Power Quality Monitoring & Mitigation in Smart Grids using Dynamic Voltage Restorer (DVR)

K. Bharathi, N. Rajeshkumar Gowd, P. Shashavali

[1]PG Student in Department of EEE, SKU College of Engg.and Tech., SK University, Anantapuramu-515 003.
[2,3]Lecturer in Department of EEE, SKU College of Engg.and Tech., SK University, Anantapuramu-515 003.

Abstract:-This paper considers the real-time voltage quality monitoring in smart grid systems. The goal is to detect the occurrence of disturbances in the nominal sinusoidal voltage signal as quickly as possible such that protection measures can be taken in time. Based on an autoregressive model for the disturbance, we propose a generalized local likelihood ratio detector, which processes meter readings sequentially and alarms as soon as the test statistic exceeds a prescribed threshold. The proposed detector not only reacts to a wide range of disturbances, but also achieves lower detection delay compared with the conventional block processing method. Then, Dynamic Voltage Restorer (DVR) can mitigate the voltage sag during the Disturbances we further propose to deploy multiple meters to monitor the voltage signal cooperatively. The distributed meters communicate wirelessly to a central meter, where the data fusion and detection are performed. In light of the limited bandwidth of wireless channels, we develop level-triggered sampling scheme, where each meter transmits only one-bit each time asynchronously. The proposed multi-meter scheme with DVR features substantially low communication overhead, while its performance is close to that of the ideal case where distributed meter readings are perfectly available at the central meter.

Key Words: ***Voltage signal disturbance, Dynamic Voltage Restorer (DVR), auto-regressive model, change detection, level-triggered sampling.***

I INTRODUCTION

At Present the power quality has become a critical security concern for the emerging power grid system, due to the rapidly growing number of equipments that not only generate but also are sensitive to various disturbances. In addition, the power system degeneration has also increased the challenge of meeting customers' high power quality standards [1]. For that matter, one crucial task is monitoring the power signal for malicious disturbances that could lead to device damage or even network blackout. In general, power quality disturbances include the voltage quality disturbance and the current quality disturbance. In this paper, we focus on the voltage quality disturbance.

In practice, the monitoring procedure is commonly realized by sampling and analyzing in real-time the voltage waveform. In order to capture some voltage disturbance of interest, meters are required to sample at a significantly high rate (e.g., 3.6kHz could be used for 60Hz AC supply), and moreover, the meter readings are subject to the influence of noise [2]. Specially, the noise level could be comparable to that of the disturbance when the low-voltage distribution system is considered. Consequently, there are two main steps involved in voltage quality monitoring:

1) Detection and
2) classification.

In the first step, the occurrence of a voltage waveform change needs to be detected based on the noisy measurements. In the second step, once a waveform change is declared, the system control can take further measures in real time, such as, activating meters to record informative measurements for off-line assessment and analyzing the distorted waveform.

The second step is able to determine whether the detected deviation corresponds to normal operations, where no online treatment is required, or it is related to potential hazardous event. For the latter case, the disturbance type will be identified so that automatic protection or man-force involvement will be decided. Specifically, this paper investigates the first stepof the voltage quality monitoring, i.e., to detect the voltage disturbance from the observed noisy waveform as soon as possible after its occurrence.

Alternatively, the Auto-Regressive (AR) model is employed for the voltage disturbance detection in , which is capable of capturing a broad range of spectral property, whereas the sinusoidal model can only capture a certain fixed number of frequency components. However, the method in is based on examining the residual during the waveform transition, making it vulnerable to noise.

Under the change detection frame work, a sequential online approach based on the weighted CUSUM test was introduced, by examining the different distributions of the observed waveforms before and after the occurrence of the disturbance. However, the disturbance signal is treated as independent over time. Another noteworthy approach to combating the noise is to employ cooperative meters. In reality, voltage disturbances tend to occur to a group of connected electrical buses within a certain network at the same time (in fact, they propagate through the network in the speed of light), which brings about the opportunity of detecting the disturbance occurrence in a collaborative fashion. That is, by employing multiple meters at these connected electrical buses, one can draw on the diversity across meters to achieve better detection performance than using a single meter .

