Advanced Sensor Deployment for Distribution System State Estimation and Fault Identification

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Introduction

One of the challenges to the electric distribution system utilities and operators is the lack of visibility at different circuit levels on the distribution grids. This paper presents simulation studies to demonstrate the benefits of an advanced, high-fidelity sensor technology, called as the Meta-Alert System (MAS), developed by Electrical Grid Monitoring, Ltd. (EGM), on the distribution grid. Two use cases: (a) distribution system state estimation (DSSE) and (b) fault identification are explored to evaluate the performance of the MAS technology on the EPRI J1 distribution test feeder.

Meta-Alert System

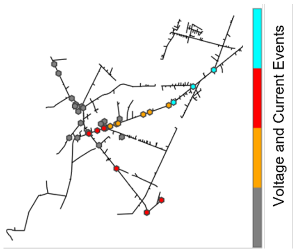
The MAS is a technology solution for the electric grid that offers real-time field monitoring and advanced analytics capable of generating useful information for operation, maintenance, and engineering. It comprises:

1) multi-sensor units (MSUs) attached to grid lines,
2) communication adaptor units, and
3) a Meta-Alert Management System (MAMS) at the control center.

Sensor and MAMS Modeling

A simplified software-based model of the MAS is developed for the simulation studies. The developed sensor model has the following capabilities:

(1) Output measured electrical parameters, such as root-mean-square (RMS) current, RMS voltage, frequency, and power factor.
(2) Generate electrical reports and energy meter reports for a pre-defined time period.
(3) Issue alarm notifications indicating abnormal behavior.



Example visualization of how the MAMS analytics estimates the fault type and location

Grid Simulation

A. Use case 1: DSSE

A DSSE algorithm that uses line power flow and voltage measurement data from the EGM sensors is implemented. It evaluates network states efficiently to validate the use of EGM sensors in providing real-time network situational awareness to the system operator.

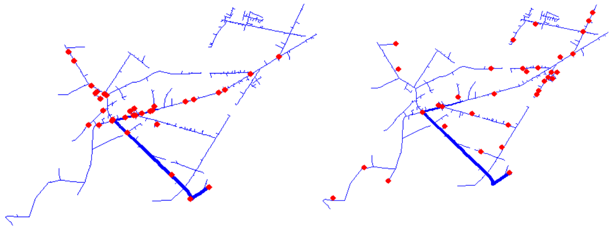
B. Use case 2: Fault identification

Multiple scenarios of faults (single- and multiphase) on the test feeder are used to evaluate the advantage of the MAS technology for fault identification. Further, the performance of the MAS technology is compared with traditional scheme of fault detection.

Sensor Deployment

The recommendations defined by EGM to place the sensors on the grid are as follows:

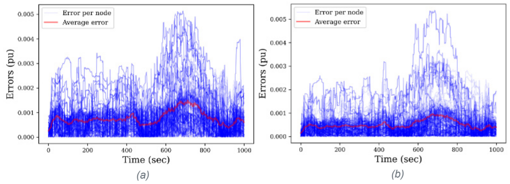
(1) Sensors are placed on each phase, and the MAMS recognizes that relation.
(2) Place the sensors before splits of the feeder for better detection resolution.
(3) Maintain the defined minimum distance between any two sensors.



Sensor deployment Scenarios; (a) sensors are placed mostly on the major lines and at junction points, (b) sensors are placed at some end lines (lateral branches) in addition to junction points

Numerical Results

A. DSSE

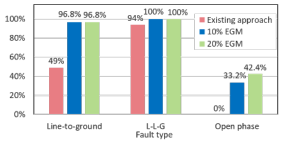


DSSE error plots with (a) random and (b) optimal sensor deployment on 10% of the lines.

The average mean-square error over 1000 seconds is 0.0771% with random sensor placement, whereas with optimal sensor placement, the average mean-square error is 0.0486%. This demonstrates that even having only a small number of EGM's sensor would benefit with improved DSSE accuracy.

B. Fault Identification

(1) Analysis I: Random distribution of hundreds of faults on the feeder and calculate the percentage of faults detected.



Percentage of faults detected under the three scenarios (existing approach, 10% EGM sensor, and 20% EGM sensor) for three different fault types

The MAS system could detect significantly greater number of faults than the traditional fault detection approach.

	Scenario				
	Existing/ traditional approach	With 10% EGM		With 20% EGM	
		Deployment Scenario 1	Deployment Scenario 2	Deployment Scenario 1	Deployment Scenario 2
% of open-phase faults detected	0	34%	39%	44%	46%

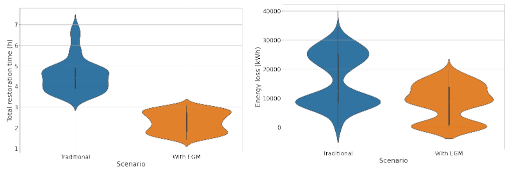
Open-phase fault detection percentage change with change in deployment and number of sensors

Open-phase fault detection depends on the number as well as the location of sensor units placed. It requires a larger number of sensors than the two other fault types to detect more faults.

B. Fault Identification

(2) Analysis II: Evaluate the performance of each scenario with metrics

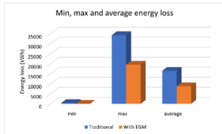
A total of 300 individual line-to-ground fault occurrences were simulated at selected random times within a day to evaluate the performance with the pre-defined metrics.



Statistical distribution of the total restoration time and total energy loss with and without the MAS

The total restoration time (time from the start of the fault to normal operation) distribution shows a significant reduction in average time in the scenario with EGM. The lower total restoration time with EGM implies a faster recovery from the fault events and therefore lower energy loss.

The MAS system is effective at faster fault detection, identification, and restoration.



Min, max and average energy loss comparison

Conclusions

1) EGM's sensor and MAMS capabilities were numerically modeled to investigate the DSSE and fault identification use cases.
2) The simulation studies demonstrated that EGM's MAS can provide significantly improved DSSE accuracy with only a small number of sensors.
3) The studies showed a significant increase in fault detection speed and accuracy, reduced energy lost as a result of faults, and improved customer load availability compared to traditional schemes.

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