A Review on MPC Based Self Recovering Intelligent Advance Meter for Smart Grid: Scheme and Challenges

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Abstract:

The Model Predict Control (MPC) based Intelligent Advance Metering (IAM) is a core maneuver of future smart grids (SG). SG is the advanced generation of electric power and utility system that improve operation technology (OT) and information technology (IT) to provide nonstop, self-recovery, self-configuration, low-cost, and security-based electricity to the consumer in real-time. Smart metering (SM) allows SG to connect the electric, gas, and oil utilities through sensors. Power plants, consumers, and utility companies will be received real-time wireless control IAM with fifth generation (5G) network technology. The aim of 5G network technology is to enable power grid digitalization (PGD) and facilitate the (IOT) Internet of Things for the future advance SG with benefits such as high-rate public safety, low latency, ultra-high speed, large number of connectivity, and reliability. In this paper, we analyze future predictions about energy needs by using MPC, fast self-recovery system, self-configuration, and upgradation, better performance of service provider, faster power connecting after an outage, control electric theft, minimize electric leakage, a large number of wireless connecting of IAM home-based, and real-time monitoring via human machine interface (HMI) and for customer end IAM operation over 5G networks to reduce billing price, reduce meter cost, lower outage cost, and as well as personalized control over electricity consumption and future challenge in this area.

Keywords: MPC, 5G, IOT, HMI, IAM, SG, Sensors.
Introduction

The demand for continuous power has become a critical issue that needs significant attention in the smart grid (SG) era (Irfan et al., 2023). Electric power grid is the center of power generators, transmission lines, transformers, and distribution stations, to provide power to the consumer (Kader et al., 2023). Power plants produce electricity from different energy sources, e.g., Solar plate farms, Wind turbines, hydropower dams, and Coal plants (Niaz et al., 2023). Transmission lines need to carry electricity safely, legally, and cheaper, from power plants to long-distance electric grids. The electric grids distribute the high voltage electricity from transmission lines to medium voltage and low voltage according to the consumer requirements and provide them through substations, transformers, and ending at the meter of customer.

Due to voltage leakage (Seong et al., 2020), electricity theft (Yan et al., 2021), loss of utility companies, and manual analysis SG is a fast-growing demand. The idea of SG is being implemented in wireless communication to improve the performance, reliability, security, and safety of electric supply to customers. IAM is the key to next-generation SG; as shown in Fig. 1, IAM not only allows the customer to use electricity but can enable monitoring and measuring electric flow (Shelar et al., 2022).

IAM help to troubleshoot any electric fault, or errors, then alert customer and specific department in SG through a wireless 5G network (Rivas et al., 2020). IAM can collect daily, weekly, or monthly readings of used voltage and send them to customers and utility companies to help the consumer control their electricity consumption, reduce billing costs, and save energy. SG meters need a real-time, fast, secure network to communicate with the base station and consumer. 5G Network promises Fast, reliable Network speed and as well as provides a large amount of Connectivity. IAM will predict the Future consumption of electricity in the past few weeks’ experience. The aim of this paper is to analyze the importance of IAM in future generation SG. In addition, Challenges of Communication, Security, and solution of IAM in SG are also proposed.

![Figure 1. Transformation from Traditional Metering to IAM](Shelar et al., 2022)

Framework

IAM based Smart grid

Big data and a large number of connectivity is the big challenge in the SG era (as shown in Table. 2). SG consists of electricity production, decentralization, and easy energy distribution. Fig. 2. electric grids are networks between the place where electricity produce, such as power plants, and transformed for the consumer, e.g., housing societies and industries. advanced analytics and IoT technologies are essential technologies that can implement in SG (Niaz et al., 2022; and Ponnusamy et al., 2021). 5G communication network promises to provide ultra-fast speed, reliable and large number of connectivity as well as provide safe and secure
communication between smart devices. Ultra-low latency, more reliability, massive network capacity, increased availability, Higher performance, and improved efficiency empower new user experiences and connects new industries (Sah et al., 2022). In our proposed SG network, 5G wireless is the main medium to connect IAM to customer and customer to Local Control Room (LCR) and IAM to LCR.

