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Remote Power Management System for Cellular Sites with Enhanced Features and Redundant Connectivity

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Abstract

In today's world, telecommunications infrastructure holds a significance to that of roadways in the early 19th century, serving as a vital link for governments and individuals alike. With heightened market competition and decreasing calling rates, coupled with rising expectations for Quality of Service (QoS), operators are striving to enhance QoS while optimizing resources to manage operational costs. However, challenges such as power shortages and fuel theft persist, leading to frequent network outages. To address these issues, a remote monitoring systems is proposed to prevent fuel theft and report electrical parameters remotely. This system proposes a redundant communication pathway using existing cell site's physical alarms, eliminating the need for additional servers and SIM cards. Notably, it enhances fault detection capabilities, particularly in detecting gradual fuel theft and addressing voltage fluctuations. These advancements promise to significantly reduce operational expenditure and increase network availability, thereby positively impacting cellular operators' revenue streams.

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1 Introduction

The telecom industry has made significant strides over the past couple of decades. Pakistan's teledensity has reached its peak with the highest number of phone service subscribers ever recorded. Most Pakistanis now own smartphones with SIM cards from multiple operators. While subscriber growth was rapid in the past decade, it has now stabilized. Subscribers no longer buy new connections but switch between networks based on competitive pricing and service quality [1, 2]. Meeting financial targets has become increasingly challenging for telecom operators. They now prioritize maintaining high-quality service and optimizing resources to reduce operational costs

(OPEX). Operators invest heavily in thousands of cell sites across the country, crucial for network coverage. These sites house various electrical and electronic equipment that require uninterrupted power supply.

Although the National Electrical Grid is the primary power source for these sites, Pakistan has faced severe power shortages for decades. Cities endure 8 to 10 *hours* of load shedding, while rural areas face 10 to 16 *hours*. Any power outage at a cell site results in loss of network coverage in the affected area. Consequently, every site is equipped with electrical generators that activate during grid failures. These generators run on diesel stored in on-site tanks. However, due to high fuel prices and its utility, significant amounts of fuel are frequently stolen from these tanks [3, 4]. Despite substantial OPEX allocations for fueling, network availability continues to suffer due to theft. Furthermore, electrical issues like voltage fluctuations and inadequate battery backup reporting compromise site availability.

Efforts are underway to mitigate these challenges at cell sites. Monitoring systems now track fuel levels and electrical parameters, each connected to servers via separate SIM cards. However, issues such as fuel theft are increasingly sophisticated and bypass current monitoring systems. Voltage fluctuations, which often lead to equipment failures, also go unreported, with no corrective actions taken. Moreover, these systems increase communication costs and server loads due to multiple SIM cards, complicating operations and maintenance.

To address these issues effectively, there is a pressing need for a Remote Monitoring System (RMS) with improved and cost-effective communication capabilities. Enhancements should include real-time reporting of voltage fluctuations and preemptive measures to prevent equipment malfunctions. Systems must be redesigned to detect and report instances of fuel theft comprehensively at cell sites.

In this paper, we propose utilizing existing cell site network transmission equipment to report fuel theft, eliminating the need for separate SIM cards. Additionally, this system will report electrical issues that impact network coverage. We also tackle the challenge of detecting gradual fuel theft that current systems overlook.

Section II reviews related work, while Section III examines the current Remote Monitoring System (RMS) deployed by telecom operators. Section IV outlines our proposed enhancements to address connectivity issues and introduce advanced features. Section V presents the results and discussion.

2 Related Work

Researchers have shown considerable interest in similar works aimed at practically resolving issues related to cellular sites. [5] explores system and methods utilizing wireless 802.11 protocol to control diverse power devices remotely. This architecture is not limited to power load control but also encompasses other types of control and metering devices. Additionally, [6] focuses on system and methods for energy management within an organization's infrastructure. This system communicates with mobile devices and executes power management commands on electrical and/or electronic devices, enabling monitoring and management of various operational aspects.

The authors in [7], have developed a remote fuel theft detection system capable of detecting fuel theft solely based on sudden changes in fuel level. Similarly, [8] is engaged in monitoring real-time fuel levels of vehicles and relaying this information to users' mobile devices. In another study, [9] utilized IoT devices equipped with sensors such as ultrasonic, vibration, and GPS, along with an ESP32 controller, for fuel theft monitoring in vehicles. Moreover, [10] has devised an IoT-based system that not only detects fuel theft but also reports the refilling process to monitoring devices. Additionally, [11] has created a system aimed at preventing fuel theft in trucks carrying oil tankers, featuring a security measure to allow only authenticated users to access the tanker.

