INTERNATIONAL JOURNAL of SMART GRID
A. Al-Abri et al., Vol.6, No.1, March, 2022

Electricity Sector of Oman and Prospects of Advanced Metering Infrastructures

Ahmed Al-Abri*, Waleed Al Khalil*, Kenneth E. Okedu*‡

*Department of Electrical and Communication Engineering, National University of Science and Technology, PC 111, Muscat, Sultanate of Oman

*‡Department of Electrical and Electronic Engineering, Nisantasi University, Istanbul, Turkey

(ahmed190651@nu.edu.om, waleed190660@nu.edu.om, okedukenneth@nu.edu.om)

‡ Corresponding Author; Kenneth E. Okedu, Department of Electrical and Communication Engineering, National University of Science and Technology, PC 111, Muscat, Sultanate of Oman, Tel: +968 9144 6270, okedukenneth@nu.edu.om

Received: 10.03.2022 Accepted:30.03.2022

Abstract- Advanced Metering Infrastructures (AMI) help utility providers and customers to better control the use and production of electrical energy. Recently, AMI development was carried out for better energy efficiency and smart grid operations in Oman. Some benefits and functions of AMI were analyzed in this paper, considering the expected challenges that might be faced during its implementation in the power distribution grid of Oman. In addition, three design topologies of employing AMI in the power grid of Oman were investigated and compared, based on their economic benefits. Recommendations for the best practices in expanding the use of AMI, in the Oman power sector were given.

Keywords Advanced metering infrastructure, energy, tariffs, current transformers, grid operations.

1. Introduction

Advanced Metering Infrastructures (AMI) is the technology of automatically collecting the consumption, and diagnosis of data status from water meter or energy metering devices (gas, electric) and transferring these data to a central database for billing, troubleshooting, and further analyses [1-4]. This technology mainly saves utility providers the expense of periodic trips to each location to read a meter. Another advantage is that billing can be based on near real-time consumption rather than estimates based on past or predicted consumptions [5-7]. The timely information obtained from the analysis of AMI can help utility providers and customers to better control the use and production of electrical energy.

AMI devices are electronically matched with accounts. As an advanced technology, additional data could then be captured, stored, and transmitted to the main computer. Often, these devices could be controlled remotely. This can include events alarms such as tamper, leak detection, low battery, or reverse flow [8-10]. Many AMI devices can also capture interval data, and log meter events. The logged data can be employed to collect or control the time or rate of data used in; water or energy usage profiling, time of use billing, demand forecast, demand response, rate of flow recording, leak detection, flow monitoring, water, and energy conservation enforcement, remote shutoff, e.t.c., [11-14]. AMI is the new term coined to represent the networking technology of fixed meter systems that is beyond the Automated Meter Reading (AMR) technology, considering remote utility management. The meters in an AMI system are often referred to as smart meters since they can often use collected data based on programmed logic.

Mazoon Electricity Company (MZEC) is a shareholding company in Oman, established pursuantly to the promulgation of the Sector Law (Royal Decree 78/2004 and amended by Royal Decree 59/2009) [15-16]. MZEC is authorized to carry out regulated activities of distribution and supply of power in AlDakhliya, South Sharqiyah, North Sharqiyah, South Al Batinah governorates, and Al Suwaiq, under the license issued by the Authority for Electricity Regulation (AER) in Oman [17-19]. The head office is situated in Sayh Al Ahmer, Bidbid. The company's main business is to construct 33 kV, 11 kV, and Low Tension (LT) networks, their maintenance, customer connections, distribution and sales of electricity, in the authorized areas [20-21].

This paper presents an overview of the electricity sector of Oman and illustrates a case study aimed at the evaluation of the economic impact of expanding AMI at MZEC in the Oman power network, for possible renewable energy penetration [22-23] and smart grid applications [24]. Some of the contributions of this paper are:

- To introduce the MZEC data analysis of existing energy meters in Oman
- To illustrate information about AMI, its methodology, and benefits
- To carryout risks assessment and impact of not employing AMI in Oman, and
- To analyse and compare the different topologies of installing AMI and their implementation costs in Oman.

2. Overview of Advanced Metering Infrastructure Development

Advanced metering systems can provide benefits for utilities, retail providers, and customers. Benefits will be recognized by the utilities with increased efficiencies, outage detection, tamper notification, and reduced labor cost, as a result of automating readings, connections, and disconnections. Retail providers will be able to offer new innovative products in addition to customizing packages for their customers. Besides, with the meter data being readily available, more flexible billing cycles would be provided to their customers, instead of following the standard utility read cycles. With timely usage information available to the customers, benefits will be seen through opportunities to manage their energy consumptions based on actual metering data.

AMI could be used in data management and communication systems to enhance a two-way channel of communication of utilities and end users' consumption of electrical energy at a higher frequency [25], making it widely used in many countries. A lot of data processing is required in demand side management in order to understand the patterns of the load, optimization of the power distribution grid, manage reserve and responses of the power grid frequency. The collection of these data is vital for power suppliers and operators of the distribution system to know the customer's behavior and market signals. Reference [25], employed big data, data mining, and predictive analytic approaches for high computing performance of AMI systems. A study on AMI in modern power grids was carried out in [26], where advanced metering systems consisting of digital information technologies, were designed with hardware and software models. The designed model was able to enhance the remote communications of the smart meters at the terminals of the end-users or service providers.

