Lecture Notes in Electrical Engineering 487

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Ravi Seethapathy · Vijay L. Sonavane
S. A. Khaparde · Pradeep Kumar Yemula
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Editors

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Part I
Smart Grid and IoT Technologies

Developing SMARTGRID Projects with Global Perspective in Indian Scenario

Amit R. Kulkarni, M. S. Ballal and Shrikant S. Rajurkar

Abstract This paper discusses in brief various aspects related to SMARTGRID technology developments and their importance in adopting in Indian scenario. It covers some of the practical SMARTGRID technologies developmental aspects in the state of Maharashtra in Indian context. It also discusses initiatives taken by MAHATRANSCO in developing these technologies in the field of Wide Area Measurement System (WAMS). It covers some of the aspects like understanding grid disturbances/events in the system with the help of WAMS to know about oscillations in the grid during these events along with case studies. It discusses in brief improving situational awareness of the grid based on WAMS. This paper covers consideration to Flexible AC Transmission Systems (FACTS) devices in the system, as a part of initial steps taken by MAHATRANSCO in understanding dynamic compensation-related requirements in the system to meet dynamic voltage variations. It also covers importance of Dynamic Line Rating (DLR) technology for transmission utilities in Indian scenario. It further focuses on how to streamline developmental activities amongst centre and state as far as some of the aspects of Renewable Energy utilisation and integration into the grid and Renewable Energy Management Systems (REMS)/Renewable Energy Management Centre (REMC) in India at centre and state Level are concerned.

Keywords WAMS · SMARTGRID · Situational awareness · Oscillations FACTS · DLR · REMS/REMC

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1 Introduction

This paper covers six sections. Section 2 gives brief description of MAHATRANSCO initiatives in WAMS development; Sect. 3 discusses utilisation of WAMS for analysing the grid events along with case studies. It also covers use of Prony analysis for understanding oscillations in the system during these events and also focuses on utilisation of situational awareness system. Section 4 describes other SMARTGRID technology developmental aspects in MAHATRANSCO. Section 5 presents various issues pertaining to Renewable Energy (RE) utilisation, its integration and related important aspects needing attention in Indian scenario.

Figure 1 shows 400 kV network overview of MAHATRANSCO system. MAHATRANSCO is the largest State Transmission Utility (STU) in India with 634

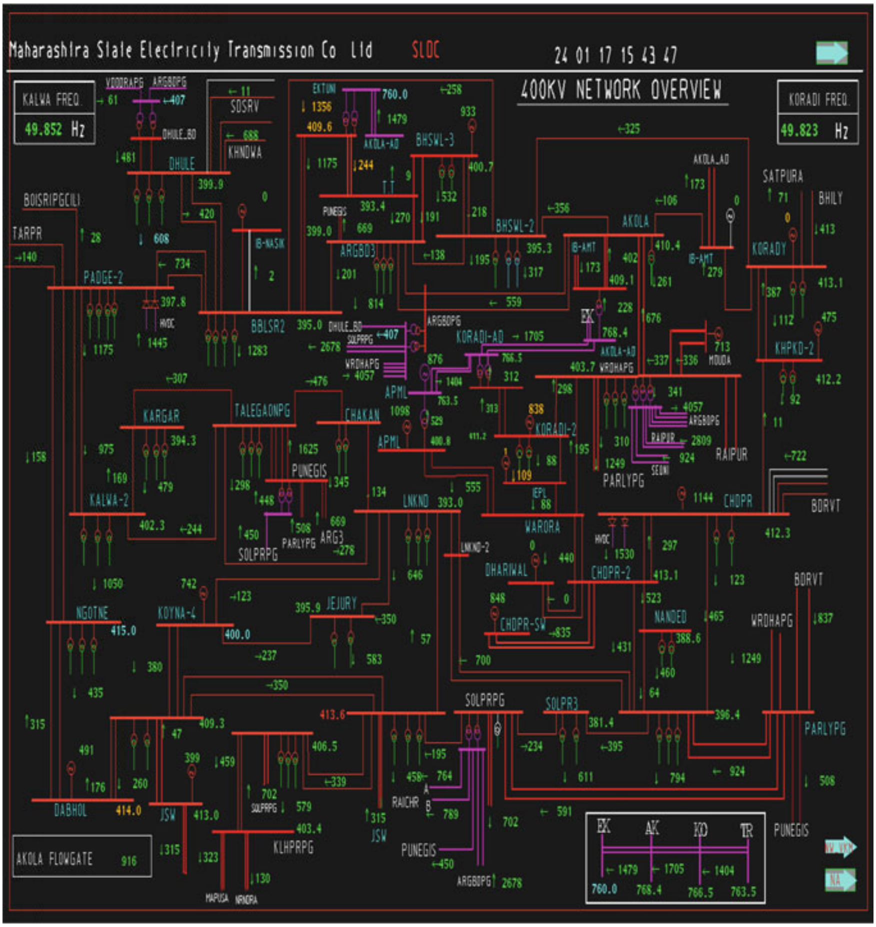

Fig. 1 400 kV network overview of MAHATRANSCO

EHV substations, 110,000 MVA of transformation capacity and 47,000 circuit kilometres of EHV transmission lines.

This paper discusses in brief initiatives taken by MAHATRANSCO in Indian context towards development of some of the SMARTGRID technologies along with case studies for the same. This paper also covers in brief, issues needing attention while harnessing RE power in Indian context.

