Use of DFR's for Distribution Substation Monitoring

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***Abstract*—The traditional approach and justification for the use of Digital Fault Recorders (DFR's) for the monitoring of disturbances in the Electrical Grid, has typically been focused on Transmission Level Substations. This justification has mainly been the result of both the capital investment associated with DFR's, as well as the operational impact of Transmission Level assets on the Bulk Electric System (BES), and overall reliability of the Grid. This paper attempts to make the case, that the time has come, for the monitoring of Distribution Substations, from a financial, operational, and system analysis perspectives.**

Keywords—DFR, Grid, BES, Distribution, Disturbances

I. INTRODUCTION

Given the ever-increasing level of complexity we are experiencing in distribution systems, with the introduction of Distributed Energy Resources (DER's), Micro-Grids, and their associated auxiliaries/supporting equipment, DFR's can and will bring a very needed source of high-speed, high-volume, high resolution data acquisition, that will most certainly increase the ability to record, store and evaluate the cause and nature of distribution system disturbances and operational anomalies.

Who can argue about the level of complexity, and breath of impacts being introduced in distribution networks, affecting existing protection schemes, power quality, generation-load balancing, voltage and frequency regulation and stability, etc.?

All of these factors can have a substantial impact on the reliability and resiliency of the overall grid, and could potentially have adverse effects on your distribution system's operational and reliability indices.

The potential impact on the overall integrity and reliability of the Bulk Electric System associated with Distributed Energy Resources located in distribution systems, now needs to be included in the overall assessment also, as these new DER assets, could in fact have regional, and multi-entity effects.

Added to the complex nature of the issues we are starting to have in our modern distribution networks, is the fact that there are a significant number of these systems that are still being monitored/protected with legacy electro-mechanical relays. It is logical to conclude then that DFR's are in fact a very valuable data recording asset for the proper monitoring of these medium-voltage grids.

An important question to be asked is: what monitoring option makes the most sense, individual feeder monitoring or whole substation approach? This paper attempts to justify the latter.

II. THE LEGACY

Ah, the simple, olden days of distribution systems. A substation feeder breaker, with a countryside meandering, radial feeder, containing a number of down-stream reclosers, maybe voltage regulators, shunt capacitors, and fused-laterals…Remember those days? Missed those days?

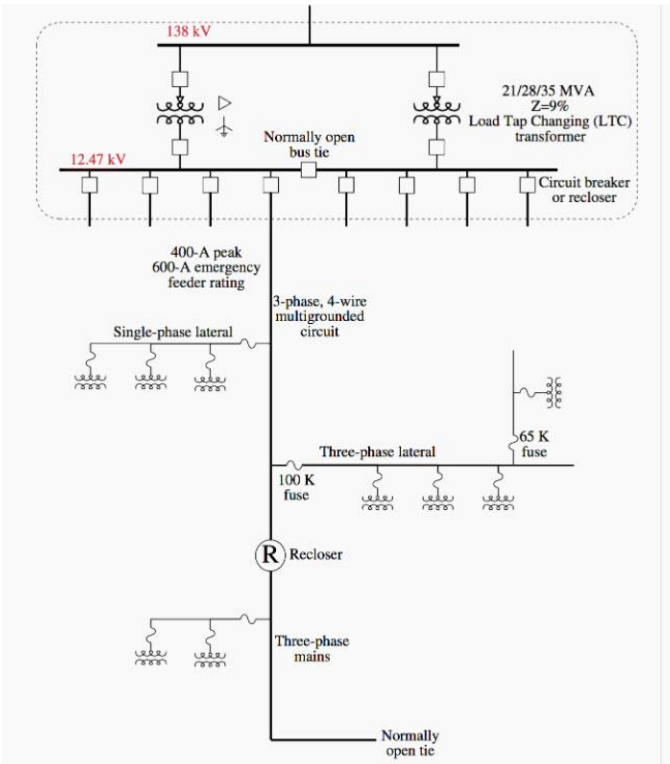

Figure 1. 1980's Distribution System

capturing high-volume amounts of high-speed, operational and/or disturbance data?

Everything was fairly simple then… However, although simpler, analysis and troubleshooting of disturbances in these legacy systems, was often-times difficult, due to the lack of disturbance recording capabilities, as these medium-voltage assets were typically not worthy of the capital investment associated with high-speed DFR's, mainly due to the fact that their overall impact on the integrity and reliability of the Grid, was minimal to non-existent.

III. THE REALITY

Nowadays, we have a very exciting life for any engineer involved in the planning, analyzing, operations and/or maintenance of these modern distribution networks.