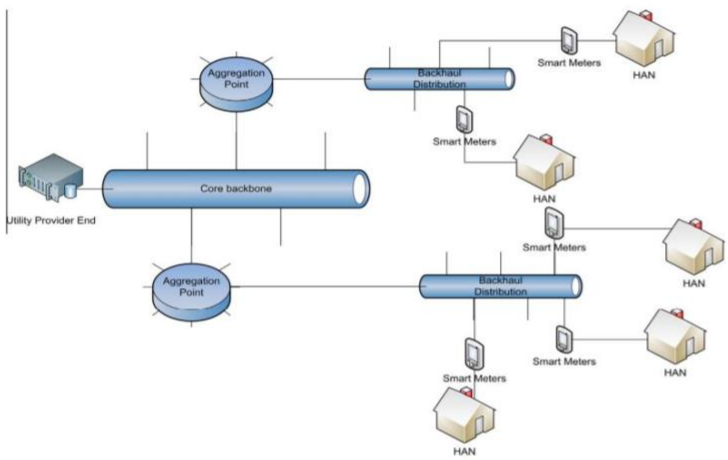
Several analytic schemes have been developed on smart metering data as part of AMI implementation, as reported in [27], for the case of Puducherry, India, that is a smart grid pilot project. In this study, the analytic metering data extracted at different resolution and horizon times, helped in the supply of steady power. Identification of the challenges in the existing distribution system and manner of proper operation was done by energy audit. The study reported that integrating the analytic management information system would give idea of the network performance index, demand growth and power supply quality, for a proper decision making process. In addition, consumers would know behavior of their consumptions, to enable them control and optimize use of the supplied power. More so, consumers would be able to take part in demand response program and effectively manage available resources.

A comprehensive survey study on the role of AMI on smart grids, was carried out in Reference [28], as part of feasibility study for net-zero community creation in Ontario, Canada. The authors of the paper introduced AMI technology and its current status, as smart grids foundation, that enables the collection of data and consumers' load pattern information. The study further explained the features of smart grids and the three main subsystems of AMI along with security issues. An overview of the subsystem sequence of a smart grid development, AMI representation, and utility network with smart meters are given in Fig. 1 based on Reference [28]. Fig. 1 shows the various subsystems of smart grid development and the AMI representation considering data collection, storage facilities, the various communication networks and end user devices, with respect to a typical utility layout with smart metering operations.

The security concerns in AMI is very vital and has recently become a critical issue in the operation of smart grids. Over the years, there are improvement topologies in the safe operation of AMI systems. A remote detecting technique was proposed in [29], for illegal electricity usage considering smart metering, while in [30], genetic support vector machines were used in abnormalities detection and electricity theft. A mathematical approach for energy theft identification and tampering of meters based on central observer meter, was proposed in Reference [31], while a comparative analysis of electricity theft [32], and the overviews, issues and preventions, using smart meter based approach for theft control was presented in [33]. These techniques were further extended to the security improvement of the AMI system. In Reference [34], electricity thefts were minimized using smart meters in AMI, while in [35], possible cyber security issues for AMI were analyzed and solutions were proffered for safe operations.

In light of the above benefits of AMI and the ways of overcoming the security issues in its operation, many utilities are moving towards implementing some types of AMI solutions. In the near future, AMI may be required by law [36]. The benefits of AMI in Oman for utility systems are shown in Fig. 2, and this could be extended to the neighbouring Gulf Corporation Countries (GCC), to consider AMI in the near future, as a prospect in their power grids.

(ii). AMI representation.



(i). Subsystem sequence of a smart grid development.

(iii). Utility network with smart meters.

Fig. 1. Overview of advanced metering infrastructure

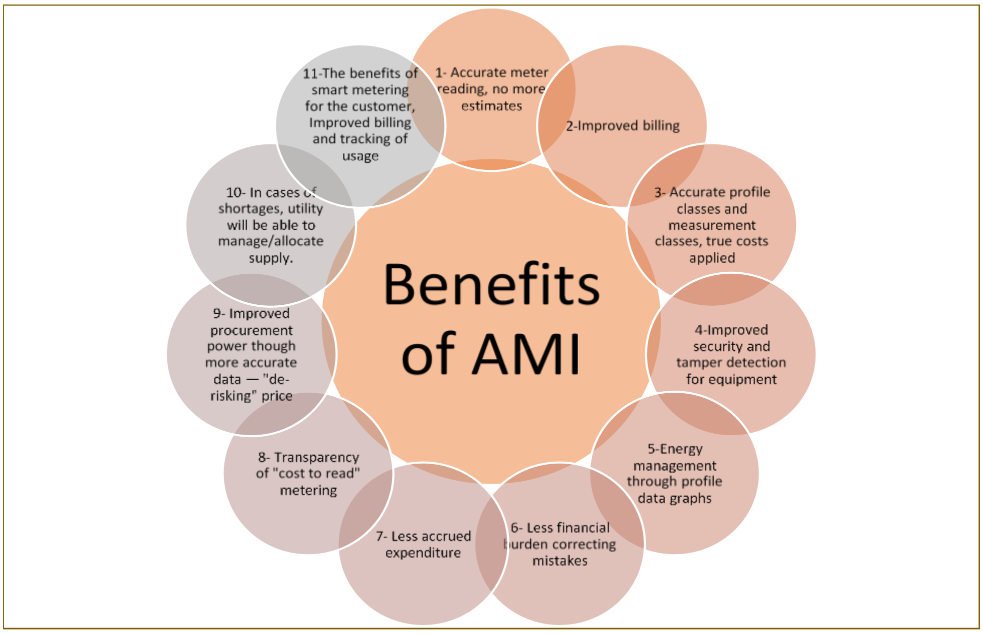


Fig. 2. Benefits of advance metering infrastructure in Oman.