2 MAHATRANSCO Initiatives in Development of Wide Area Measurement System

Figure 2 shows architecture of WAMS infrastructure in MAHATRANSCO system. Present MSETCL's Wide Area Measurement System (WAMS) infrastructure includes Phasor Measurement Units (PMUs), GPS clock and antenna installed at various locations at twelve 400 kV and three 220 kV level substations. Central Phasor Data Concentrator (PDC), visualisation software and historian software are installed at State Load Despatch Centre (SLDC) of Maharashtra located at Kalwa. The Real time data transfer of parameters like Voltages (*V*), Currents (*I*), Active Power (*P*), Reactive Power (*Q*), Frequency (*F*), Rate of Change of frequency

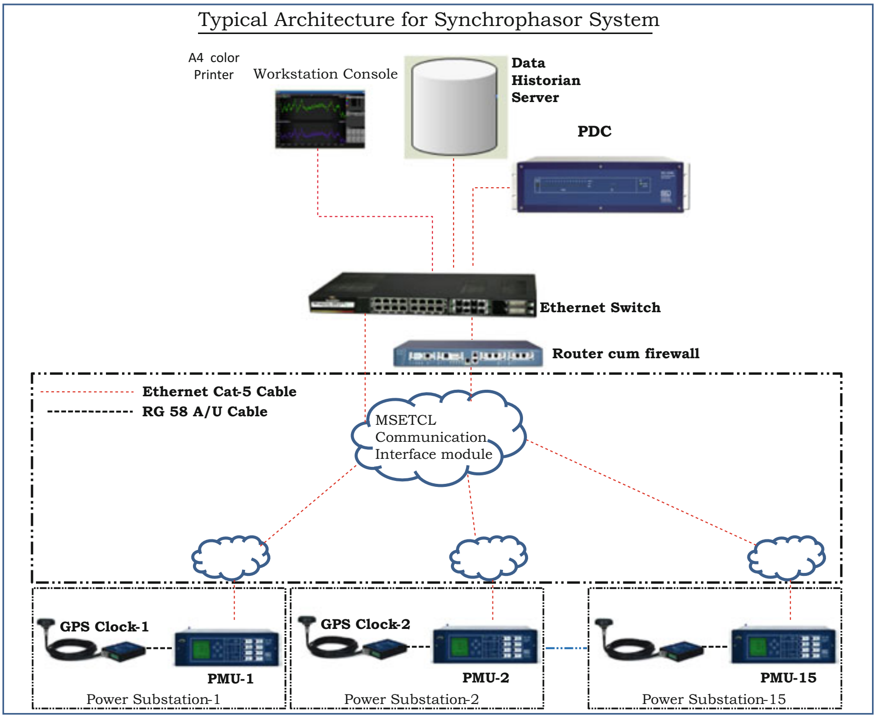

Fig. 2 Architecture of WAMS infrastructure in MAHATRANSCO

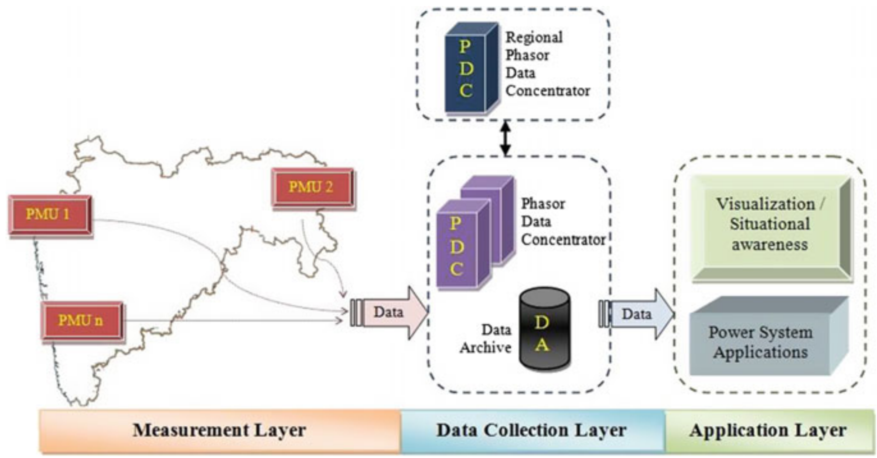

Fig. 3 Three-layer architecture of WAMS infrastructure in MAHATRANSCO

(D*F*/D*T*) and Delta (δ) is done from PMUs located at important locations and Critical substations in MAHATRANSCO grid to PDC located at State Load Despatch Centre (SLDC)-Kalwa.

Figure 3 shows three-layer architecture showing how the data flows from physical WAMS infrastructure spread across MAHATRANSCO system in Maharashtra state in India to data storage/archiving system comprising of Phasor Data Concentrator (PDC), historian, etc., and further to application software.

3 Utilisation of Synchrophasor System for Grid Event Analysis and for Detecting Oscillations

This section discusses utilisation of synchrophasor system for analysing grid events with case studies for the same. It also discusses in brief Prony analysis technique used along with PMU data to understand type of oscillatory modes excited during these events.

3.1 Case Study-1: CGPL Ultra Mega Power Plant (UMPP) Blackout Analysis Dated on 13 July 2016 in Western Regional Grid in India Using Synchrophasor System

On 12 July 2016 due to insulator tracking at Varsana substation and subsequent fault, there was loss of all 400 kV elements from 400/220 kV Varsana substation in