This notion is made practical by the recent advance of integrating smart meter network and wireless communication techniques into the smart grid system .For instance, Srivastava *et al.* and Bisceglie *et al.* employ the wireless sensor network to aggregate power quality indices via message passing. Also, in the context of deploying wireless Cyber-network for voltage profile monitoring, meter installation and communication protocols. Specially, the proposed Neighbourhood Oriented Energy Management System (NOEM) there allows the operator to create groups of smart meters. Nevertheless, specific signal processing techniques of cooperative disturbance detection on top of these physical infrastructures is yet to be investigated.

Moreover, we consider the scenario where multiple meters are employed for cooperatively monitoring the voltage waveform. Though the operator can configure the group of cooperative meters via NOEM, we particularly focus on multimeter cooperative detection within a substation network at the distribution level. Despite the robustness against noise, distributed meters inevitably impose communication challenges. Conventionally, meters transmit their local measurement (quantized with multiple bits) to the central meter, where the cooperative detection is performed.

First, we are faced with a change detection problem with composite post-change hypothesis; more importantly, we propose a new method to address the drawback of level-triggered sampling scheme, i.e., the accumulation of overshoot errors. The reminder of this project is organized as follows. We formulate the disturbance detection as a sequential change detection problem based on the AR model and develop a generalized local likelihood ratio (GLLR) test. We study the multi meter cooperative detection and develop the decentralized GLLR test based on the level-triggered sampling.

II CO-OPERATIVE MONITORING BASED ON LEVEL-TRIGGERED SAMPLING

In this section, we consider the cooperative detection of voltage disturbances within a substation network at the distribution level. Cooperative detection takes advantage of the fact that the substation buses are affected at the same time by a voltage disturbance, and allows us to achieve fast decision. Particularly, it is implemented by deploying multiple meters at local buses across the substation network that communicate wirelessly with a central meter which is responsible for making the global decision is shown in Fig.1.

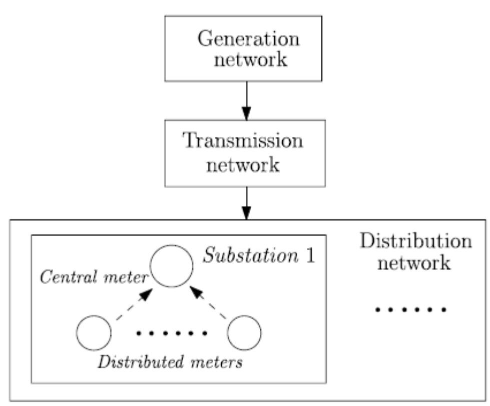

Fig.1: Illustration of cooperative detection in a substation network at the distribution level.

Consider L meters that are linked wirelessly with a central meter and perform the cooperative disturbance detection. The straight forward scheme is to make the distributed measurements fully available to the central meter by transmitting very finely (infinite-bit) quantized measurements at every sampling instant, i.e., the centralized setup. However, in practice, the wireless links between the distributed meters and the central meter are characterized by limited bandwidth. Therefore in designing a practical system, two constraints need to be considered, namely the *rate constraint* (i.e., the distributed meters should communicate with the central meter at a lower rate than the local sampling rate) and the *quantization constraint* (i.e., each meter should transmit a small number of bits every time it communicates with the central meter).In particular, considering the high sampling rate at distributed meters (e.g., for 60Hz AC supply in North America, the sampling rate could be 3.6kHz with 64 samples per cycle)and the large number of quantization bits in order to achieve an acceptable accuracy at the central meter, where the distributed meters communicate with the central meter in some low-rate fashion, becomes necessary. To that end, we propose a level-triggered sampling scheme which efficiently lowers the communication overhead in terms of both the communication frequency and the number of information bits at each transmission, while preserving the time resolution of the disturbance detection.

III OPERATING MODES OF DVR

The fundamental capacity of the DVR is to infuse a progressively controlled voltage DVR created by an unnatural commutated converter in arrangement to the transport voltage by method for a sponsor transformer. The DVR has three methods of operation which are: insurance mode, standby mode, infusion/support mode. On the off chance that the over current on the heap side surpasses a suitable limit because of short out on the heap or expansive inrush current, the DVR will be cut off from the frameworks by utilizing the detour switches (S_2 and S_3 will open) and supplying another way for current (S_1 will be shut).