3. Business Models of AMI in Oman

A business model for Nama Shared Services (NSS) was defined in October 2017 [37] and it was derived from the Nama's holding strategy, to deal with new challenges derived from the restructuring of the power sector and to proactively propose advanced technological solutions that improve the Distribution Companies (DisCos) operational efficiency. The business model developed in Fig. 3, is a reflection of the realized strategy and describes the logic of the company, the way that it operates, and how it creates value for its stakeholders.

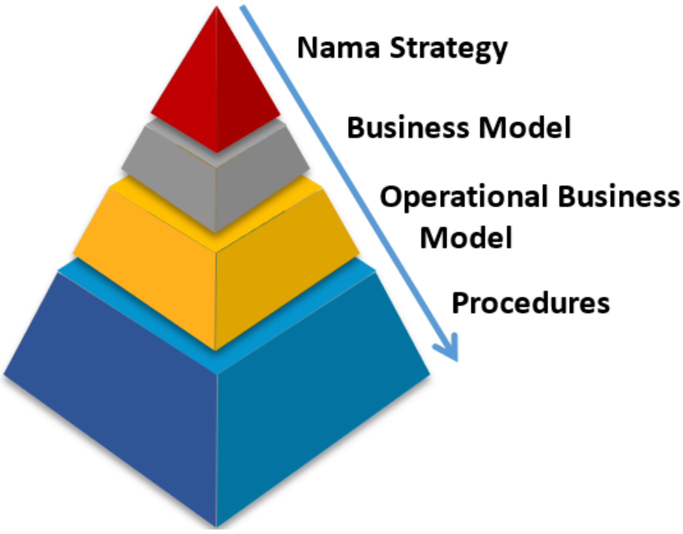


Fig. 3. Strategy and operational business model of AMI in Oman.

In order to deliver the value to all DISCOs, it was required to restructure the Electricity Holding Company (EHC) and create the NSS as a separate company, and to develop an operational business model to describe how the services will be delivered. Therefore, the operational business model describes the way that a business and the core processes are structured and how NSS delivers the value.

To effectively implement the operational model, proper tools with important degrees of automation are required as well as a suitable organization from the side of the provider of services and the beneficiary of the services. The tools to be used to provide these services are:

- The AMI system
- The MDM (Meter Demand Management) system
- The automatic integration between the MDM system and the Customer Relation Management (CRM) and billing systems.
- The automatic ticketing system to properly track the customer requirements and to measure the efficiency in the service delivery.

Service Level Agreement (SLA) with the correspondent Key Performance Indicators (KPIs) is developed to be in place as a contractual instrument to enable the operational business model to run effectively. Table 1 and Fig. 4 show the number of licenses of the AMR system split for each distribution company. It shows that MZEC has 5,971 Health Safety and Environment (HSE) licenses and 11,942 MDM licenses. Currently, MZEC has reached 3,800 AMR connected to NSS and 1,200 connected to Vijintic, India.

Table 1. Licenses for distribution companies in Oman.

Company	HSE Licenses (Each)	MDM licenses
MEDC	10,457	20,914
MZEC	**5,971**	**11,942**
MJEC	4,770	9,540
DPC	2,705	5,410
TANWEER	1,097	2,194
Total	25,000	50,000.00

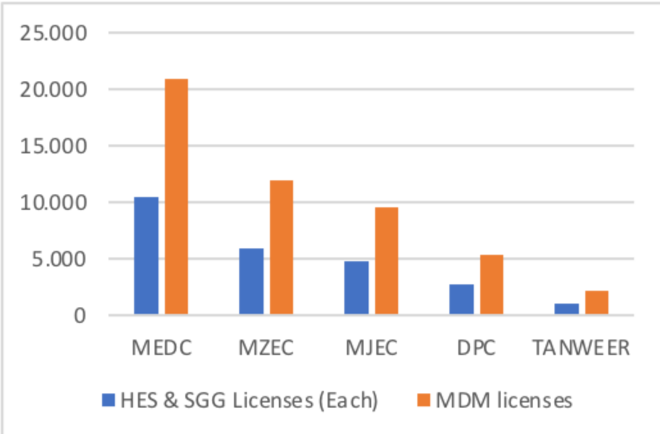


Fig. 4. Operation licenses for distribution companies in Oman.