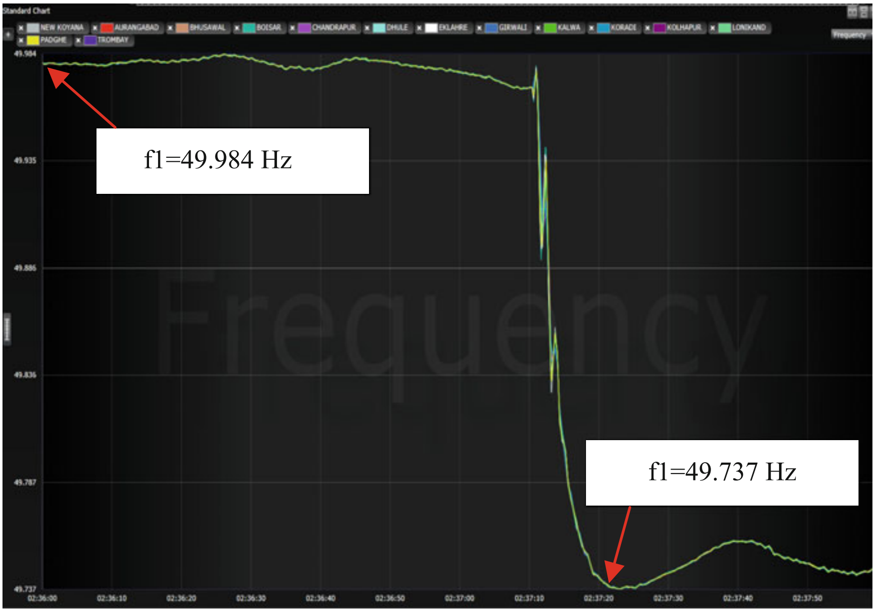

Fig. 4 Frequency behaviour during CGPL-UMPP occurrence

Gujarat. On 13 July 2016 around 2:37 am, 400 kV Bachau–Varsana line was charged from Bachau end. Seven seconds after charging this line, fault was developed in Y-phase which later got converted into three-phase fault at gantry end of this line at Varsana end. It was seen that all the remaining lines from CGPL UMPP along with 400 kV Bachau–Ranchodpura D/C, 220 Bachau–Morbi tripped. This resulted in blackout of CGPL UMPP with tripping of all its running Units, i.e. Unit-10 [760 MW], Unit-30 [742 MW], Unit-40 [757 MW], Unit-50 [619 MW], tripped with total generation loss of 2878 MW. The loss of generation resulted in frequency decay further resulting in d*f*/d*t*-based load shedding operation to the tune of around 119 MW in GETCO system in Gujarat. Figure 4 shows frequency behaviour as sensed by PMUs in MAHATRANSCO grid during CGPL-UMPP disturbance. Figure 5 shows d*f*/d*t* as observed by PMUs at 220 kV Boisar and 220 kV Eklahare substations in MAHATRANSCO grid during this incidence. The d*f*/d*t* as indicated by PMUs was found to be around −0.3212 Hz/s.

In order to understand type of oscillatory modes excited during CGPL-UMPP occurrence dated on 13 July 2016, Prony analysis was carried out with frequency measured from PMUs at 220 kV Eklahare and 400 kV Padghe substations in MAHATRANSCO grid. Figures 6 and 7, respectively, show plot for Prony approximate and PMU measured frequency response for 220 kV Eklahare and 400 kV Padghe substation in MAHATRANSCO grid.

Table 1 shows some of the important results of Prony analysis indicating amplitude, damping and frequency of oscillations during CGPL-UMPP

Fig. 5 d*f*/d*t* as observed by PMUs at 220 kV Boisar and Eklahare substations during CGPL-UMPP occurrence

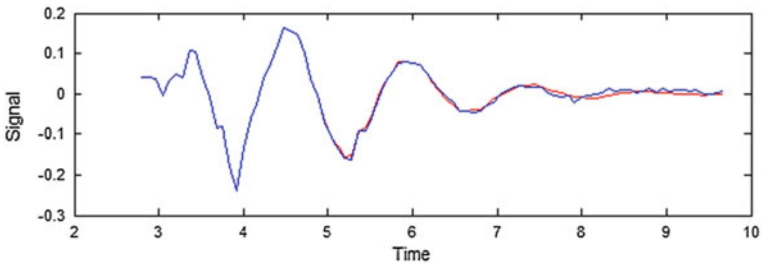

Fig. 6 Plot for Prony approximate and PMU measured frequency response for 220 kV Eklahare substation in MAHATRANSCO system

disturbance. From this Table 1 based on results of Prony analysis of PMU data for 220 kV Eklahare substation, 400 kV Padghe and other substations where PMUs are placed in MAHATRANSCO system, it can be said that inter-area modes of oscillations of frequency around 0.55 Hz were prominently seen along with negative damping during CGPL-UMPP disturbance.

Figure 8 indicates angular separation between 400 kV Padghe and Aurangabad substations in MAHATRANSCO grid before CGPL-UMPP occurrence, whereas Fig. 9 indicates angular separation between 400 kV Padghe and Aurangabad substations in MAHATRANSCO grid after CGPL-UMPP occurrence. This highlights

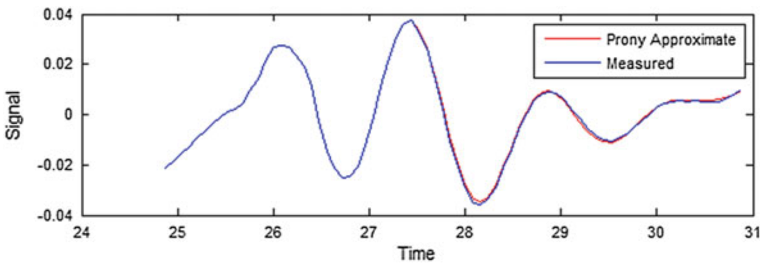

Fig. 7 Plot for Prony approximate and PMU measured frequency response for 400 kV Padghe substation in MAHATRANSCO system

Table 1 Results of Prony analysis for case study-1

Sr. no.	PMU location	Amplitude	Damping	Freq. (Hz)
1	400 kV Padghe	0.083	−2.2	0.91
		0.066	−0.43	0.78
		0.037	−0.34	0.57
		0.01	−0.045	0.23
2	220 kV Eklahare	1.0	−0.86	0.73
		1.0	−1.2	0.55

