Synchrophasor Technology: Addressing Integration of Renewable with Synchronous Grid by Real Time Monitoring through WAMS

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***Abstract*— Integration of renewable energy sources introduce uncertainties and strains to the power system operations, which is closer to stability limits. The integration of renewable generation with conventional power grid poses challenges to power system dynamics due to its variable nature and different type of renewable generation have different behavior pattern. This requires the real time monitoring of electric grid, which can be achieve through Wide Area Monitoring Systems (WAMS).**

Synchronized phasor measurements is already recognize as one of the promising technologies for developing Smart Grid applications. In recent year's power, utilities all over the world focused their attention to deployment of Phasor Measurement Units (PMUs), which measure power system parameters in real-time. GETCO had taken a pioneer step for installation of 118 PMUs at 25 Location including 4 RE rich location in Gujarat grid. This paper covered how Synchrophasor Technology will help in addressing integration of renewable with synchronous grid. GETCO experience of implemented synchrophasor technology in grid, & potential application of PMUs for Power systems operation under high wind penetration & other RE sources and impact of RE on power quality issues by using PMU data is presented.

Keywords: Phasor measurement unit (PMU) - Wide Area Monitoring System (WAMS), Synchro phasor data, Renewable energy characteristics and impact.

I. INTRODUCTION

Partial switch from conventional to renewables sources arises in last decade with concept to integrate power generation at distribution level with implementation of solar rooftop. Slowly shape of generation set-up is in transposition, windmill generator connected with transmission system and solar generator connected with transmission as well as distribution system are taking shape. In future renewables overtake conventional with increasing focus on small windmill integration at distribution level or nearby consumptions point. Distribution grid required new observables to monitor the power system parameters, and to perform the right actions for operating the system.

Compare to conventional generating plant, outputs from renewable energy sources (RES) are highly variable in nature, creates large impact on grid operation. The rapid penetration of RE in the grid needs utilities to have a real time monitoring, which can be accomplished with the help of synchrophasors.

Synchrophasor technology expected to be the dominant source of insight predictions / forecasting and then convert it to dispatch instruction to Generators, Battery storage, Hydro pump mode, synchronous condenser HVDC, FACTS, interstate line flow, active power, reactive power, voltage control with the help of sophisticated engineering analysis to improve grid operation.

II RENEWABLE ENERGY AND INTEGRATION CHALLENGES

The world is accelerating towards electricity generation through diverse renewable sources. Integration of renewable energy sources to utility grid depends on the scale of power generation, the integration challenges are:

- Variability, Unpredictable and Uncertainty Nature
- Voltage Monitoring & Frequency response
- System Stability & Systems Balancing
- Oscillation detection & damping
- Reactive power control
- Harmonics Injection

The Government of India aims to reach a renewable energy capacity of 175 GW by 2022. 100 GW of this is planned through solar energy, 60 GW through wind energy, and 15 GW through other sources. In Gujarat, renewable installation target by 2022 is 17133 MW Solar-8020 MW & Wind-8800 MW. [1] so Wind & Solar energy will plays a vital role on power system parameters/dynamics.

Distributed generation means power production could occur anywhere, Consumer / self-consumption based electricity generation is increasing, Amount of grid-supplied energy required by a particular consumer could vary dramatically based on external conditions, and if the power not self-consumed significant power coming from distribution system could weakening grid stability. How much RE varies and how much coal plants output can response to RE are key factors affecting RE grid integration. Can be address using PMU signal to conventional generating plant to balance renewable generation.

The presence of additional wind and solar power on electric grids can cause coal or gas plants to turn on and off more often or, required to change their generation more frequently, to absorb variations in renewable generation. In addition, many time voluntary or obligatory frequent start stop according to wind or solar generation availability required.