4. AMI and Traditional Metering Scheme in the Distribution Power Network of Oman

A study was been done for only 2,809 meters, to be replaced by smart meters and digital meters for both AMI and old meter replacement programs, from June to December 2019. The result shows that there was very significant consumption growth due to the following reasons but not limited to:

- Tamper cases detection
- Mismatch of meter size and meter type
- Different accuracy between ordinary meters and smart meters.
- Wrong wiring connection detection
- Defective meters
- Wrong multiplication factors used
- Wrong readings by meter readers.

In order to have a clear picture of the historical data, with respect to the normal growth expected, a four-year comparison is been demonstrated and the results are shown in Table 2. It can be observed from Table 2, that AMI consumption for 12 months between 2019 and 2020 is 59,694 kWh for each with OMR 895.415 and digital meter consumption for 12 months between 2019 and 2020 is 7,189 kWh for each with OMR 107.8. Table 3 and Fig.s 5 and 6 show the AMI, traditional readings and digital readings for the studied period. From Table 3, the average consumption and revenue per meter per year is as follows:

* AMI = MWh 235,512.75 consumption for 1,863 units, which is MWh 126.415 per meter. The revenue of each meter in this type is OMR 5,701.8.

* Digital = MWh 149,899 consumption for 787 units, which is MWh 47.617 per meter. The revenue of each meter for this type is OMR 235.07. The digital meter has only 4.1% of the total cost compared to AMI.

The AMI system will be added value to the MZEC operation when dealing with many issues, including the new tariff adjustments in terms of time and costs, as well as accurate and on-time reading collections. Fig. 7 shows the percentage contribution of the various governorates of Al Dakhiliah (DH), North Al Sharqyiah (NSH), South Batinah (SB), South Sharqyiah (SSH), where SB is the highest with 37%, compare to the other contributions. Fig. 8 shows the number of meters replaced by AMI for the different governorates, where SB is the highest with 54%, while Fig. 9 illustrates the number of meters replaced and their contributions in each district.

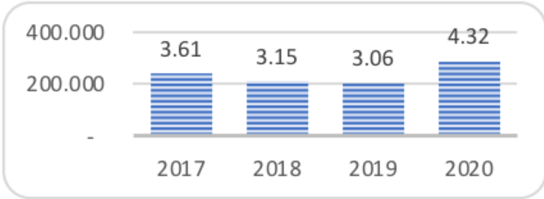


Fig. 5. AMI and traditional readings.

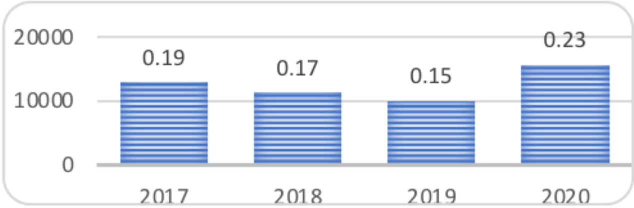


Fig. 6: Digital meter reading.

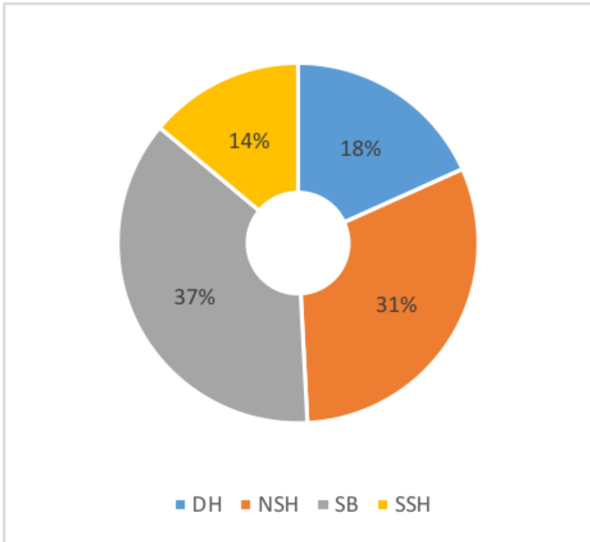


Fig. 7: Percentage contribution of the various governorates.

Table 2. Meter replaced by MZEC in the distribution power grid of Oman.

Meter replaced (MZEC)	Number of meters	Consumption of 12 months back starting (May-2019) (kWh)	Consumption of 12 months back starting (May-2020) (kWh)	Difference (kWh)	Difference in Omani Rials (OMR) *1OMR = 2.6 USD*
Smart meter (AMI)	2001	226,119,120	345,567,482	119,448,363	1,791,725
Digital meter	808	10,155,702	15,964,247	5,808,545	87,128
Total	2809	236,274,822	361,531,730	125,256,908	1,878,854

Table 3. AMI and traditional meter readings in the Omani distribution power grid.