An automated system has been deployed to monitor various fuel parameters at remote telecom sites, employing three methods for detecting and reporting fuel theft: flow sensor, ultrasonic sensor, and detection of fuel flow between the generator and tank [12, 13]. Furthermore, a fuel theft prevention system has been developed to prevent fuel theft and leakage from any vehicle, complemented by a mobile application for real-time fuel data dissemination to users [14].

3 Existing Remote Monitoring System at Cellular Sites

There are thousands of cell sites that provides network coverage throughout the country, relying on electrical power to operate their equipment. Without power, the sites go offline, resulting in no network coverage in their assigned areas.

The architecture of the existing RMS and the connectivity of its various entities are illustrated in Figure. 1 . The figure depicts how telecom equipment draws power from three sources. The primary power source is the National Electrical Grid, which connects to an ATS (Automatic Transfer Switch). The ATS then directs the AC electricity to a rectifier, converting it to DC for the telecom equipment, while the remaining AC power can be utilized for other equipment such as tube lights and air conditioners.

The secondary power source is a generator, which activates when the supply from the National grid is interrupted. The generator runs on diesel stored in a fuel tank attached to it. A fuel sensor in the tank reports the fuel level to the RMS. The electrical switching from the National grid to the generator is managed by the ATS, and the rectifier converts the AC power to DC.

The third power source is a battery bank, which operates when both AC supplies (National grid and generator) are unavailable. The battery bank exclusively powers the electronic telecom equipment. The RMS is connected to the fuel tank to log fuel levels or report any theft, and it is also linked to the generator for remote operation and status monitoring, including electrical parameters.

Additionally, the RMS is connected to the National grid supply to monitor electrical parameters and log them to a remote server. It is also connected to the equipment supply line to report power load and to the battery bank to report backup time. The RMS collects information from various equipment and transmits it to a remote server via a cellular network-based SIM card.

In Figure. 1, a dotted line from the telecom equipment to the RMS represents a novel approach proposed in this paper. This redundant communication path connects the RMS to the remote server using existing telecom network equipment and OMC software.

4 Proposed Solution for Enhanced Connectivity and Gradual Fuel Theft Detection

In this paper we propose an upgraded RMS system that will enhance the connectivity of existing system and additionally it will add features for detecting gradual fuel theft. This system will also report various important electrical parameters that are crucial for maintaining QoS of cell site.

The Figure. 2 illustrates the detailed connectivity of RMS system with different parts of cell site. The figure shows the electrical parameter of site are being measured and reported to micro-controller by the use of voltage and current sensors. The Electrical switching between Generator, National grid and Battery is done by using relays. The figure shows the connectivity of RMS is provided by the use GSM module, which make communication possible by the use of SIM card, the standard practice is to use two SIM cards per site (First from the same network and second a standby from another network). In case of 1000 cell sites would need 2000 SIM cards for communication to remote server. Therefore, the communication with remote server of RMS is not cost effective. Therefore, a new path from the existing network infrastructure is being proposed, shown with dotted (see Figure. 2).

In Figure. 2 the reports from different equipment are being sent now by cell site physical alarm equipment. Normally each cell site has physical alarm switches, which can be made ON/OFF, these ON/OFF status is being report to OMC server of the network. These switches show the triggering of some events to the remote server, e.g. battery backup is down, grid power is OFF etc. Normally there are 18 physical alarms, among which maximum 8 are used. We propose to use these extra spare physical alarms to report cell site different electrical/fuel parameters to OMC. These physical alarms are converted into large