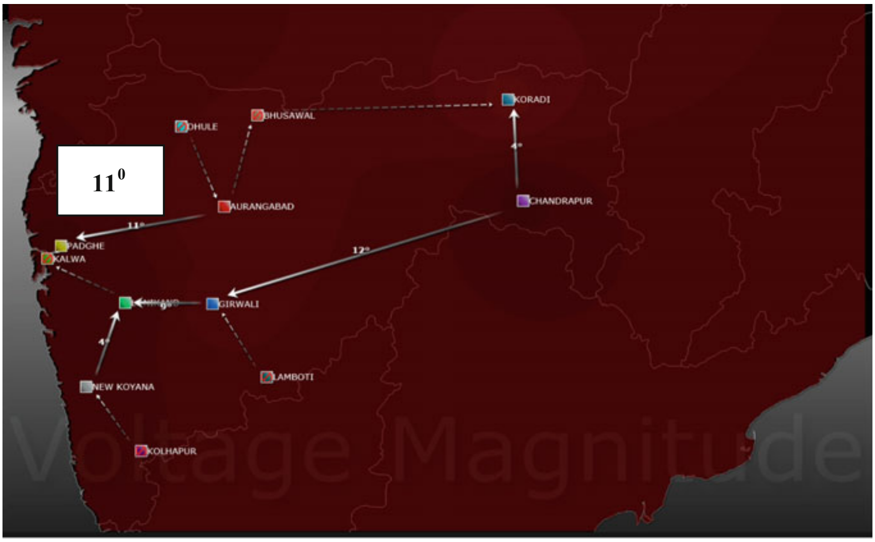

Fig. 8 Angular separation between 400 kV Padghe and Aurangabad before CGPL-UMPP occurrence

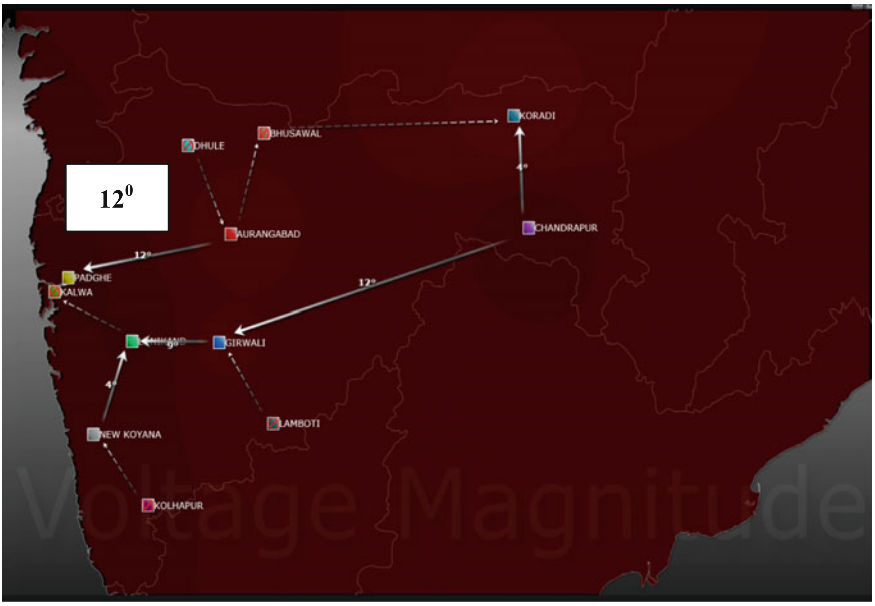

Fig. 9 Angular separation between 400 kV Padghe and Aurangabad after CGPL-UMPP occurrence

the fact that even small angular difference of 1° between two nodes can be detected using WAMS. This assists in improving situational awareness of the grid during disturbances which can further be used to devise requisite protection and control actions as per system requirements to improve the system stability.

3.2 Case Study-2: Analysis of HVDC Spikes Phenomena Dated on 07 October 2015 in Western Regional Grid in India Using Synchrophasor System

MAHATRANSCO is the only State Transmission Utility (STU) in India which owns and maintains ±500 kV bipolar HVDC link between Chandrapur in Eastern and Padghe in Western part of Maharashtra having capacity to transfer 1500 MW. On 07 October 2015, pole-1 was on outage since 7:56 am. Pole-2 was operating in monopolar ground return mode in which full return current flows through electrode line connected to earth electrode station at Anjur. The electrode line comprises of two parallel conductors EL-1 and EL-2 terminating at Anjur. During this incidence, it was found that one of the conductors of EL-1 was burnt and was hanging near to Padghe. As conductor was not completely snapped, high impedance path resulted in uneven sharing of current between the two conductors further activating ‘Electrode

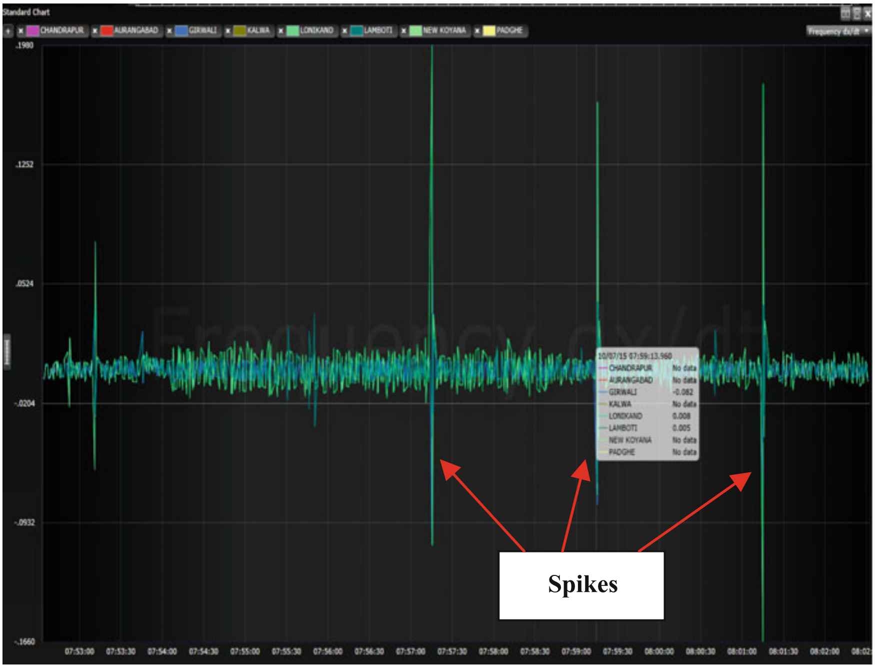

Fig. 10 Spikes indicated by WAMS during events dated on 07 October 2015

Unbalance Protection'. It was seen that trip command got reset after every two minutes by timer. This was indicated by spikes in the system parameters; one of them is for frequency as shown in Fig. 10. These repetitive natured spikes observed exactly at every 2 min on synchrophasor system. This phenomenon of spikes stopped only after ramping down power carried by pole-2 from 750 to 600 MW around 8.50 am.