	Meter Type	No meters	Net consumption	2017	2018	2019	2020
2,650 accounts of historical data	AMI	1,863	MWh	240,353	210,032	203,925	287,741
			Million Omani Rial (MOMR) (Assume tariff cost 0.015 OMR)	3.61	3.15	3.06	4.32
	Digital meter	787	MWh	12,930	11,341	9,997	15,631
			MOMR (Assume tariff cost 0.015 OMR)	0.19	0.17	0.15	0.23
	Total	2,650	MOMR (Assume tariff cost 0.015 OMR)	3.80	3.32	3.21	4.55

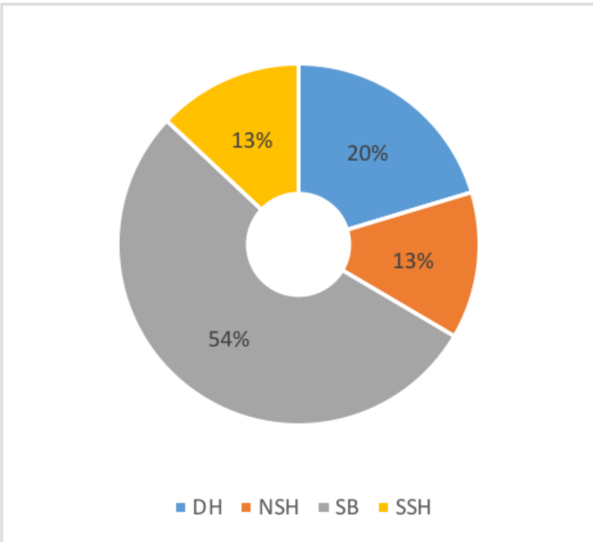


Fig. 8. Number of meters replaced by AMI.

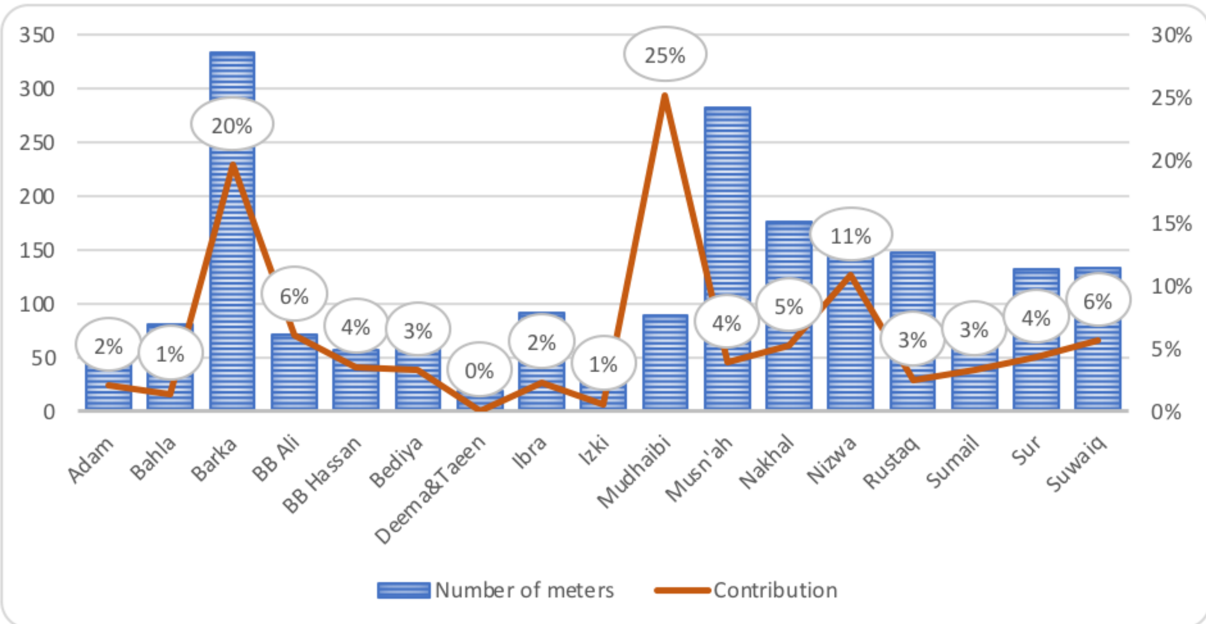


Fig. 9. Number of meters replaced by AMI and their contributions in Omani Power Grid.

5. Challenges with Existing Metering Schemes in the Power Grid of Oman

There are a lot of problems faced with the existing metering connections in the distribution power network of Oman that affects consumption readings. Some of these problems are:

- Wrong wiring/connection detection
- Tampered/meter connection
- Mismatch of meter size and meter type (CT ratio mismatch)
- Difference in accuracy between ordinary meters and smart meters.
- Defective meters.
- Wrong multiplication factors
- Wrong meter readings.
- Compliance by customers
- Demography of MZEC area
- Properties/meters location (could not be reached due to COVID-19 pandemic).

These problems lead to non-technical power losses of electricity and this will influence the loss of the company's revenue and its reputation. It also leads to the company's non-compliance with the target achievement of losses as approved by AER. Hence, MZEC spends a huge amount of money to do an energy audit, for testing the accuracy of meters and replacing defective meters and old meters, in order to mitigate the problem. Moreover, a large proportion of meters were installed in the wrong way with non-matching customer consumptions. Due to this, the meter reading collections will be less than the real consumptions, which lead to losses. As a result of the above-mentioned problems, MZEC was penalized and required to pay more than OMR 10 million in the last four years. In order to solve this problem, it is important to employ a developed algorithm for the calculation of power and energy losses, and the anomaly detection framework for security concerns in the operation of the proposed AMI scheme in Oman.