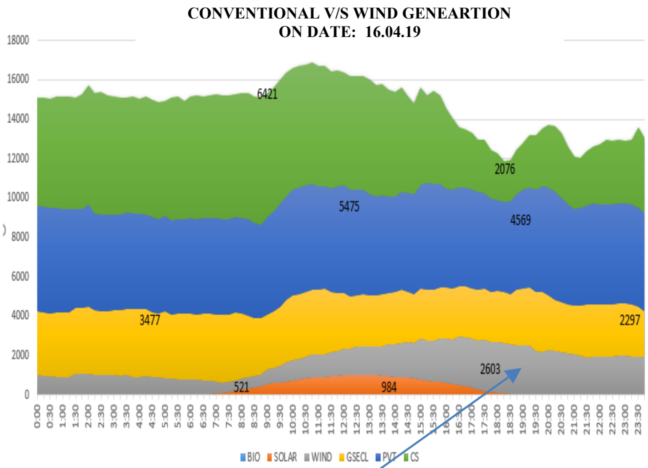


Fig.1

Fig.1 Shows wind generation profile on date 16.04.19 v/s back down / pick up conventional generation to mitigate demand.

- Low wind generation during night and increasing wind generation during daytime compel to put conventional generation on Bar from RSD and put again in RSD within a time of 8-12 hrs. Over and above pick up and backing down conventional generation available on bar.
- Wind generation curtailment was there in some pocket due to overloading of wind farm line.

New M/c taken on bar			Machines desynchronized		
Time	**Unit**	**MW**	**Time**	**Unit**	**MW**
00:36	WTPS 5	210	15:54	UTRAN 2 STG	146
00:43	STPS 4	250	15:57	UTRAN 2 GT	228
00:46	UTRAN II STG	146	17:05	GSEG 2 STG	129
08:07	GSEG II STG)	129	17:09	GSEG 2 GT	222
		733	16:22	JGPP STG)	224.5
Huge MW difference in taking M/C on bar and off bar, ultimately leads to load reschedule as shown table 2.			18:06	JGPP	144
			19:17	GTPS 3	210
			21:50	STPS 3	250
			23:34	WTPS 4	210
					1762.5

Table.1

For smooth operation of grid, compel to reschedule load.

Time in hrs.	MW
01.20 to 01.40	575
06.50 to 07.00	200
06.50 to 07.05	180
07.00 to 07.05	50

Table.2

Such type of frequent variation corrective action can be address-using PMU.

Cyclone Fani struck North – Eastern parts of India in Odisha and Uttar Pradesh and Bangladesh but impact on wind generation at western part of India i.e. Gujrat effected.

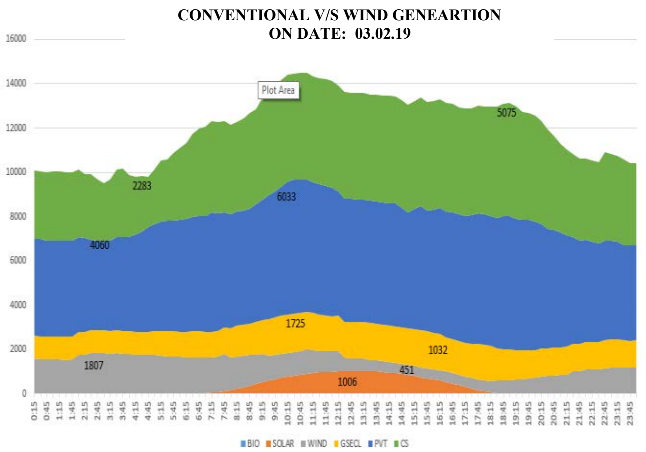


Fig.2

Fig.2 Shows wind generation profile on date 03.02.19 v/s back down / pick up conventional generation to meet the demand of day. Higher wind generation in a night (00-07 hrs.) create challenge for system operator to handle grid and easily fine tune the requirement by pick up and backing down of conventional generation.