In the standby mode the booster transformer's low voltage winding is shorted through the converter. No switching of semiconductors occurs in this mode of operation and the full load current will pass through the primary.

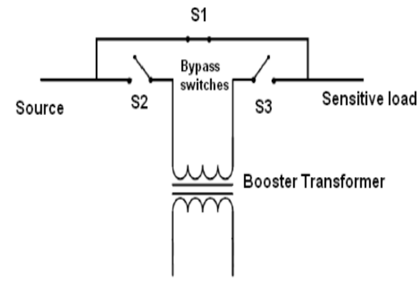

Fig.2: Protection Mode (creating another path for current)

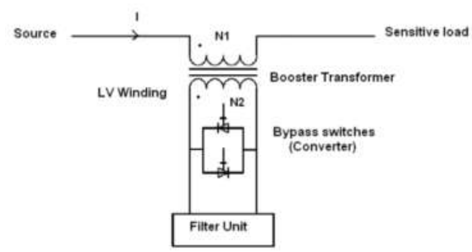

Fig.3: Standby Mode

In the Injection/Boost mode the DVR is injecting a compensating voltage through the booster transformer due to the finding of a disturbance in the supply voltage. Voltage injection or compensation methods by means of a DVR depend upon the preventive factors such as; DVR power ratings, different conditions of load, and different types of voltage sags. Some loads are sensitive towards phase angle jump and some are sensitive towards change in size and others are tolerant to these. Therefore the control strategies depend upon the type of load characteristics.

The pre-sag method tracks the supply voltage continuously and if it detects any disturbances in supply voltage it will inject the dissimilar voltage between the sag or voltage at PCC and pre-fault condition, so that the load voltage can be restored back to the pre-fault condition. Compensation of voltage sags in the both phase angle and amplitude susceptible loads would be achieved by pre-sag compensation method. In this method the injected active power cannot be forbidden and it is determined by external conditions such as the type of faults and load conditions.

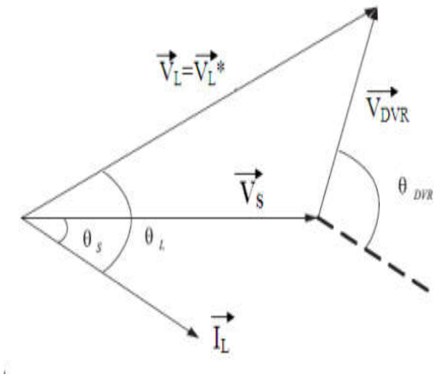

Fig.4: Pre-Sag compensation method

This is the most straight forward technique. In this technique the infused voltage is in stage with the supply side voltage independent of the heap current and pre-flaw voltage. The stage edges of the pre-hang and load voltage are distinctive yet the most noteworthy criteria for force quality that is the steady greatness of burden voltage are fulfilled.

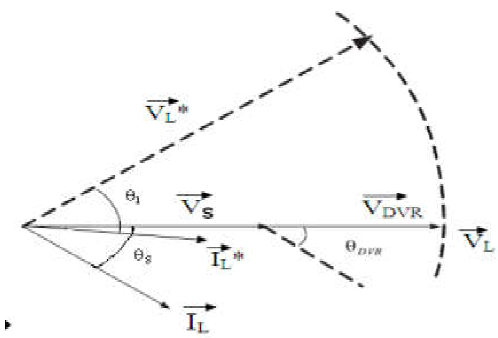

Fig.5: In-phase compensation method

One of the benefits of this strategy is that the sufficiency of DVR infusion voltage is least for certain voltage droop in association with different techniques. Reasonable utilization of this strategy is in non-delicate burdens to stage edge bounce. In this strategy the genuine force spend by the DVR is diminished by minimizing the force point between the droop voltage and burden current. If there should be an occurrence of pre-hang and in-stage pay technique the dynamic force is infused into the framework amid turbulence. The dynamic force supply is constrained put away vitality in the DC connections and this part is a standout amongst the most excessive parts of DVR. The minimization of infused vitality is accomplished by making the dynamic force part zero by having the infusion voltage phasor opposite to the heap current phasor.