Figure 2. A Smart Grid Architecture

An SG is an energy network enabling power energy and data sharing between the consumer and power generators in Fig. 3, whereby smart metering is often seen as a first step. The concept of SG became known over a decade ago. In a conventional grid (Neffati et al., 2021), we have manual collection of data and manual billing, which is the cause of expensive electricity and more time-consuming to manage user energy capacity and power generation system capacity such as thermal and hydro-electric (Mahlamäki et al., 2020). Purpose of the SG is the movement from conventional electric grids to smart electric grids by multiple factors, such as smart and intelligent evaluation metering, Big Data, real-time communication, and intelligently control devices. This is achieved by integrating information, telecommunication, and power technologies with the existing electricity system. It introduces a two-way real-time communication where electricity and information can be exchanged between an LCR and customers. Developing communication networks, smart devices, control, computers, automation and new technologies, and other intelligent tools working together to make the grid more efficient, more reliable, and more secure, which is the aim of proposed paper. LCR is software applications on service provider hardware is used to acquire data from smart meters via a wireless communication network and send it to relevant fields. LCR consists of different relevant fields such as finance for recovering and billing purposes, monitoring and security for fixing errors and monitoring electricity theft and electricity leakage, and transmission for configuration and installation to facilitate new and old consumers (Abir et al., 2021; and Alhasnawi et al., 2021).

Figure 3. Smart Grid Framework
IAM Architecture

IAM is the collective term used to describe the whole infrastructure from Smart Meter to create Communication and remote control between Consumers and LCR to share information in real-time. IAM makes 5G communications network and is the backbone of SG “Fig.4”. The objectives of IAM can be monitoring meter reading for error free data, network problem identification, power consumption, share locations GPS, Voltage Sensor, Current sensor, Anisotropic magneto resistance (AMR), Hall Sensor, shock Sensor, Thermistor, and keeping all power consumption reading for future predictions in Table.1.

Table 1. Sensors and Their Features

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Feature</th>
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<tbody>
<tr>
<td>voltage</td>
<td>Measures voltage</td>
</tr>
<tr>
<td>Current</td>
<td>To detect &amp; change current to assessable output voltage</td>
</tr>
<tr>
<td>GPS Module</td>
<td>Location, Navigation, Timing, Monitoring, Mapping</td>
</tr>
<tr>
<td>Hall Sensor</td>
<td>Detects magnetic fields (magnetic flux density)</td>
</tr>
<tr>
<td>Shock sensor</td>
<td>Meter is shaken, moved can detect this movement and vibration</td>
</tr>
<tr>
<td>Anisotropic magneto resistance (AMR)</td>
<td>Hidden switch to change meter operating modes,</td>
</tr>
<tr>
<td>NTC thermistors</td>
<td>To monitor the temperature of various thermally sensitive components on a PCB</td>
</tr>
<tr>
<td>PTC thermistors</td>
<td>Protection by detecting over current or overheating of the PCB</td>
</tr>
</tbody>
</table>

IAM devices having ability to collect information about energy, water, and gas usage and transmitting the data through wireless communication networks, LCR as well as receiving information or instruction such as billing, power consumption details, some future alerts like repairing, load shedding from LCR and conveying it to consumer in real-time. Smart meters consist of several types of quantities of their measurement.

- **Power management:** Smart meters must help the system distribution and reliability of electricity by enabling electricity distributors to identify, real-time respond to electric demand, and create complaints automatically which minimizes power outages.

- **Security communication:** Smart meters have ability to receive operational commands and sending stored data as well as take action according to instructions at priority base.

- **Financial Benefits:** Smart meter increased reliability, functionality, and reduced power Leakage, which directly affect energy cost and easy access meter reading and restore errors remotely from (LCR) through wireless communication, which will dramatically cut costs associated with providing and maintaining the grid, thereby significantly reducing electricity rates.

- **Electricity Theft:** Power theft is a common problem in residential area. IAM systems can help to monitor consumed energy and provide energy in real-time, which increased system transparency.

- **Customer Benefits:** IAM has ability to share information by detecting meter failures early, crossing power consumption limit, and intelligently save energy consumption. IAM provides flexibility in billing.

- **Check and Balance:** IAM will send and display information about consumed electricity to customers for billing in real-time and allow the users to set restrictions and limits about future electricity consumption.

As a result, based on smart meters, utility companies can provide highly reliable, remote accessibility, flexible billing, and cost-effective energy services to their consumers by combining advantages of both small, distributed power plants and large centralized plants as well as utility companies have ability to collect a large amount of data from smart meters in real-time. IAM infrastructure is the key component to implement the concept, which can collect large number of meter data and analyze and give
intelligent management system of various power related applications.