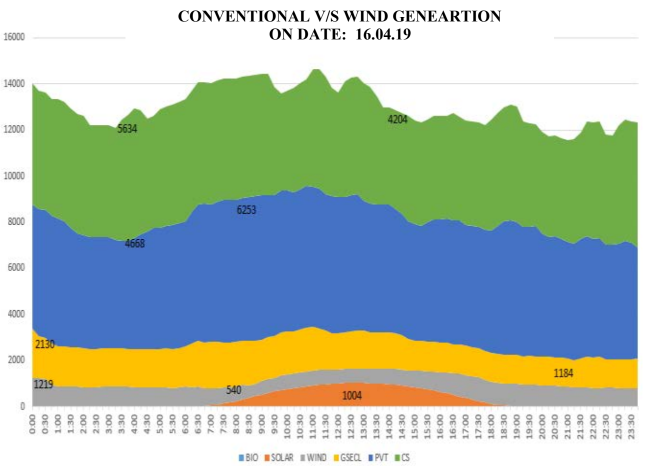


Fig.3

Fig.3 shows solar generation profile on date: 16.04.19 and how balanced with generation to meet demand of the day. Generally, gas turbines, hydropower plants, are among the most flexible generators.

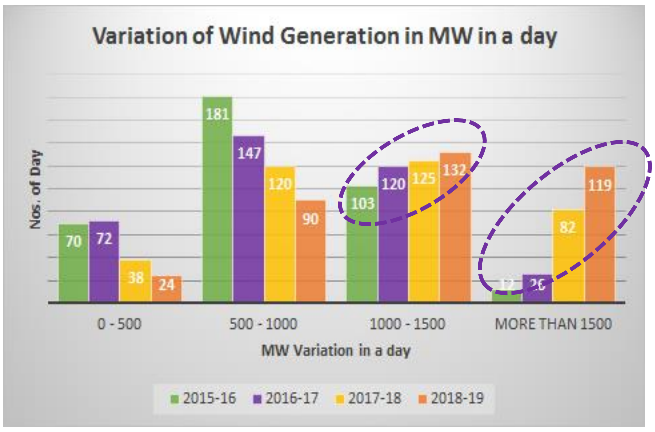


Fig.4

With the increasing penetration of RE, variation of wind generation in a day in tune of 1000-1500 MW and more than 1500 MW is increasing drastically as shown in Fig. 4. Variation of 1500 MW in day became 119 in 2018-19 against 12 in 2015-16, which is very tough operating condition for grid operator particularly when operational band is tighten day by day.

To handle such variation's PMU base real time grid monitoring tools requires for expansion and integration of renewable with grid.

PMU signals will help in managing the variation in RE, with faster dispatch to load and generation for linearly matched.

III. SYNCHROPHASOR - PREDICTING WHAT MATTERS TO THE GRID:

High-speed, wide-area, continuously recording, time-synchronized, grid monitoring and sophisticated analysis become a foundational element of grid modernization for transmission system. Phasor Measurement Units (PMU) inputs from potential transformers (PT) and current transformers (CT). Analog signal recorders with transducer, Inputs from the controller interface or the controlled device can be utilize to control / monitors (Generators, HVDC, FACTS, Hydro Pump Mode Operation, Synchronous condenser, Battery Storage, Ancillary services.) through advanced relays and other intelligent electronic devices (IED).

Installation of PMUs at each turbine is not practical, but it is essential at pooling station wise to improve aggregate wind generator behavior. Synchrophasor data offers substantial insight for forecasting and interaction between generators, as well as various grid elements to improve grid operation. Which help in the expansion and integration of renewable generation.

SLDC-GETCO had taken initiative to implement WAMS technology in Gujarat grid, at 25 Location, 118 PMUs was install @ 473 transmission elements. For RE observation, 4 Nos. of PMU was installed nearby wind & solar pooling station.

RE Integration and PMUs- How can we use synchro phasors?

- Assess grid stress and line reclosing using phase angle measurements.
- Power flows from bus with high phase angle to lower phase angle in inter area power transfer.
- The Synchro phasors can be assist for line reclosing and system restoration after events, and disturbances using Phase Angle Differences.
- Real-time monitoring of primary frequency.
- Determination of variable generation impacts on primary frequency.
- Oscillation detection and damping.
- Assessing real time inertia by developing analytics

IV. CASE STUDY

In paper, real time case study is taken to support synchro phasor technology effectiveness, & to identify impact of renewable generation integration to grid. In Case-1 impact of high wind generation on reactive power flow from grid is identify using real time data of PMU installed at 220 KV Shivlkha - Vandhiya line. In support to this case, another case is taken of 220 KV Nani khakhar-Sindhodi line, both case study data is taken during high wind generation.