In this technique the estimations of burden current and voltage are settled in the framework so we can change just the period of the hang voltage. IPAC technique utilizes just receptive force and unfortunately, not al1 the lists can be moderated without genuine force, as a result, this strategy is reasonable for a restricted scope of droops. A little drop in voltage and little bounce in stage edge can be endured by the heap itself. In the event that the voltage degree lies between 90%-110% of ostensible voltage and 5%-10% of ostensible state that won't exasperate the operation attributes of burdens. Both degree and stage are the control imperative for this technique which can be accomplished by little vitality infusion.

IV VOLTAGE SOURCE INVERTER

Fig.6 demonstrates that three-stage voltage-source inverter structure. A DC voltage source bolstered by a nearly huge capacitor nourishes the 3-stage inverter circuit. The DC voltage source is a battery, energy component stack, diode rectifier, and/or capacitor. Six switches are utilized as a part of the fundamental circuit each is traditionally made out of a force transistor and a restricting parallel (or freewheeling) diode to give bidirectional current stream and unidirectional voltage blocking office. It has certain confinement of the voltage source inverter. The AC yield voltage is restricted beneath and can't surpass the DC voltage. The V-source inverter is a buck (venture down) inverter for DC-to-AC power transformation. The upper and lower gadgets of every stage leg ought not to be gated on simultaneously in light of the fact that a shoot-through would happen and demolish the gadgets. The shoot-through issue by electromagnetic obstruction (EMI) clamor's misgating-on is a primary executioner to the converter's steadfastness.

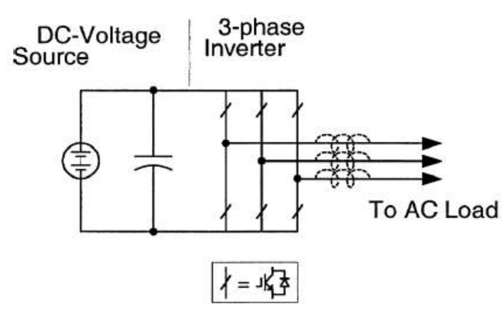

Fig.6: Voltage Source Inverter

The present source inverter has certain limits of the AC yield voltage must be greater than the first DC voltage that bolsters the DC inductor or the DC voltage made is constantly littler than the AC input voltage. The present source inverter is a help inverter for DC-to-AC power transformation. No less than one of the upper gadgets and one of the lower gadgets must be gated on and kept up on whenever. Or the consequences will be severe, an open circuit of the DC inductor would happen and decimate the gadgets. The open-circuit issue by EMI clamor's misgating-off is a fundamental worry of the inverters unwavering quality. The principle switches of the I-source inverter need to square turn around voltage that requires an arrangement diode to be utilized as a part of amalgamation with fast and superior transistors, for example, protected door bipolar transistors (IGBTs). This keeps the straight utilization of minimal effort and elite IGBT modules and shrewd force modules (IPMs).

V SIMULATION RESULTS

In this section, we first apply the proposed detector on some typical power quality disturbances to demonstrate that it promptly detects the occurrence of these disturbances. In specific, we compare the proposed detector with the widely used RMS method, the STFT method and the weighted CUSUM method. Then we examine the performance of the proposed cooperative detection scheme as well as its decentralized implementation based on the level triggered sampling. In our simulation, the disturbance signals are obtained by constructing simulation systems using the popular MATLAB toolbox SimPower Systems. We mainly consider the disturbance of voltage sag induced by a distribution line fault (simulated by constructing the network in Fig. 7. and the transient disturbance induced by the capacitor bank switching (simulated by constructing the network in Fig. 8. In particular, Fig. 3corresponds to a simplified distribution network where three phase power supply is transmitted and distributed to “load 1”and “load 2”. Three meters are deployed to monitor this distribution network. In Fig. 8, “Capacitor-1” and “Capacitor-2”constitute the capacitor bank which can be switched ON and OFF to adjust the power factor. Throughout the MATLAB,