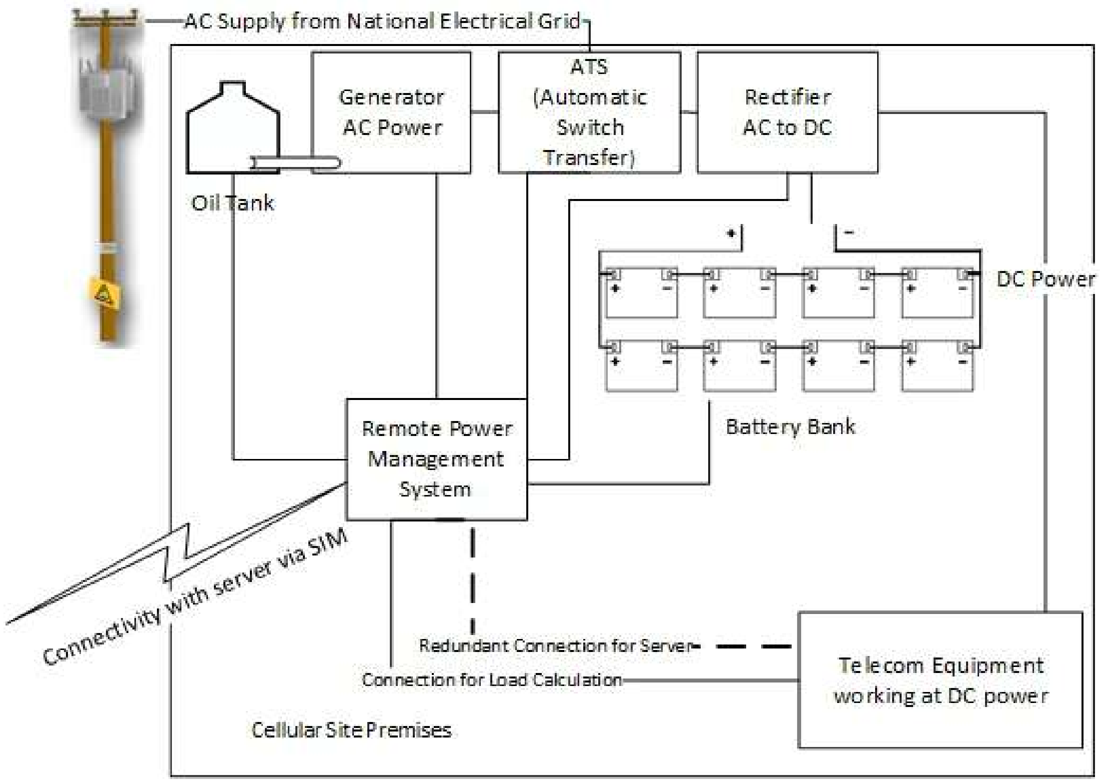

Figure 1. An architecture of existing RMS for cellular sites that reports various parameters to Operations Monitoring Centre *OMC* and executes various remedial actions.

numbers of logical alarms.

Figure. 3 illustrates the physical connectivity of RMS micro-controller with telecom equipment alarm switching ports. The figure shows eight ports that are connected with telecom equipment to report its network alarms like TRE_DOWN (alarm for show transmission equipment is down), ABIS_DOWN (air interface for transmission is down), CHANNEL_BUSY(the channel show busy can cannot take further communication load) etc. The remaining 10 ports are connected with micro-controller to report different RMS parameters like voltage values, fuel level, generator status, battery back time, equipment load etc.

There are 10 physical alarms available for the use of RMS system. These 10 physical alarms are converted into logical alarm by considering each physical alarm ports as single binary bit, and then the combination of whole 10 bits is use to represent logical alarms. With 10 bits we can have:

The Table. 1 illustrates how 10 physical alarms are converted into 1024 logical alarms/combinations. Now these 1024 combinations can represent and report 1024 different information/values from cell site to OMC server. 1024 logical alarms are in good number to represent the values of different parameters like fuel level, fuel theft, voltage, current, voltage

Logical	**Physical bits / Alarm ports**						
	1st	**2nd**	**3rd**	…	**8th**	**9th**	**10th**
0th	0	0	0	…	0	0	0
1st	0	0	0	…	0	0	1
2nd	0	0	0	…	0	1	0
3rd	0	0	0	…	0	1	1
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
1022nd	1	1	1	…	1	1	0
1023rd	1	1	1	…	1	1	1