This phenomenon was analysed with the help of Prony analysis to understand kind of oscillations seen in the system during this incidence. Figure 11 indicates frequency signal as obtained from PMU at 220 kV Boisar substation in MAHATRANSCO grid considered for analysis purpose. In this, section 'a' of signal indicates first spike and section 'b' indicates another spike as observed during this event.

Figures 12 and 13 show comparison of Prony approximate and PMU measured frequency signal for section 'a' and section 'b' of Fig. 11, respectively.

Table 2 gives some of the important results of Prony analysis. During this analysis, it was observed that these oscillations were present during duration of this event and disappeared after power order for pole-2 was reduced from 750 to 600 MW. From this, it can be said that control mode of around 4.7 Hz was seen with negative damping during this incidence. This can be related to control system

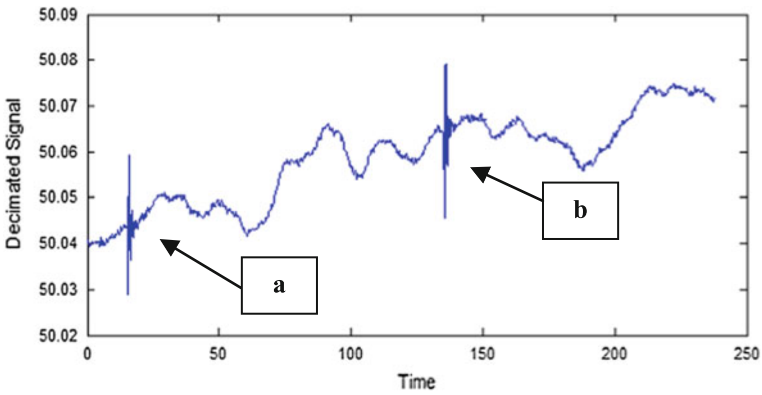

Fig. 11 Frequency signal as indicated by PMU of 220 kV Boisar considered for Prony analysis

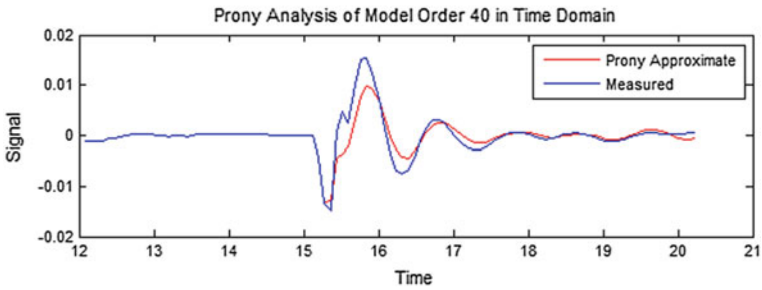

Fig. 12 Plot for Prony approximate and PMU measured frequency response for 220 kV Boisar substation at section 'a'

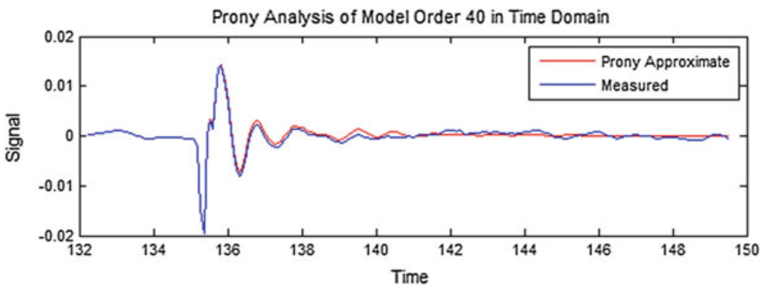

Fig. 13 Plot for Prony approximate and PMU measured frequency response for 220 kV Boisar substation at section 'b'

Table 2 Results of Prony analysis for case study-2

Sr. no.	PMU location	Amplitude	Damping	Freq. (Hz)
1	220 kV Boisar (Instant 'a' in Fig. 11)	0.028	−1.1	3.2
		0.028	−1.2	3.5
		0.025	−1.3	4.1
2	220 kV Boisar (Instant 'b' in Fig. 11)	0.021	−1.6	4.2
		0.065	−2.5	4.3
		0.011	−1.6	4.7

behaviour of HVDC system which was activated after 'Electrode Unbalance Protection' initiation during this event.

4 Other SMARTGRID Initiatives in MAHATRANSCO

Apart from WAMS, MAHATRANSCO system adopts High Tension Low Sag (HTLS) technology, IEC-61850 compliant numerical relaying system, IEC-104-based SCADA system, ABT metering system for effective energy accounting, ERP system for streamline works of different verticals of the organisation.

4.1 Adoption to FACTS Technology

MAHATRANSCO system experiences dynamic voltage variations in many parts of the system having RE concentration like that observed in areas like Karad, Lamboti, Dhule, Nashik. In view of this, MAHATRANSCO is also planning to adopt other SMARTGRID technology options like adoption to Flexible AC Transmission System (FACTS) devices to cope up with multiple challenges of reactive power management, to enhance system transmission capacity and improve system stability. Experience in this field world over has shown that overall costs and performance of power system operation can be best managed if voltage control and VAR control are well-integrated. In one such exercise being carried out in MAHATRANSCO, studies for adoption of dynamic compensation for Renewable Energy (RE) rich Karad area in Maharashtra is undertaken. The preliminary studies indicate that, provision of FACTS devices like Static VAR Compensators (SVC), Static Synchronous Compensator (STATCOM) can be considered to address the issue of varying voltages beyond acceptable limits in this area.