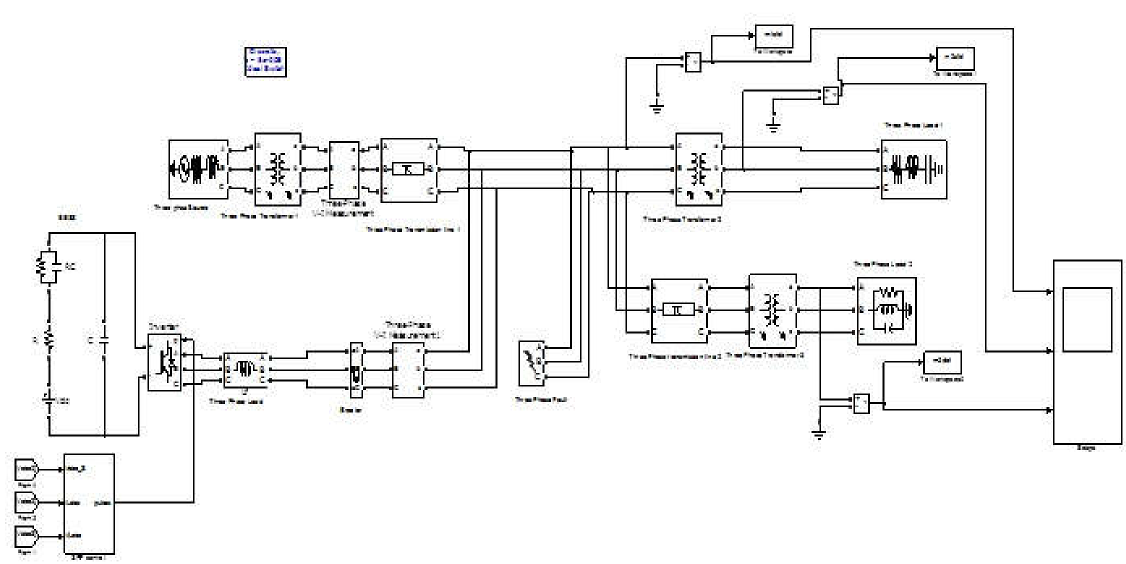

Fig.7: The simulation system for fault-induced power sag disturbance.

By focusing on the single-meter detection, we compare the proposed GLLR detector with the widely adopted methods, namely the RMS method, the STFT method and the weighted CUSUM test. Fig. 5 illustrates the power sag disturbance incurred by the “Phase A line” fault at t = 0.0869s (the occurrence is marked with dashed blue line). Fig. 6 illustrates the power transient distortions incurred by closing “capacitor-1”in Fig. 4 at t = 0.105s. They correspond to the voltage waveform at “meter

1” in Fig. 3 and Fig. 4 respectively. Both the RMS method and the STFT method are implemented with a one-cycle window that slides point by point, achieving the best possible time resolution. Thus the STFT method performs the 64-point FFT within each window. The weighted CUSUM (W-CUSUM) is implemented using the Gaussian prior as proposed.