Case-2 Impact of RE generation tripping on synchronous grid is highlighted with PMU data.

Case-3 Low frequency mode oscillation was observe at 220 KV Shivlkha SS bus during high wind injection in grid, oscillation is identify with the help of PMU data & developed analytic tools of oscillation stability availed at SLDC Gujarat.

Case-1: High wind integration to grid drawl of reactive power flow from systems.

Fig. 5 & 6 is PMU's real time data of active & reactive power flow of 220 KV Shivlkha - Vandhiya line on dated 13.06.18, 05:05:31 to 11:41:19 hrs. of Shivlakha end.

Active Power monitoring of renewable energy systems using PMUs, Grid importing active power from wind farm. However, injection of active power in the grid is not linear, A sharp increase observed in reactive power absorption from grid when machines switched in simultaneously. Therefore, it is essential to keep the load perfectly balanced.

In Fig. 5 at 8:51, P_{max} is @ 99 MW (Import to grid at Shivlkha GETCO S/S), at the same time wind farm pooling station absorbing Q at 13.757 MVAR from grid. Voltage magnitude of Bus is @ 222 KV as fig. 6, which is reasonably good voltage profile observed in high wind injection, because of strong leading local VAR support is available at GETCO grid substation.

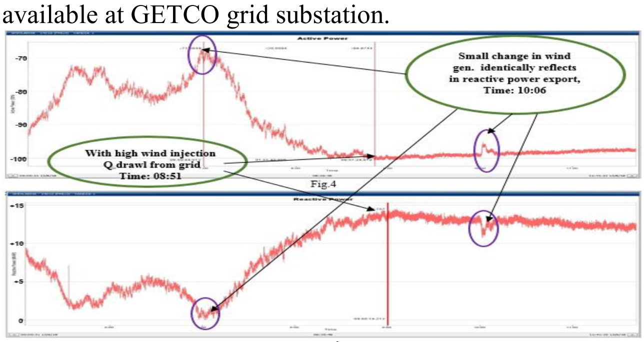


Fig.5

PMU measurements/data will provide better situational awareness for dispatchers to track voltage stability during fast wind ramps. In fig.7 at 10:06 hrs. small variation in generation reflected identical in bus voltage at 220 KV Shivlakha s/s, & it can be possible for operator to track real time P & Q from control center if synchrophasor data of wind pooling s/s is available.

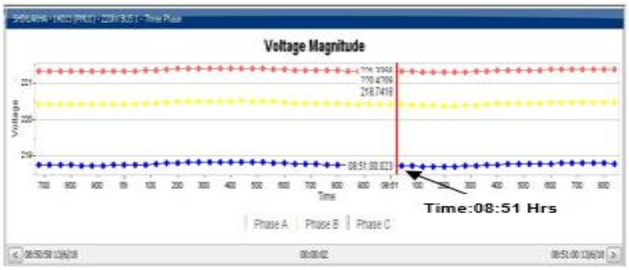


Fig.6

Fig.7

The "Voltage" and "Frequency" is the main parameters of electric grid, for maintain proper voltage profile of the grid, it is necessary to match supply of VAR with the VAR demand. The VAR generated by over exiting generator, Capacitors, EHV lines (Light loaded). Generally, Wind mill induction generator having characteristics to absorb Q from system. All electrical devices working on electromagnetic principal consume the VAR. Supply of VAR is more than its demand, it may lead high voltage in system.

Case: 1.1 At 220 kV Nanikhakhar S/s on dated: 06.08.18 from 06:00 hrs to 08:00 hrs. typical phenomenon observed. As per fig. 8, 07:10 hrs 220 kV Sindhodhi line 1 & 2 of wind farm pooling station absorbtion of high reactive power from grid Total Q is @ 286 MVAR, against import of Active Power Total P is @ 69 MW. Voltage profile of 220 kV Nanikhakhar S/S observed reasonably good during same period at 220 kV of Bus.