4.2 Adoption to Dynamic Line Rating (DLR) Technique

In Maharashtra's over 40,000 MW of installed generation capacity, RE share is of around 17% and with State and Central Government's RE centric policies it is posed to increase in coming years. In this context, Karad area of MAHATRANSCO grid in the state of Maharashtra having around 2500 MW of wind generation, multiple co-generation plants injecting into the grid along with solar generation or Nashik and Ahmednagar area where high wind concentration exists are suitable locations to adopt DLR technology. This technology option thus can be adopted in above-mentioned areas where high renewable penetration like wind energy exists. Line loading can be changed dynamically considering weather conditions by adopting Dynamic Line Rating (DLR) in such cases. Addition of new lines to relieve the congestion during peak RE periods is not an economical solution, as high wind periods are limited throughout the year and the same is true for solar peaks. In such scenario, DLR offers a more desirable solution as high wind speeds also mean increased capacity of lines if proper monitoring of temperature and corresponding line flow increase is coordinated. Generally, it is observed that operator at load dispatch centres loads the line conservatively and there exists a scope to transfer more power through the same corridor, so DLR technology can be used at suitable locations for enhancing power transfer capability. DLR technique can be used in association with PMUs to devise Remedial Action Schemes (RAS) to enhance reliability of the system under uncertain, intermittent Renewable Energy (RE) sources in RE-rich areas in the state of Maharashtra in India.

5 Managing the Renewable Energy

In India during last one decade, it was observed that, in order to utilise renewable sources of energy effectively and to reduce dependence on imported fuel, Central and various State Governments are promoting renewable sources of energy with policies like Renewable Purchase Obligation (RPO) and with various regulations in this regard. With launch of Jawaharlal Nehru National Solar Mission (JNNSM), there is a rise in utilisation of solar energy in India. Maharashtra being one of the leading state in India harnessing Renewable Energy (RE), it has installed capacity of around 7000 MW of RE generation. Under Government of Maharashtra's new RE policy, it is proposed to add 14,400 MW of RE in coming years, thus taking the total to approximately 21,100 MW. Out of this, 7500 MW would come from solar, 5000 MW from wind and remaining 1900 MW from small hydro, baggase-based co-generation, biomass, Municipal Solid Waste (MSW), industrial waste, etc. Considering uncertainty, intermittency and variability of RE sources like wind and solar, their integration to the grid for effective utilisation is a big challenge, which can be dealt with by adopting Renewable Energy Management Systems (REMS).

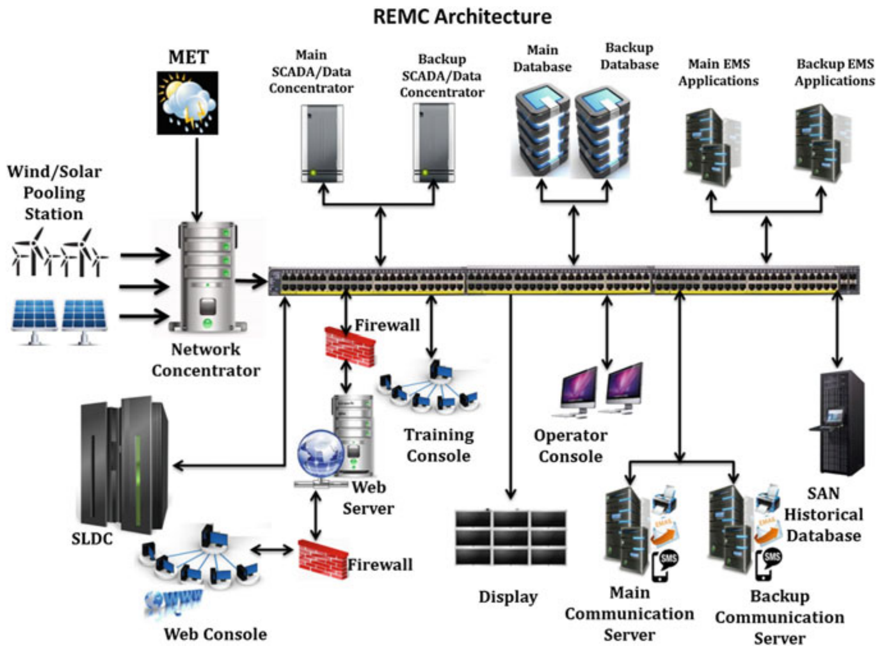

Fig. 14 Typical architecture of REMC

Figure 14 shows typical architecture of REMC that can be made operational for better grid management.

For real-time operation, monitoring and control of RE sources and for its effective integration, RE sources like wind must possess advanced characteristics like fault ride through capability, VAR control and regulation, active power control, ramping and curtailment, primary frequency regulation, inertial control, short-circuit current control. Whereas consideration to Solar irradiance, effect of cloud on solar output, solar energy prediction etc., are some of the important factors for real time operation, monitoring and control of solar energy. Taking into account the importance of RE integration and data transfer from RE generation clusters to central dispatch centre data transfer architecture can be modified as per requirements.

5.1 Issues Needing Attention for Utilisation and Integration of Renewable Energy in Indian Context

(1) Operationalising REMS/REMC infrastructure as per road map overcoming the challenges in its implementation.