6. System Losses in the Power Distribution Network of Oman

In 2014 and 2015, MZEC got an incentive by achieving the losses target that is approved by AER. From 2016 till date, MZEC could not reach the target losses, consequently, penalties of approximately OMR 10.6 million in 2016, 2017, 2018, and 2019 were given by AER of Oman. These penalties will continue if MZEC does not take any action to reduce losses to achieving the target. Table 4 shows the incentives and penalties of MZEC from 2014 to 2019.

Table 4. System loss penalties and incentives for MZEC.

System loss		
Year	**Incentive**	**Penalty**
2014	244,638	
2015	628,774	
2016		(304,573)
2017		(859,530)
2018		(5,360,188)
2019		(4,087,513)
	873,412	**(10,611,804)**

From Table 4, MZEC in 2018 started auditing meters for accuracies and installations, and 103 cases were found in government offices, that were not in proper connections; either wrong connections or tampered, resulting in recovery losses of about OMR 113,250. On the other hand, 1,687 cases in the private sector were also not in proper connections and the recovery loss of these cases is OMR 811,368. Table 5 shows the cases encountered for 12,000 auditing meters only. This means if there are 1,790 cases of non-proper connection for 12,000 meters audited, then there will be 67,125 illegal connections for 450,000 meters. These illegal connections cost MZEC, a huge amount of money with calculated losses of nearly OMR 4.5 million a year, as per the target approved by AER.

7. Economical Evaluation of the Installation Options of AMI in the Power Grid of Oman

This section discusses the three proposed options for the installation of AMI in the distribution power network of Oman, for technical and financial assessments based on current data. The three options and their structures are summarized below:

Option-1: All CT meters to be replaced with smart meters and AMI.

Replacement of 13,342 CT meters with smart meters and AMI will represent only 3% of total non-smart meters in the MZEC network. This percent will not affect the reduction of losses and the problem will remain the same, without any way forward to solve the issue.

Option-2: All CT meters and all three-phase meters to be replaced with smart meters and AMI.

Replacement of 243,013 3-phase meters and CT meters with smart meters and AMI will represent 55% of total non-smart meters in the MZEC network. This investment will help to reduce approximately 50% of MZEC non-technical losses, which is better than Option 1.

Option-3: All MZEC meters to be replaced with smart meters and AMI.

Replacement of 444,537 single-phase meters, 3-phase meters, and CT meters with smart meters and AMI, will represent 100% of total non-smart meters in the MZEC network. This investment will help to reduce approximately 95% of MZEC's non-technical losses, which is better than options 1 and 2.

In order to select the best option of AMI installations in Oman, it is imperative to compare the three alternatives. The connection topologies of the different options are shown in Fig. 10. Table 6 and Fig. 11 show the comparison of the metering options in terms of new investment and expenditures. The breakdown of the savings and investments are shown in Table 7 and Fig. 12, respectively.

Table 6 also shows the investment spent to replace all meters with smart meters and AMI, in order to achieve the percentage reduction in losses in each year until it reaches approximately 95% of reduction. Option-3, with replacement of 444,537 single-phase meters, 3-phase meters, and CT meters with smart meters and AMI requires an investment of OMR 52,587,467 by MZEC from 2021 to 2030. Therefore, it is recommended to separate the capital cost into five years as shown in Table 8, as this will help to divide the investments spent for five years, with the next five years spending of the operational cost of the investment.

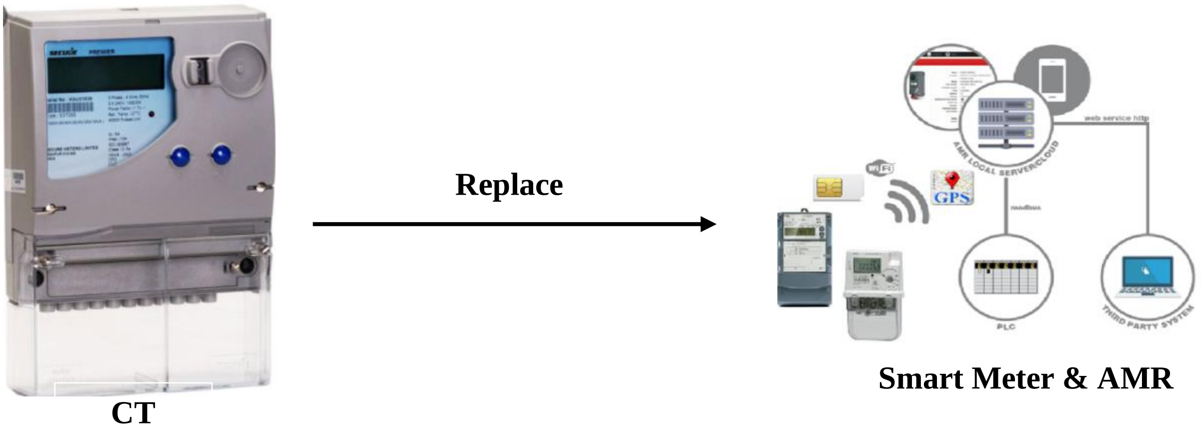
Table 5. Tampered and wrong connections for MZEC network.