Table 1. Conversion of 10 physical alarms to 1024 logical alarms

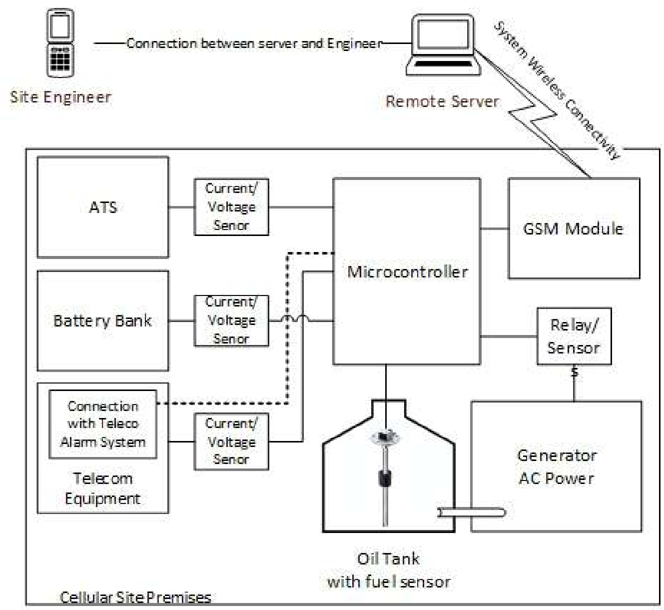

Figure 2. A detailed connectivity of RMS system with various parts of cell site. It also shows how measurement of various entities status via micro-controller and different sensors.

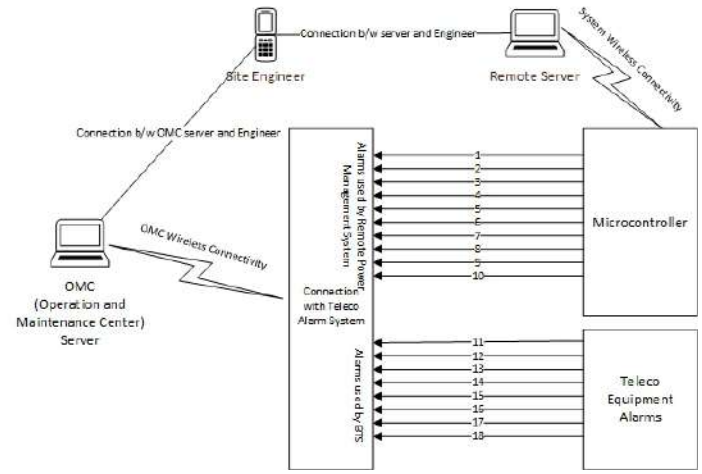

Figure 3. Connectivity of physical alarms of the telecom equipment with micro-controller of RMS for adding redundant path for reporting various site parameters.

fluctuation etc.

Logical	Physical bits / Alarm ports				
	1^{st}	2^{nd}	...	9^{th}	10^{th}
Fuel Reporting	x	x	...	0	0
National grid voltage reporting	x	x	...	0	1
Equipment load reporting	x	x	...	1	0
Battery backup time reporting	x	x	...	1	1

Table 2. Logical alarm bits assignment for reporting various parameters.

The Table. 2 illustrates how 10 physical bits are assigned to represent values of various site's parameters. The 9^{th} and 10^{th} bits are used to represents four combinations of reporting report fuel levels (00), voltage of National grid supply (01), Telecom equipment load (10) and Battery Backup (11). The rest of the eight bits (1^{st} to 8^{th} bit) can be used by corresponding each 9^{th} and 10^{th} bit combination (00, 01, 10 and 11, See Table.3). With 8 bits, each 9^{th} and 10^{th} bits combination would have 28 = 256 logical combination to represent the values of assigned parameters, e.g., if 9^{th} and 10^{th} bits are (00) then it represent fuel level reporting, with bits from 1st to 8^{th} we can have 256 different values which can represent 256 different fuel levels.

Logical Nos	Physical bits / Alarm ports 1^{st}	2^{nd}	...	9^{th}	10^{th}	Logical Names
0^{th}	0	0	...	0	0	0 litre
1^{st}	0	0	...	0	1	1 litres
2^{nd}	0	0	...	1	0	2 litres
3^{rd}	0	0	...	1	1	3 litres
⋮	⋮	⋮	⋮	⋮	⋮	⋮
39^{th}	1	1	...	1	0	39 litres
40^{th}	1	1	...	1	1	40 litres

Table 3. Logical alarm bits assignment for reporting various fuel levels.

The Table. 3 of illustrates, how 40 levels of fuel can be reported by using 41 logical alarms out or 1024 logical alarms stock. This table shows, if site have fuel tank of 40 litres. The proposed system of logical alarms is scalable, therefore you can have up to 256 litres of fuel tank, and such situation there would be need to increase the numbers of logical alarms for fuel reporting. For the Table. 3 the of 9^{th} and 10^{th} bit will remain (00) because this represents the reporting of fuel levels.