(2) As most of the Wind Turbine Generators (WTGs) in India don't have FRT features, motivating them to adopt newer technologies compliant to this is a challenge.
(3) Adopting regulatory and policy frameworks in line with latest developments in RE field and streamlining centre and state policies in this regard.
(4) Establishment of communication infrastructure, weather stations, RTUs, SCADA system in timely manner in RE-rich states for reliable real-time data transfer to central location and funding provisions for the same.
(5) Coping with the challenges of grid management with increased RE penetration.
(6) Coping up with the challenges of operating the RE systems with hourly, subhourly and 15 min block under Availability-Based Tariff (ABT) system in Indian context.
(7) Achieving accuracy in RE forecasting, load forecasting and real-time scheduling of RE power.
(8) Understanding and addressing impacts of complex interactions between four major stakeholders in RE sector such as RE developer focusing on maximising profits, grid operators starving for secure, reliable and economic operations of the grid, utilities trying to opt for RE power at competitive rates and financial traders is an important issue to deal with.
(9) Issuing guidelines regarding RE and SCADA applications covering various aspects related to power plants, turbines, substation and load despatch level.
(10) Plan for developing ensemble forecasting and provision of funding for the same.
(11) Studies related to understanding impacts of dynamic behaviour of RE sources on grid operation.
(12) Developing economical and effective ancillary services support, energy storage systems.
(13) Guidelines regarding protection system requirements of RE sources.
(14) Addressing reactive power management issues with high level of RE penetration and provision of dynamic compensation devices for the same.
(15) Efficient scrutiny, checking of Detail Project Reports (DPRs) of RE developers and standardised mechanism for approving the same along with developing mechanism for periodic RE project review.
(16) Ensuring timely completion of RE projects with due telemetry, protection system, smart metering system, SCADA system, forecasting system at developer end as well as required reactive power compensation provided as per system requirement.
(17) Developing effective mechanism for RE pricing as well as for incentives to developer, utilities, consumers, etc.
(18) Creating environment in which RE sources can be effectively used with ancillary services support, energy storage systems, demand response initiatives and with electrical vehicles.

(19) Human resource development with due training to execute RE projects and to deal with various technical issues while operationalising REMC and real-time grid operations.

(20) In REMC proposed at state level in India forecasting tool must give output of state-level aggregated RE forecast, so for this internationally best proven methodology used by utilities needs to be adopted.

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Smart Energy Metering Using LPWAN IoT Technology

Shobhit Jain, M. Pradish, A. Paventhan, M. Saravanan and Arindam Das

Abstract The last-mile networking for Internet of Things (IoT) applications using short-range networks in ISM band such as IEEE 802.15.4 LoWPAN mesh, WiFi, Zigbee, Bluetooth Low Energy has been studied widely in the last few years with demonstration in many industrial scenarios. However, the reliable connectivity in last-mile scenarios like individual energy meter in the home area network (HAN) connecting to the data concentrator in turn to the meter data management systems (MDMS) through WAN connectivity is considered to be a challenge in certain areas. There are emerging low-power WAN (LPWAN) technologies such as LoRa, Wi-SUN, Sigfox—all operating in unlicensed band, and NB-IoT—in licensed band that can provide alternative long-range connectivity option for realizing IoT networks. In this paper, we discuss the Indian smart metering deployment in both rural and urban scenarios where the short-range IoT solution built-in may not always work best to the needs of long-range expectations. Further, we highlight how emerging LPWAN technologies will help in building a reliable, low-cost, low-power, long-range, last-mile technology for smart energy metering solutions. We also present our prototype implementation of end-to-end LoRa connectivity for smart metering solution and discuss final visualization platform.

Keywords IoT · LPWAN · Smart metering solution · LoRa · DLMS protocol

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1 Introduction

Growing electricity demand, distributed generation, integration of renewables, advancements in IoT networks which attempts for managing the power system network with various levels of automation, managing outages, etc., have focused attention on the role of converting the electric grids to be smarter and efficient. One way, it helps in increasing electricity reliability—especially by increasing the grid system flexibility for various solutions. The smart grid, which overlays the traditional electrical grid with an IoT network that includes smart meters, will help in managing and monitoring various parameters of consumption pattern of customers on near real-time basis. A smart grid needs to introduce the transformation within the traditional electricity network with a series of new smart technologies. These include smart sensors, new backend IT systems, smart meters, and a communications network [1]. Moreover, it explores different technologies to automate the entire grid operation which includes power generation, transmission, and distribution [2]. For example, smart grids are used to improve the precision in operation and lowering the costs involved during the time of deployment of electricity infrastructure in developing countries. The introduction of small "remote" systems for rural electrification considered as a cost-effective approach can easily be extended to national or regional infrastructure [3]. But extending this to developing countries seems to be really challenging task due to huge infrastructure cost involvement for installation and recreating new environment. Some of the unlicensed technologies like LoRa, Sigfox and cellular technologies like LTE-M, NB-IoT are actively being deployed on a pilot basis in developing countries as a proof of concept without changing the complete environment. In utility sector, implementing such pilot projects will depend on the consumer requirements, geographical area, and the existing system based on the suitable technologies and standards that are adopted for achieving seamless end-to-end connectivity.

In this paper, our approach is to apply the emerging technology to the existing energy meter system that can communicate in real time or near real time benefiting both consumers and utility. So, we anticipate that the proposed system will enable the smart meter functionalities like automated meter reading (AMR) to utility companies using any last-mile connectivity on a near real-time basis. The challenges in such implementations in rural areas, is the requirement of the low-power and long-range connectivity with minimum installation cost. Hence we have chosen the LPWAN technology for the existing energy metering system.

LPWAN technologies allow utility sector to receive information over much longer range than traditional solutions in both rural and urban areas as we tested with our prototype for smart metering solutions. Moreover, in this paper we describe the metering architecture using LoRa for collecting data from the meter through low power microcontroller using RS-232 communication. LoRa supports two-way wireless communication for the metering infrastrucutre connectivity to the cloud through the gateway for realizing smart metering solutions.

Rest of the paper is organized as follows: Sect. 2 represents the background of technology and metering protocols, Sect. 3 describes LoRa components used in our prototypes, and Sect. 4 discusses the implementation setup of prototype demonstration and the results. The concluding remarks are presented in Sect. 5.

2 Background

With recent advancements in IoT networks, globally the power utility companies are deploying smart meters with various communication technologies. LPWAN technologies are the one that is extensively available in today scenario for a long range which can be leveraged for the smart metering implementations. Energy meter could be configured with this smart module and achieve most of the benefits of smart meters. The data transmission uses low-power, long-range, and narrow-band transmission resulting in increased range of operations, better network stability, reliability, and optimum cost for implementation. This module could be configured to give personalized notifications at programmed intervals to the utility and the consumers. In this section, we describe the background details of the technology used and the relevant metering protocols.