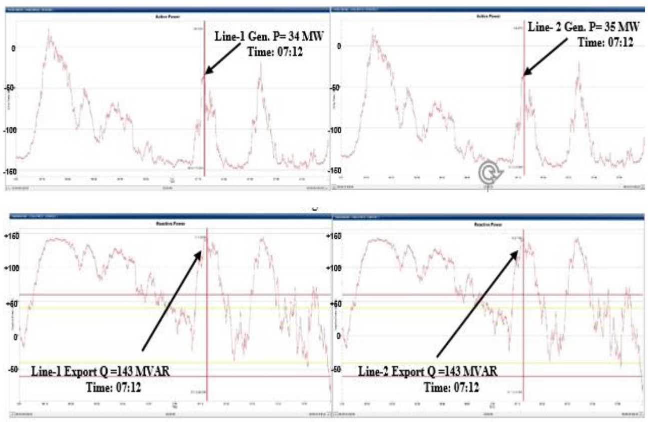


Fig.8

Case:-2 Impact of RE generation tripping on synchronous grid:

At 220 kV Nanikhkhar S/S, wind farm line of 220 kV Suthari line-1 was tripped on single phase to earth fault on date: 05.09.18, 02:26 hrs. As per PMU data,

- As per Fig.9, fault current is 1.5 kA. 58 MW generation,
- As per Fig.10, DF/DT variation is +0.50/-0.48 is observe.

Fig.10, Voltage profile of B ph. is get dipped by 185 kV of 220 kV Bus at Nanikhkhar S/S

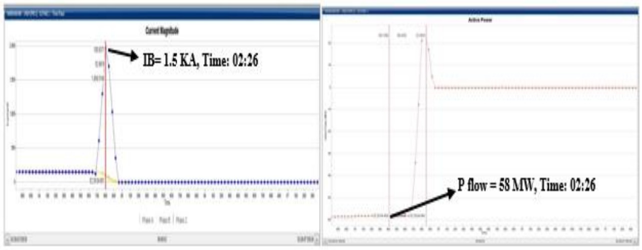


Fig.9

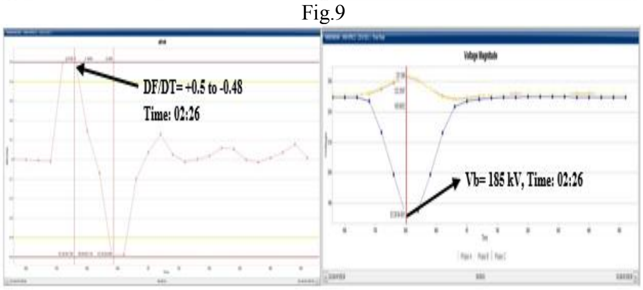


Fig.10

GETCO has installed PMU at 400 kV & 220 kV voltage level, No direct observability of 66 kV Grid through PMU, on date: 02.10.18, 66 kV Shivlkha-Shikarpur line-1 of wind generation tripped at 02:15 hrs. disturbance effect on 220 kV Shivlkha bus is observed with PMU data.