Logical	Physical bits / Alarm ports					Logical
Alarms	1^{st}	2^{nd}	...	9^{th}	10^{th}	Names
41	1	x	...	x	0	x litres theft

Table 4. How 41 levels of fuel can be reported by using logical alarms

The Table. 4 illustrates the combination of bits when any level of fuel is reported, however, there has been fuel theft on site as well, so therefore the fuel theft representation the 1^{st} bit should be high (1), the 9^{th} and 10^{th} bit should be (00) to represent fuel reporting values, and from bit 2^{nd} to 8^{th} can be any combination of Table. 4 to represents any level of fuel.

Similarly, the combination of bits can be used to report any voltage value of AC supply National grid and equipment load to the OMC server. The reporting of voltage will help the engineer to diagnose the faults in telecom equipment and AC supply. The telecom equipment is very sensitive to fluctuation in voltage, such report will provide aid for rectification of faults, and also it can be used to perform automatic or manual switching of AC supply to generator from National grid supply. We propose, programming at site micro-controller can be done to switch to generator supply from National grid in case there is more fluctuation in voltage in particular span of time. This switching instruction can also be issued from OMC as well. But it is suggested to do switching from site micro-controller, to avoid overloading OMC. As proposed in Table. 4 the value of 9^{th} and 10^{th} bit for voltage reporting will be (01) and equipment load (10).

The Tables.(1, 2, 3, 4) and Figures.(1, 2, 3) have illustrated how the redundant communication system can be established, how 10 physical alarms were used to create 1024 logical alarms, and how the different combinations of logical alarms can be used to report various values of fuel level, theft, voltage, current etc.

The Figure. 4 proposes the feature of gradual theft detection in RMS system. In existing RMS system, fuel theft cannot be detected when generator is running and fuel is taken from fuel tank gradually. In the proposed solution, such theft can also be detected as shown in Figure. 4. Fuel theft still will be reported if decrease in the fuel level is higher than the standard decrement + error (5%). When the generator is turned ON and it starts consuming fuel, and after the grid power is restored the generator gets turned OFF. The fuel consumption during that instance will be compared with the estimated fuel consumed and a margin of error in estimation will be set by the system Administrator. This margin can be set w.r.t to the quality of generator consumption consistency. This is an important addition to RMS and can large revenue of the operator's expense.

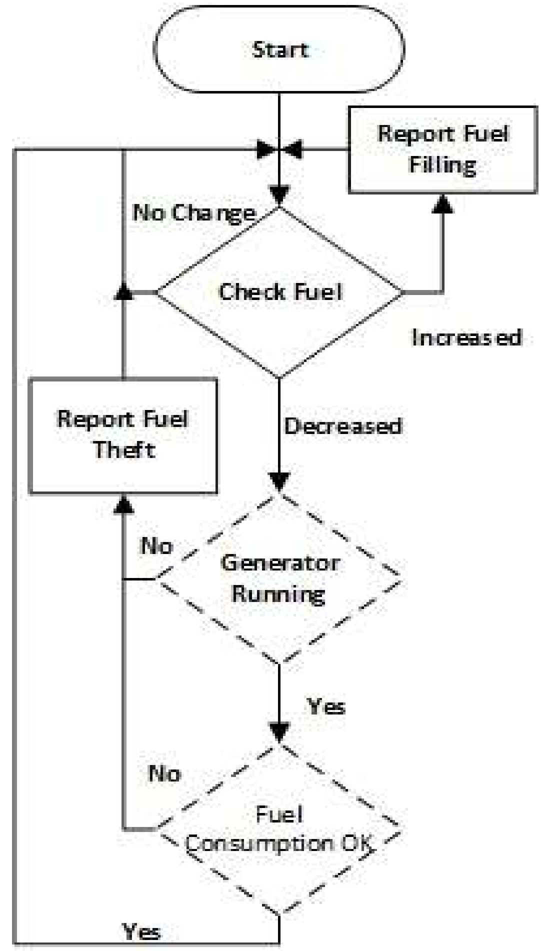

Figure 4. Detection of gradual fuel theft on site's fuel tank

$$\delta = \tau \times \kappa_i \quad (1)$$

The estimated fuel consumption δ is calculated using Equation. 1, which derives fuel consumption data from the generator manufacturer's datasheet. This datasheet specifies fuel consumption in liters at different load percentages (See Figure. 6 for load percentages). In Equation. 1, τ represents the generator's operating time in a given instance, while κ_i denotes the fuel consumption rate in liters per hour for a specific load, as provided by the manufacturer's datasheet.