LPWAN technology is used when other wireless networks are not a good fit with some case studies—Bluetooth and BLE (and, to a lesser extent, WiFi and Zigbee) and even that are often not suited for long-range performance. Cellular M2M networks are usually very costly, and it consumes lot of power as well as expensive as far as hardware and services are concerned [4]. The newly introduced LPWAN technologies are most suitable for this type of applications where the connecting devices generate small amounts of data and try to communicate over a long range, while maintaining long battery life [4]. We would like to discuss in this paper two main areas that best suits for LPWAN technology implementation relevant for smart grid automation:

1. Fixed, medium-to-high density connections which are alternative to the cellular M2M connections for introducing automation in grid distribution.
2. Long life, battery powered applications which are best fit for connecting the energy meters to substations and for other relevant purposes like water metering, gas detectors, smart agriculture, and operating door locks and access control points in home and office environments.

Sigfox [5] and LoRa [6] are the prime competitors in the LPWAN space for last two years. While the business models are quite different, the technologies and end goals are very similar. Both works for IoT application with low-power, long-range network with limited differences. Sigfox is a narrowband technology that uses a standard radio transmission method called binary phase-shift keying (BPSK), and it works with very narrow parts of spectrum and changes the phase of the carrier radio wave to encode the data [5]. It requires an inexpensive end-point radio and a more sophisticated base station to manage the network [7], whereas LoRaWAN [6] works at a wider amount of spectrum. NB-IoT is a low-power wide area (LPWA) technology that works virtually anywhere using cellular networks by generating more secure transactions [8]. It connects devices efficiently on already established mobile networks and handles low bandwidth two way communication, securely and reliably. This next-generation cellular IoT technology is not ready for the deployments till 2018 and needs operators support for end-to-end connectivity.

In the current scenario, 2G networks are not fully suited to IoT applications due to battery life constraints as well as higher complexity. NB-IoT and LTE-M technologies are not ready for immediate implementations due to the licensed spectrum issues and standards are still being developed. Whereas, LoRaWAN uses unlicensed spectrum by encoding multiple bits per symbol with integrated packetization and error corrections. The benefits of LPWAN technology with respect to LoRa can be presented here by mentioning the merits and facts [9].

(a) Spectrum: It uses unlicensed spectrum (865.20–867 MHz in India and 915 MHz in US).
(b) Long Range: With 2–4 km in dense urban areas and up to 15–30 km in rural areas. (depends upon line of sight).
(c) Power: 10+ years of battery life (The device's power produced cannot exceed 10–25 mW, to comply with usage of ISM frequencies, and to limit data consumption and preserve battery life).
(d) Radio chipset cost: $2 or less.
(e) Radio subscription cost: $1 per device/year.

Existing wireless networks are already established technologies, and they have well-established standards such as WiFi, Bluetooth 4.0, Zigbee, and Z-Wave [6]. Some of the issues with local area networks/personal area network are the battery consumption and connectivity range. Similarly, the cellular networks such GSM, 3G, 4G, LTE are also established proprietary mobile networks developed for better network coverage and data throughput, but it is not considered best when it comes to power consumption. On the other hand, LoRaWAN is a platform that can be built according to the specification. LoRa is exclusively developed to work with IoT devices which needs better battery life, low data transmission and minimal cost for deployment. On other hand, LAN and cellular network are quite expensive to deploy in a wide area, whereas LoRa usage would be much easier and cost effective for the implementation, and it follows the open standards. Next, we will discuss the relevant metering technology which supports our implementation.

Device Language Message Specification (DLMS) is an application layer protocol supporting multiple transport layer options including Ethernet and PLC. Companion specification for Energy Metering (COSEM) specifies the data model with their attributes and methods [10, 11]. DLMS/COSEM is open standard managed by DLMS user association. This protocol is accepted for use in most of the metering arena across the world. Moreover, it is accepted by most energy utilities in the wake of liberalized energy market. Several countries including India have framed metering specification based on DLMS which will act as a guideline for utilities to specify their metering requirements and ultimately improve consumer data collection, billing, and revenue.

OBIS code is the vital component used within DLMS protocol supported meters [12]. OBIS, an Object Identification System, provides the standard identifiers for all data within the metering equipment, both measurement values and abstract values. Moreover, the OBIS names are used for the identification of COSEM objects and the data displayed on the meter and transmitted through the communication line to the data collection system [12]. Easily, we can interpret the values extracted from meters through OBIS codes. The extracted values are communicated to the cloud through LoRa module used in our implementation. Now, using this new technology, we can extract the multiple relevant parameters from the general energy meter used in households for the analysis. We have also designed an analytical model for recommending certain schemes relevant to the consumers in a cloud setup.

3 LoRa Module Components

In our prototype, in order to connect the energy meter for reading and communicating, we have employed LoRa module which consists of two main interfacing components: a microcontroller that is attached with a LoRa RF module to get the details out of the meter and LoRa gateway for aggregation as shown in Fig. 1. The microcontroller block can be considered as the main block of the entire circuit, as it is programmed to control all the components to perform the desired operation. Here, in this project ARM® Cortex® microcontroller along with Semtech SX1272 LoRa extension board and programmed using the Arm Mbed OS platform. The energy meter is interfaced with the microcontroller using a serial converter device compatible with the meter's serial port. Similarly, LoRa modem is interfaced with a microcontroller to GPIO pins using interfacing connectors and cables.

LoRaWAN architecture uses a star topology network in which gateways acts as a transparent bridge relaying messages between end-devices and connects to the central network server in the backend [8]. In this setup, gateways are connected to the network server through a standard IP connection and the end-devices use single-hop wireless communication to one or many gateways [7]. Here, all end-point communications are generally forced to be bidirectional and it supports operation such as multicast enabling software upgrade over the air or other mass distribution messages to reduce the on-air communication time [8]. The communication between the end-devices and gateways are based on different frequency channels and different data rates [13, 14].