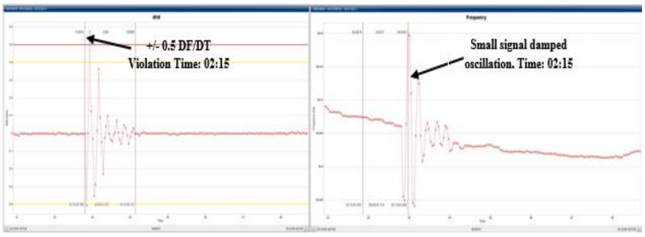


Fig.11

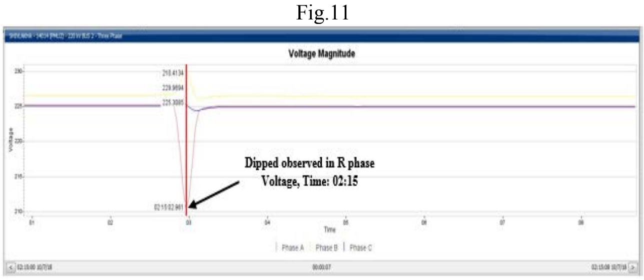
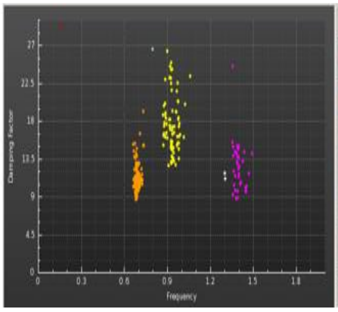


Fig.12

DF/DT, Frequency, Voltage graph of 220 kV Bus of Shivlkha S/S is in fig.11, 12 respectively. DF/DT crossed it alarm limit +/- 0.5, Small signal damped oscillation was observed at 220 kV bus, this event has raised alarm at control center operator console. From real time data of PMU it was indication to SLDC control room operator for tripping of wind farm pooling station line. Presently most of renewable pooling station are integrated with 66 kV transmission network, and this pooling station are beyond reach for dynamic observation in SCADA systems. Hence, PMU data is very useful to grid operator for monitoring pooling station behavior for any abnormal situation, with this information of wind generation from PMU data, operator at control center has flexibility to pick up, back down the conventional generation for smooth & reliable grid operation.

Case: 3 Identification of low frequency oscillation during high wind penetration:

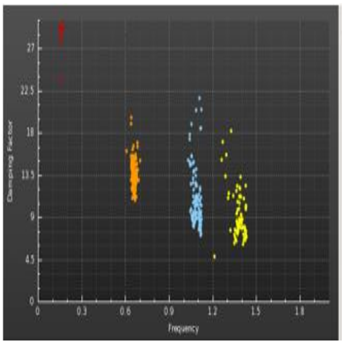
The integration of a large amount of renewables with Synchronous Grid may pose new issues to its control and operation. One of important issues is that low frequency oscillation may be induce by the variation of the wind power, which is also state as a forced low frequency oscillation. On date: 04.09.18 16:00 hrs. at 220 kV Shivlkha SS bus, depicted in graph fig.13, Frequency vs damping, low frequency oscillation was observed in the range of 0.690, 0.796, 0.934, 1.301, 1.398 Hz damping is reasonably good in the range of 10 to 20 %. At present, Gujarat power systems having strong inertia and reasonably good damping is observe during high wind penetration.



f (Avg)	f (Std Dev)	ζ (Avg)	ζ (Std Dev)
0.158	0.000	29.286	0.000
0.690	0.016	11.410	1.657
0.796	0.000	26.563	0.000
0.934	0.037	17.621	3.308
1.301	0.001	11.492	0.329
1.398	0.034	12.540	2.873

Fig.13

Comparative analysis is carried out on same date & time at 220 kV Haldarva S/s in south region of Gujarat grid, from fig.14 it can depicted that low frequency oscillation in narrow frequency band observed. Range of low frequency oscillation observed at nearby wind farm pooling station is relatively more as compare to oscillation observed at other location of Gujarat grid.



f (Avg)	f (Std Dev)	ζ (Avg)	ζ (Std Dev)
0.159	0.009	28.379	1.745
0.659	0.014	13.608	1.553
1.085	0.024	11.066	3.183
1.377	0.041	9.239	2.486

Fig.14

Analytics developed based on synchro phasor data can be useful to observe low frequency oscillation during high wind penetration in grid, according corrective action can be taken by operator to increase the small signal stability of grid.

Realistic Challenges for Synchrophasor technology:

- Voltage control, Effective reactive power sharing
- Power from conventional plant need to transfer via stable & limited path
- System operators respond & understanding of phasor data with available options for action.
- Institutional problems with putting PMUs on generator terminals.
- Lack of policy support like incentive to extend PMU deployments with technological advancement.