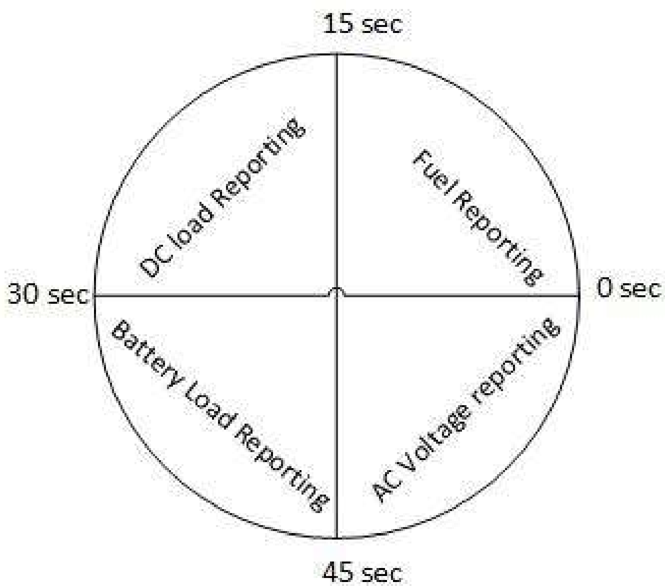

Figure 5. Reporting time (minute) of various site parameters

The Figure. 5 shows the reporting of alarms for four different purposes within the window of 1 *minute*. The logical alarms reporting can only be done serially due to sending of all 18 bits simultaneously at one time; Therefore, four different types of alarms are reported at different intervals of a *minute*. Between 0 to 15 sec the fuel information will be disseminated to OMC server. In the second quarter of *minute* between 16 to 30 sec the load of the equipment will be reported, where in the third quarter the battery load and in the fourth, AC supply voltages will be reported to server. The division of such reporting will have no queuing delay from site and will improve the system efficiency. With a good throughput, the time can be densely multiplexed to further increase the number of logical alarms reported from the site.

5 Results and Discussion

An Arduino-based experimental setup was developed and deployed for a 30 *kVA* power generator. Although this work focuses on issues related to power at telecom sites, access to an operational telecom site was not provided due to its sensitivity. Therefore, the experimental setup was installed on another offsite generator supplying power to a non-critical/non-telecom site. The site's load was varied to record and analyze varying load values, which are crucial for determining average fuel consumption. The generator operated for different duration with varying loads on different days, repeated ten times. Figure. 6 shows the load reported by Arduino sensors.

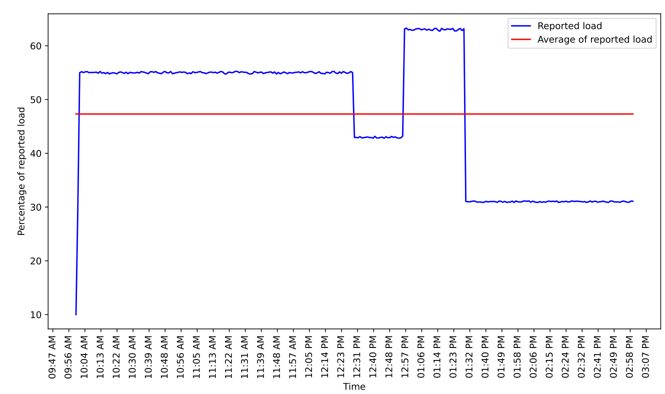

Figure 6. Load reporting from site to RMS system, varying load is successfully reported.

In the Figure. 6, Initially, the generator operated at 55% load from 10 am to 12 : 29*pm*, after which it was reduced to 43% for the next 30 minutes. Subsequently, the load was increased to 62% and finally reduced to approximately 31% for the last hour and a half. The sensor accurately verified and reported the load. In similar way, 10 instance of varying load were recorded and tested on proposed RMS system.