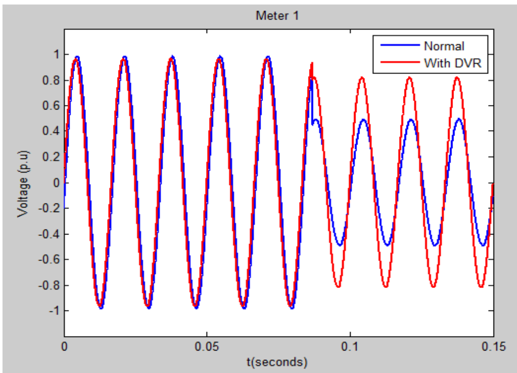

Fig.(a) Source Voltage

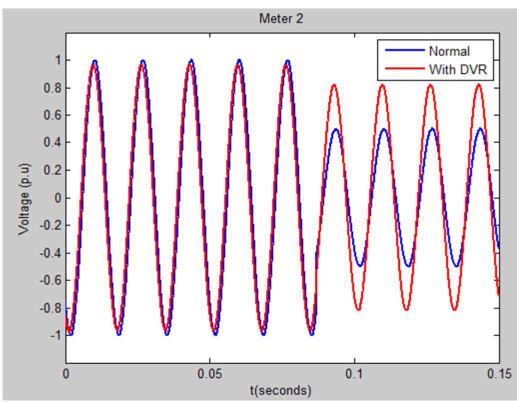

Fig.(b) Load Voltage

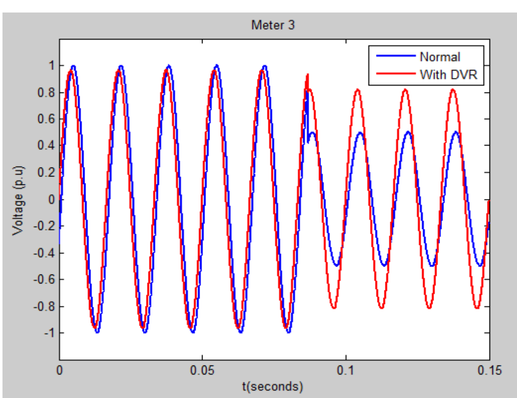

Fig.(c) Injected Voltage.

Fig.8: Original voltage waveform with fault-induced power sag disturbance at Meters 1-3.

We next incorporate more meters in the network and examine the performance of cooperative detection. Focusing on the power sag event, the disturbance signals observed at Meters 1-3 are illustrated in Fig. 9. We see that the disturbance signals induced by the same event occur at the same time to multiple buses but vary from each other in terms of the waveform. In Fig. 10, the decision statistics of the single-meter detector (S-GLLR), the centralized cooperative detector (C-GLLR), the decentralized detector based on level-triggered sampling (LTS-GLLR) and the enhanced LTS-GLLR (LTS-GLLR) are plotted. First, the cooperative detector exhibits steeper increase of the decision statistic compared to the single-meter detector, implying amore prompt reaction to disturbance signals. In the meantime, the global decision statistics of LTS-based decentralized detectors are updated with a much lower frequency than the centralized one. In particular, the original LTS-GLLR detector clearly diverges from the centralized one due to overshoot accumulation over time, while the enhanced decentralized detector matches closely with the centralized detector.

Next we examine the cooperative detectors in terms of detection delay versus the false alarm period. The local thresholds for the level-triggered sampling is chosen as $[-\Delta, \Delta] = [-1.6, 1.6]$, under which, at each distributed meter, we have $E\theta_0(\tau)$= 14 samples under normal condition, and $E\theta_1(\tau)$ = 4 samples after the occurrence of disturbance. Compared with the single-meter case, it is seen that cooperative detection with three meters substantially improves the performance in terms of achieving a shorter detection delay. Notably, the proposed LTS-based decentralized detector only exhibits a minor increase of detection delay compared to the centralized detector. As expected, the improvement of LTS-GLLR over the original LTS-GLLR becomes more significant as the detection delay grows and overshoot errors accumulate.

In Fig. 11, we also demonstrate the power of the level triggered sampling by comparing the proposed decentralized detector with a simple decentralized detector, where each local meter computes its local statistic and transmits it to the central meter every $\tau > 1$ sampling instants (also termed as uniform decentralized detector, which we refer to as U-GLLR in the experiment). Note that when τ = 1, this scheme becomes the centralized detector. Here we set τ = 14 for the simple decentralized detector to match that of the eLTS-GLLR under normal condition. That is, the simple decentralized detector transmits equally frequently as LTS-GLLR under the normal condition. However, due to the lack of addictiveness, the time resolution of U-GLLR is limited by τ even in the presence of

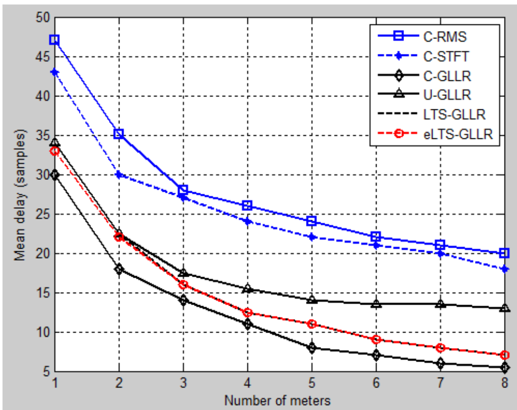

Fig.9(a). The detection delay versus the false alarm period for the single meter detection and the cooperative detection (centralized detectors).