Description / year	Total account No.	Adj_amount	Usage_units
GOVERNMENT			
2018	15	9,435	542,454
2019	47	17,871	2,318,594
2020	41	85,943	3,952,556
Total	103	113,250	6,813,605
PRIVATE			
2018	369	89,853	9,807,886
2019	692	566,408	34,526,142
2020	626	155,107	9,166,963
Total	1,687	811,368	53,500,991
Grand Total	1,790	924,618	60,314,596

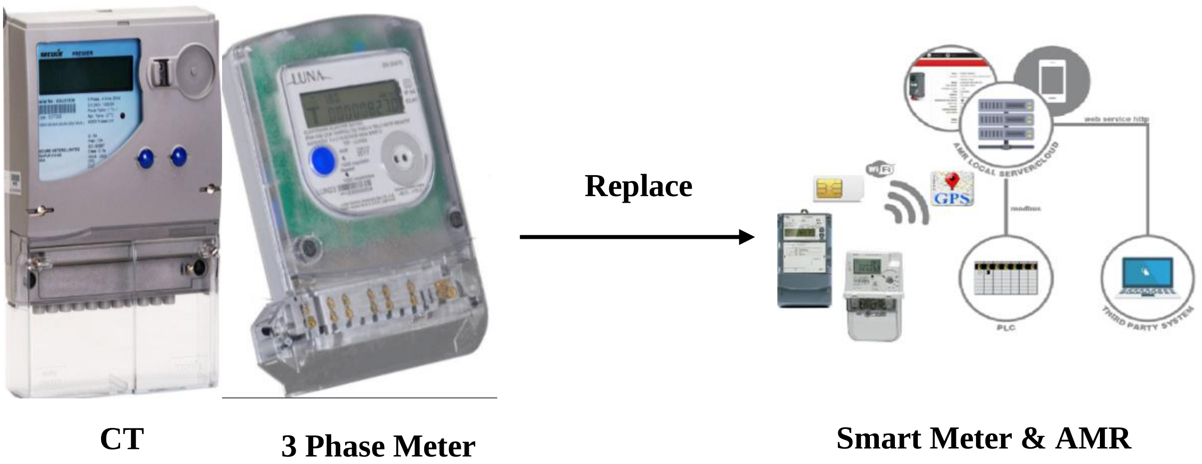
Table 6. Comparison of the metering options in terms of investment and expenditures.

		Year 2021	Year 2022	Year 2023	Year 2024	Year 2025	Year 2026	Year 2027	Year 2028	Year 2029	Year 2030	Total in 10 yr Expenditure
Current	**Total Current**	**8,900,000**	**8,900,000**	**8,900,000**	**8,900,000**	**8,900,000**	**8,900,000**	**8,900,000**	**8,900,000**	**8,900,000**	**8,900,000**	**89,000,000**
Option 1	Investment	2,235,476	660,489	625,463	592,294	560,885	531,141	502,974	476,301	451,043	427,124	7,063,190
	Continuous in current investment	7,418,000	7,418,000	7,418,000	7,418,000	7,418,000	7,418,000	7,418,000	7,418,000	7,418,000	7,418,000	74,180,000
	Total Op 1	**9,653,476**	**8,078,489**	**8,043,463**	**8,010,294**	**7,978,885**	**7,949,141**	**7,920,974**	**7,894,301**	**7,869,043**	**7,845,124**	**81,243,190**
Option 2	Investment	23,339,743	1,068,990	1,012,301	958,618	907,782	859,643	814,055	770,886	730,005	691,293	31,153,317
	Continuous in current investment	4,450,000	4,450,000	4,450,000	4,450,000	4,450,000	4,450,000	4,450,000	4,450,000	4,450,000	4,450,000	44,500,000
	Total Op 2	**27,789,743**	**5,518,990**	**5,462,301**	**5,408,618**	**5,357,782**	**5,309,643**	**5,264,055**	**5,220,886**	**5,180,005**	**5,141,293**	**75,653,317**
Option 3	Investment	37,912,134	1,392,106	1,318,283	1,248,374	1,182,172	1,119,481	1,060,115	1,003,896	950,660	900,246	48,087,467
	Continuous in current investment	450,000	450,000	450,000	450,000	450,000	450,000	450,000	450,000	450,000	450,000	4,500,000

Option 1: All CT meters to be replaced with smart meters and AMI.



Option 2: All CT meters and all three-phase meters to be replaced with smart meters and AMI.



Option 3: All MZEC meters to be replaced with smart meters and AMI.