Real-time voltage reporting is another critical parameter. Figure. 7 depicts voltage readings during a period when power was supplied from the National grid for approximately five *hours*. The grid voltage remained stable at approximately 218 *V* for the first three *hours*. Intentional fluctuations were then introduced to test the system's responsiveness, which successfully reported the spikes shown in Figure. 7

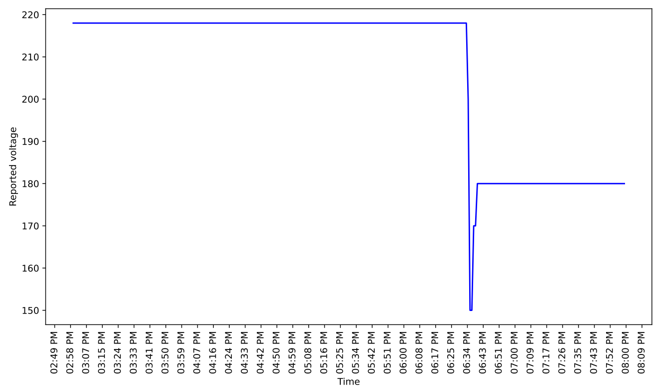

Figure 7. Reporting of various level of voltage with intentional fluctuation that is successfully reported by the system.

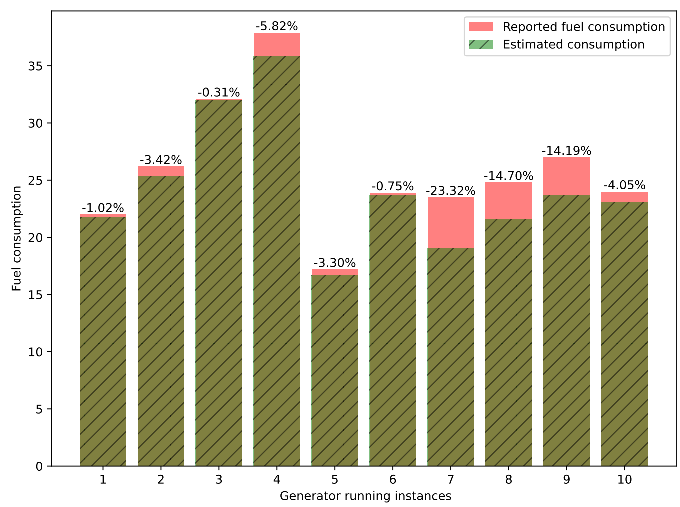

Figure 8. Reporting of fuel consumption against the estimated consumption to detect the fuel theft

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around time 06:34 *pm*. During the last *hour* shown in Figure. 7, the voltage intentionally was dropped to 180 *V* to verify accurate reporting by the system with varying values of voltage.

Similarly, the system reports load, voltage, and fluctuations from the generator, battery backup load and voltage, and National grid via physical alarms. Integrating digital pins with the cellular sites' physical alarms is essential for obtaining reports on various site power parameters and fuel consumption. However, at this stage of project such experimental connectivity was not possible.

Fuel theft detection is a crucial feature of the proposed RMS. Figure. 8 presents 10 instances where the site generator was activated to monitor and compare estimated fuel consumption against actual reported consumption. In Figure. 8, the red bars indicate the percentage difference between estimated and reported fuel consumption, while the green bars represent reported fuel consumption from the site. The negative percentages shows the reported fuel consumption is more than the estimation, and this can lead to fuel theft if certain set threshold of error is crossed. System administrators can set thresholds based on percentage differences to detect fuel theft on-site.

6 Conclusions and Future Work

The paper introduces a remote monitoring system with an enhanced connectivity concept aimed at reducing the operational expenditure of cellular sites. This reduction in OPEX primarily hinges on improved fuel theft detection. Additionally, reporting various site parameters utilizes existing physical alarms of the site instead of requiring dual SIM cards at each site.

The proposed system's features were initially tested on a local offline non-critical site to validate their effectiveness. All the important site parameters were successfully reported from local offline site, this ensure that the proposed system feasibility for deployment on the real-time operational cellular site. However, the full potential of the system can be realized by testing it on multiple active sites and integrating it with the telecom OMC system. The RMS can also integrate Machine learning models for accurately estimating the fuel consumption and reduce the margin of error. The collected data over time from RMS can be used to predict the faults in the telecom equipment due to various factors and take remedial actions.

Author Contributions

Mohammad Asif Khan: Conceptualization, Methodology, Software **Sajid Khan**: Data curation, Writing- Original draft preparation. **Khuwaja Haider Ali**: Visualization, Investigation. **Imtiaz Ali Halepoto and Sharjeel Afridi**: Writing- Reviewing and Editing

Compliance with Ethical Standards

It is declare that all authors don't have any conflict of interest. It is also declare that this article does not contain any studies with human participants or animals performed by any of the authors. Furthermore, informed consent was obtained from all individual participants included in the study.

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