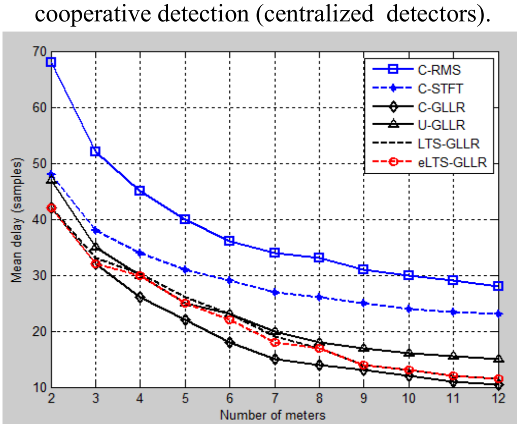

Fig (b) Decentralized Detector

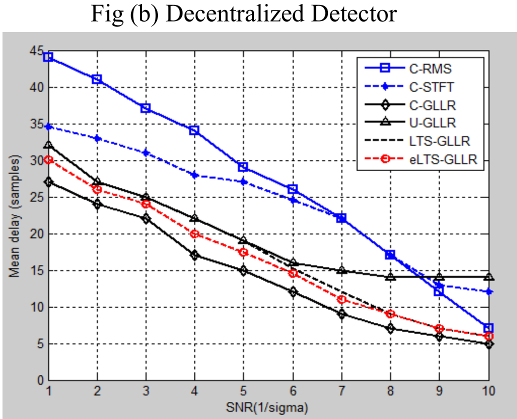

Fig.10: The mean detection delay versus increasing number of meters.

Remarkably, it is seen in Fig. 9 that even with only one-bit transmission, level-triggered sampling still outperforms the traditional uniform-in-time sampling that transmits infinite number of bits. Finally, Fig. 10(a)-(b) depict the performances of the centralized and, decentralized detectors as the number of meters grows. Again, we consider the power sag event. The communication rate of the simple decentralized detector is fixed at τ = 14, and the average communication rate of proposed decentralized detector is controlled to be E$\boldsymbol{\theta}$0 (τ)= 14 andE$\boldsymbol{\theta}$1 (τ) = 4. The false alarm period is set as $\gamma = 2 \times 103$.

VI CONCLUSION

We have simulated and presented the results for a cooperative sequential change detection framework with Dynamic Voltage Restorer (DVR) for power quality monitoring and mitigation. Specifically, local meters observe the voltage signal independently and communicate wirelessly with a central meter to detect the disturbance. The goal is to achieve the quickest detection under a certain false alarm constraint. We have also simulated the decentralized version of the GLLR detector, which is specifically tailored toward the low bandwidth requirement imposed by the wireless transmissions between the distributed meters and the central meter. This is achieved by a novel level triggered sampling scheme that features single-bit information transmission. Finally we have provided extensive simulation results to demonstrate the superior performance of the proposed centralized and decentralized cooperative detectors over the existing methods.

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AUTHORS PROFILE

Ms. K. BHARATHI is doing M.Tech Degree in Electrical Power Systems (EPS) from S.K.U College of Engineering and Technology, S. K. University, Ananthapuramu-515003, A.P, India, she Received her B.Tech Degree from the G. Pullareddy Engineering College, Kurnool, A.P, India. Her areas of interest are Power Systems.

Mr. N. RAJESH KUMAR GOWD has graduated his B.Tech from St. John's College of Engg& Tech, Kurnool, A.P, India and M..Tech (EPE) from Bharath institute of Engineering and Technology Ibrahimpatnam, Hyderabad, T.S, India. Presently he is working as Lecturer in Dept of EEE in Sri Krishna Devaraya University college of Engineering and Technology, Ananthapuramu - 515003, A.P,India. He has published 7 International Journals & 3 National conferences. His research areas of interest are Electrical Power System-Smart Grid, Reliability, Power electronics design.

Mr. P. SHASHAVALI Received his B.Tech Degree from the JNT University Hyderabad. He received Master of Technology degree from G. Pulla Reddy Engineering College, Kurnool. Currently he is Pursuing Ph.D degree from JNT University Anantapur. Presently, he is working as Lecturer in the Department of Electrical and Electronics Engineering, S.K. U. College of Engineering & Technology, S.K.University, Ananthapuramu-515 003, Andhra Pradesh, India. His research area of interest is Reliability concepts in Power Electronic Converters, Renewable Energy Sources and Facts Devices.