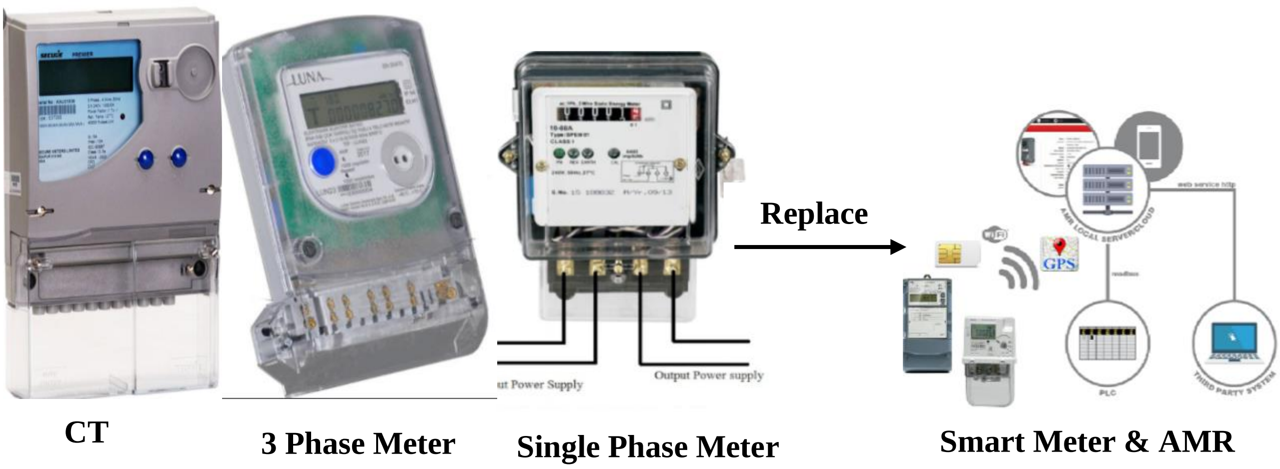


Fig. 10. Connection topologies of the different metering options.

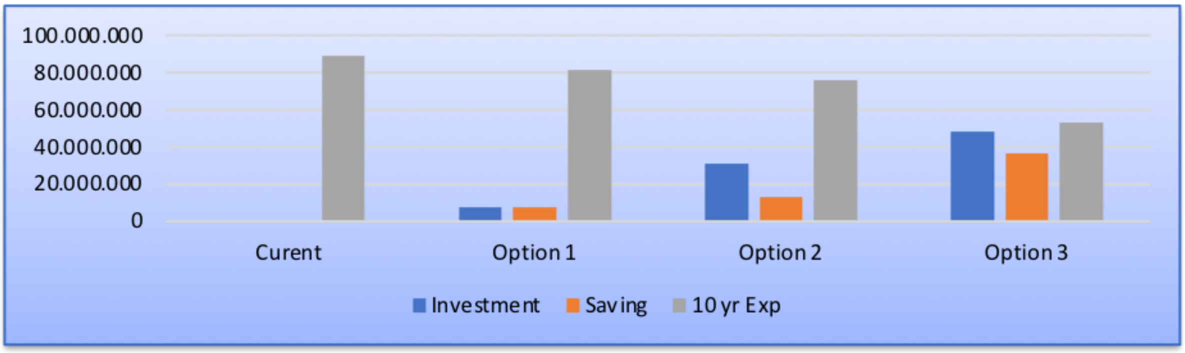


Fig. 11. Comparison of the options in terms of investment and expenditures.

Table 7. Savings using the considered options.

	Investment OMR	Value (saving) OMR
Option 1	7,063,190	7,756,810
Option 2	31,153,317	13,346,683
Option 3	48,087,467	36,412,533

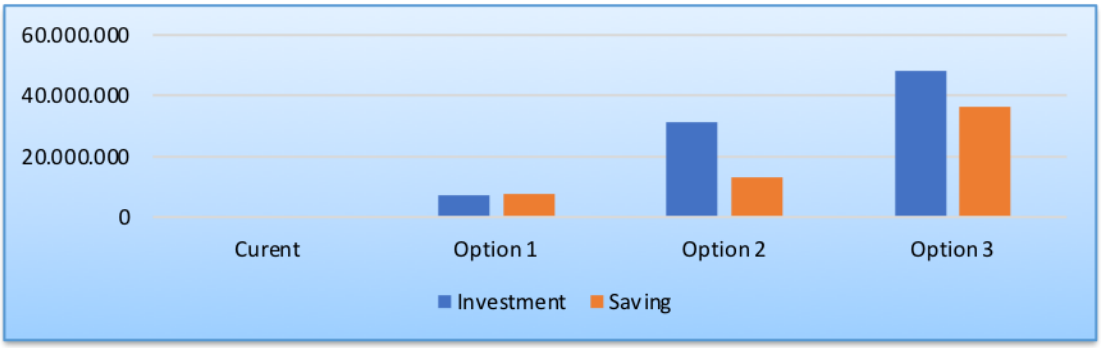


Fig. 12. Investment and savings of the considered options.

Table 8. Expected investment periods for option 3.

Year	**2021**	**2022**	**2023**	**2024**	**2025**
Investment	7582426.88	9052491.28	9052491.28	9052491.28	9052491.28
NPV cost	7,582,427	8,572,435	8,117,836	7,687,345	7,279,683

8. Conclusion and Recommendations

Considering the current situation in Oman, Advanced Metering Infrastructures (AMI) have a huge potential economically. This paper presented the methodology of the proposed AMI scheme considering the Mazoon Electricity Distribution Company (MZEC), in Oman based on three different options, with respect to cost, installation, and impact assessment. All the expected risks and challenges were identified in order to avoid errors, during implementation.

Based on the analyses carried out in the paper, the recommended option is Option-3 (replacement of all MZEC non-smart meters with smart meters and AMI). A total investment of Omani Rial (OMR) 52,587,467, and Net Present Value (NPV) of OMR 48,087,467 is required. Therefore, MZEC recommends the execution of this exercise with a total of OMR 52,587,467, from the first quarter of the year 2021, to the 4th quarter of the year 2025, and then continue to pay operation costs for AMI services.

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