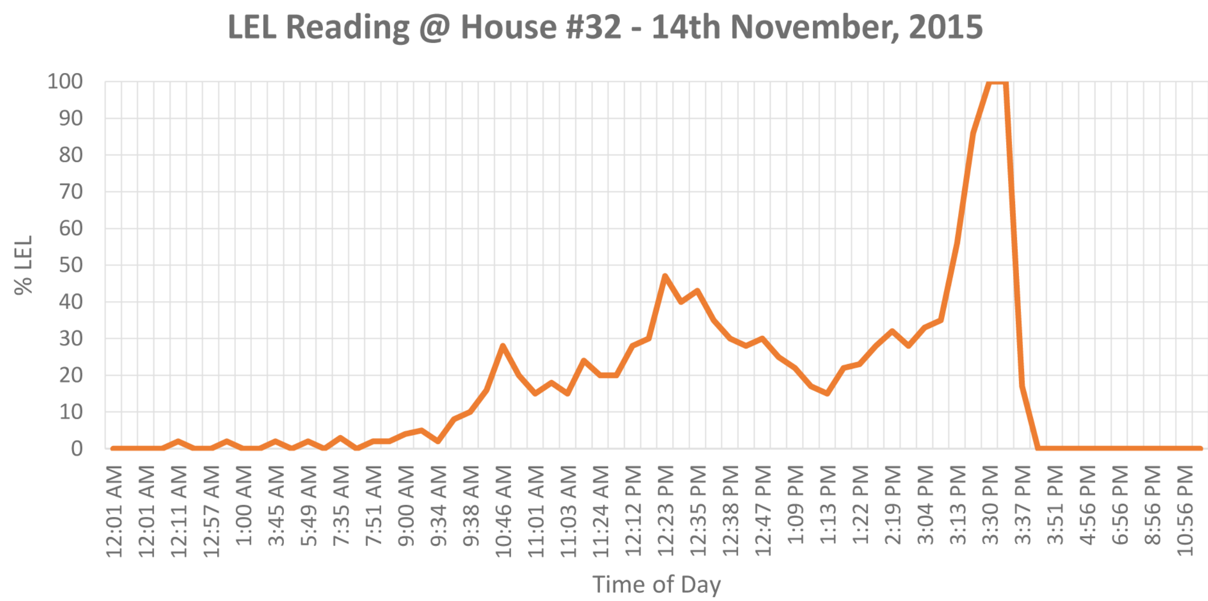

Figure 4—Plot of the gas readings leading up to and after a gas alarm detected by the wireless gas detection system

Throughout the operation of the system, various issues have arisen and been fixed. Although rare due to the dry local climate, rainwater tends to collect at the underground locations of the gas detectors. The water tends to cause false alarms. Periodic maintenance was put into place to prevent such occurrences.

Implementation of the wide-area wireless telemetry network based gas detection system in the client's VIP compound has seen great success. Over a single year, the system has led to a reduction in manhours spent detecting leaks upwards of a thousand. Consequentially, the yearly incurred cost for the client from daily surveying teams has reduced by more than a quarter of a million Saudi riyals.

Furthermore, leaks are now identified immediately, whereas, before the gas release could go undetected for days unless reported by a resident. Overall, the wireless system not only increases the safety of the residents of the compound, but also minimizes the hazard employees might face in manual surveys.

Conclusion

A wireless, wide-area telemetry network based gas detection system was designed and developed, using resources indigenous to Saudi Arabia, for the monitoring of methane release in an underground gas delivery network at a residential compound. This involved the design of a state-of-the-art wireless data acquisition and monitoring system utilizing the VHF RF band. Remote gas detectors were installed at each source of leak. Readings from the sensors were collected by the system's dual redundant controllers and reported by the system monitors at multiple locations. The wireless system was deployed and was able to successfully reduce human-dependence and labor costs, while decreasing the emergency response time, increasing the overall safety of the compound, and maintaining reliability comparable to traditional wired gas detection solutions.

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