V. SYNCHROPHASOR-BASED TOOLS FOR RE INTEGRATION ISSUE:

- Synchrophasor tools like state estimation to improve situational awareness with wide-area visualization for operators & to improve visibility of remote wind generation.
- Different tool sets required to concentrate on transmission and distribution level.
- Transfer of RE through long transmission lines is a challenges, can be addressed using PMU based application.
- Many distributed generators are unmonitored, with PMUs at the distribution level generation / load monitoring enhance.
- Active power control and voltage control of wind plant need feedback from fast measurement of PMUs.
- Automatic oscillations detection will help to detect islanding / trip-off, / curtail wind plants on vulnerability by creating oscillations to the grid, instead of rotation / proportion basis.
- PMUs enable dynamic line ratings could help to reduce wind curtailments
- Unknown status of planned outage of wind mills unavailability of real-time outages / tripping of WTGs.

VI. CONCLUSION:

To meet the rising demand of consumers and climate change, electricity utilities are integrating various renewable energy sources with conventional energy sources. Different type of renewable generation have different behavior pattern, present measuring system is not able to capture the dynamics of the system due to slow rate of capturing data, synchrophasor technology having high sample rates (25-50 samples per second) required to replace the SCADA. In near future micro grid / energy storage / EV charging may be a key elements of power grid, and with increasing penetration of renewables, quick measurement with control action for renewable generation is essential, considering same synchrophasor technology enhances the planning, designing and operation of the power system network. The synchrophasor technology also has the potential to improve the operator's confidence significantly to carry out real time grid operation, and able detect and respond to possible disturbances.

In future, more execution will take place where renewable power generation would be in one resource rich state may require to transmit to other renewable deficit states, which lead to instantaneous penetration of renewables. In addition, distribution level wind and solar generation take place. Transmission-level RE generation provide real-time generation data to power system operators, whereas distributed RE generation do not, so it difficult for a system operator to know whether an increase in net load is due to increasing demand or dropping RE generation, with help of PMU same can be identified.
Presently power systems is so capable to absorb fluctuation of frequency, voltage, Var but to achieve target of 175 GW, and particularly when from 175 GW, 100 GW will be connect to distribution level. To make systems more robust & responsive monitoring of voltage ride through LVRT / HVRT, flicker, sudden voltage change, protection coordination etc. requires, it can be achieve using PMU data.

Gradually Indian power system journey climbing towards maturity where year by year frequency band tighten step by step, now with implementation of DSM 4 & 5, operational band will be tighten near zero crossing, with compulsory sign change required at least after 12^{th} / 6^{th} time block (From 01.04.2020) to avoid huge penalty. When no immediate revision in power sale / purchase can be feasible for deviation, in demand / forecast due to RE / conventional generation variation / tripping, and with different conventional generator having different ramp up / down rate. With huge RE integration we cannot change the weather but we can manage around it with PMU measurement, by converting in to a corrective action towards ancillary services, assist in a smooth running of power grid.

It is like instead of self-medication detail diagnosis and then Doctor's Prescription. Required policy framework to continue and widen PMU placements on renewables generation.

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BIOGRAPHICAL INFORMATION

D.N. Shah, Executive Engineer, State Load dispatch Center, Gujarat Energy Transmission Co. Ltd., Vadodara. He has been associated with GETCO (erstwhile GEB) for more than three decades. Having work experience in the field of Operation & Maintenance of Thermal Power Plant, and EHV transmission lines and Switchyard, Erection, testing & commissioning of EHV lines and Substation @ 12 years Protection and Testing division @ 3 years.

In addition, ten + years, of experience @ SLDC Gujarat in field of Grid Operation, MIS, outage management, Scheduling, Energy Accounting, Open Access, Regulatory affairs, SCADA and Phasor Measurement Unit (PMU) / Wide Area Monitoring System (WAMs) and Renewable Energy Integration at SLDC. Graduate Electrical Engineer from BVM, S P University, V. V. Nagar BEE certified Energy Manager as well as Energy Auditor