Model Predictive Control (MPC)

MPC techniques will be used to solve different control issues in SG. MPC have ability to predict future results according to previous experience; we use MPC here at user end (Sotelo et al., 2022; Elmorshedy et al., 2021) with IAM to keep recording previous error solutions, energy consumption data records (Urrea et al., 2021), billing records, and predict future action automatically according to experience as well as predict future energy consumption in advance which will help to inform the service provider about capacity of power production their future consumption capacity as shown in Figure 5. MPC have few more benefits mentioned below.

- Increases in process knowledge.
- Higher levels of automation, auto operators to focus on more important tasks.
- Extended scope of control strategy for optimization, e.g., specific energy consumption.

Further Developments of SG and Challenges of Smart Meters

Table refers to the inherent capability of a communication network to reliably and efficiently transmit data. In the smart grid context, it is crucial for supporting distributed approaches and enabling coordination among smart meters and electric devices. Utilizing advanced technologies such as 5G, digital twin (Shoukat et al., 2022), which offers notable benefits such as high-speed data transmission, robust reliability, and enhanced security, can significantly augment the operational performance of the smart grid. However, challenges such as transmission delays, errors, and the need for energy management strategies should be considered. Research on future technologies like 6G is being explored to address
evolving communication demands and improve efficiency, reliability, and security. Entails the integration of advanced artificial intelligence technologies within the smart grid framework. This integration leverages the interconnected nature of smart meters and IoT to facilitate intelligent behavior and coordinated operations. By employing AI algorithms, the smart grid can enhance decision-making, self-organization, and cognitive capabilities, thereby achieving comprehensive system awareness akin to a grid operator. The training of these algorithms with data gathered from smart meters enables their adaptation to smart grid operations. Nonetheless, challenges remain, such as addressing the limitations of existing AI algorithms and establishing effective collaboration between humans and AI in smart grid operations. Overcoming these challenges is critical to fully harnessing the potential benefits of AI in optimizing the functioning of the smart grid.

Table 2: Future Challenges and Solutions.

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Challenges</th>
<th>Issues</th>
<th>Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gultom et al.,</td>
<td>Communication System</td>
<td>Interference</td>
<td>Using interference detection and channel switching techniques.</td>
</tr>
<tr>
<td>Nawaz et al.</td>
<td>Challenges</td>
<td>Need for common standards</td>
<td>Follow the standard set by various organizations, such as IEEE 802,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Data transmission rates</td>
<td>Use ANSI to develop such standards by choosing the correct transmission protocol.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fast switching</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low latency Rate.</td>
<td></td>
</tr>
<tr>
<td>Sharma et al.</td>
<td>Big Data Challenges</td>
<td>Real-time applications</td>
<td>Using predictive algorithms data integration, data fusion and development of</td>
</tr>
<tr>
<td>Niaz et al.</td>
<td></td>
<td>Heterogeneous Data.</td>
<td>standardized software presenting the data in the right way.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Data compression and visualization.</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Big number connectivity</td>
<td></td>
</tr>
<tr>
<td>Khan et al.</td>
<td>Security Challenges</td>
<td>Exploited device system architecture layers they target.</td>
<td>Firewall and cyber security protocols</td>
</tr>
<tr>
<td>Shoukat et al.</td>
<td></td>
<td>False Data Injections</td>
<td></td>
</tr>
<tr>
<td>González et al.</td>
<td>Automation Challenges</td>
<td>Self-recovery and repairing</td>
<td>Sensors, AI, Cloud based backup,</td>
</tr>
<tr>
<td>Shoukat et al.</td>
<td></td>
<td>Self-Configuration and upgradation</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Auto optimizations</td>
<td></td>
</tr>
<tr>
<td>Ourahou et al.</td>
<td>other challenges</td>
<td>Low-cost equipment's friendly use equipment's</td>
<td>Seminar and work to train local peoples, Advertising about Manual Instruction short videos,</td>
</tr>
<tr>
<td>Shoukat et al.</td>
<td></td>
<td></td>
<td>solve language barrier</td>
</tr>
</tbody>
</table>

Conclusion

This paper explains how we can implement MPC to converting meters into IAM to do automation and optimization with reduce loss, cost, high-rate monitoring in energy sector to improve public safety and save natural resources wastage which we use in production in unmanage energy. Further we discuss about what is expected challenges and how we solve these issues in upcoming fully automatic SG. The Aim of 5G technology provide real-time communication between customer and LCR to share data information vice versa. MPC will perform future predictions about energy needs, system faults and provide self-recovery, Auto switch on/off, emergency alerts function when needed according to past experiences. IAM based on 5G technology will bring a big impact on saving natural resources and public safety with full automation in future SGs.

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