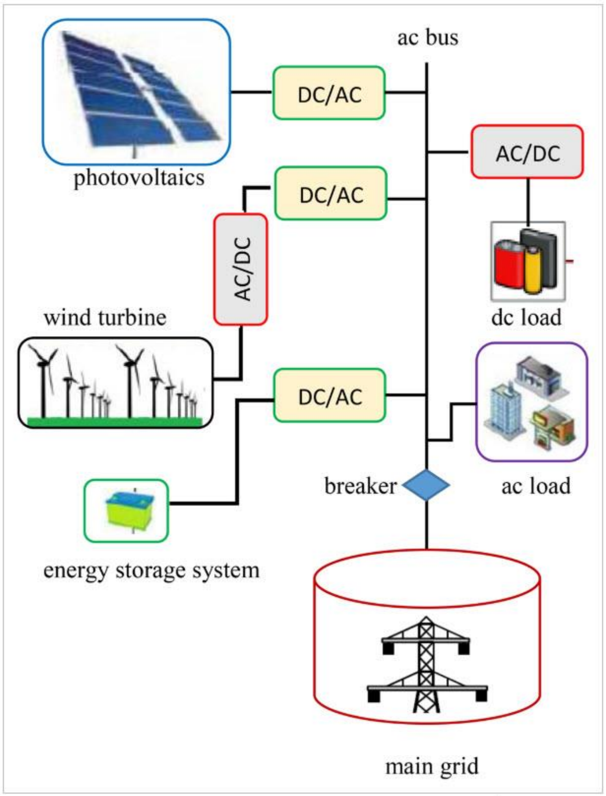

Figure2. 2020's Distribution System

The mere attempt of quantifying the level of complexity in all facets of a modern distribution network, whether in terms of planning, operating, maintaining and/or analyzing, of the day-to-day operations, as well as short and long-range operational and planning horizons, is actually a very challenging exercise in and of itself…

How do we expect to evaluate and resolve the incredibly complex and varied assortment of issues that will be part of the daily operations of these assets, without the capability of capturing high-volume amounts of high-speed, operational and/or disturbance data?

IV. THE VALUE OF DFR'S

Are DFR's a logical and economical investment for the real-time and/or post-disturbance monitoring of distribution substations?

In general, a typical DFR includes the following, concurrent/simultaneous functionalities:

1. High Speed Oscillography (high capacity, multi-seconds)
2. Sequence of Events (1000 + events/day)
3. Low Speed RMS (high capacity, multi-minutes)
4. Continuous RMS Data recording
5. Seasonal RMS Trend recording
6. PMU streaming
7. IEC 61850 GOOSE (some available in SV versions also)
8. Power Quality recording capabilities
9. Centralized, Server-based data retrieval and archiving

When the above list of data acquisition functionalities, is coupled with the ability to monitor a large number of system elements (transformers, busses, feeders, capacitor banks, etc.) all at once, with the use of one monitoring device, the end-user should be able to have the ability to evaluate the vast majority (if not all) of disturbances and anomalies in the distribution grid.

Notwithstanding a DFR's intrinsic value in terms of high volume, high-speed, high-accuracy, high-diversity data acquisition, in a Substation, regardless of its voltage class/rating, their use in distribution-class substation, even when equipped with digital and/or microprocessor-based protection devices, can reduce bottom-line costs by streamlining the retrieval of operational and/or disturbance data from one device, in one connection/transaction.

We need to keep in mind that associated with the exponential increase in the complexity and variety of the distribution grid elements, will also come a very complex set of element-element and system-system interactions, hence the legacy approach of only reviewing/evaluating the behavior of the one element that started/caused the anomaly, will very likely not suffice, as many distribution system assets will be interacting with one-another, as part of their normal operation.

The availability of high-volume (DFR) system data, which is also synchronized to high-precision time sources, will be a critical component in ensuring optimal distribution systems operational and reliability indices.

Another avenue where DFR's can bring unquestionable value to the operations and disturbance analysis of distribution systems, is in legacy distribution substations where protection devices are still of the Electro-mechanical type, where system disturbance data acquisition is very likely non-existent.

The author, presents a case where a customer with such a substation (one equipped only with electro-mechanical relays), was experiencing frequent, random feeder faults, that they were not able to understand/resolve. They temporarily installed a portable DFR, and wired-it to monitor a number of feeders in the distribution bus, in an attempt to collect sufficient data to troubleshoot the issue.

Below is the substation's simplified one-line drawing.

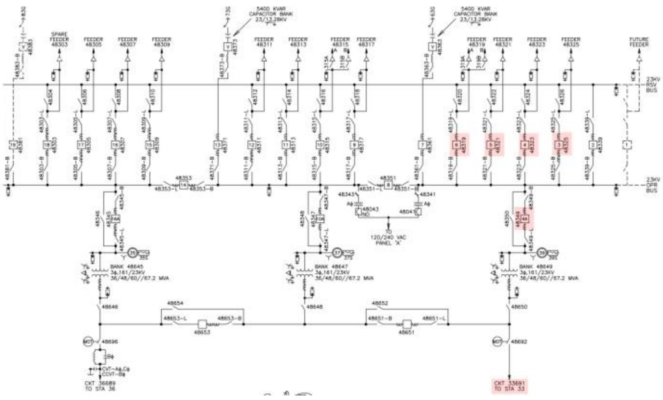

Figure 3. Sample Substation One-line

Highlighted elements were the one's being monitored. Over a period of a few months, a number of events were captured/recorded. A sampling of the various data types and their associated graphical views are presented as an example of the granularity that can be used in evaluating system operations and/or responses to anomalous events.

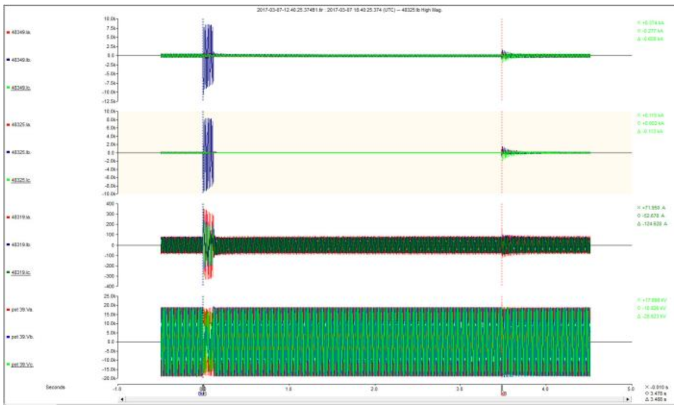

Figure 4. Full Event Oscillography

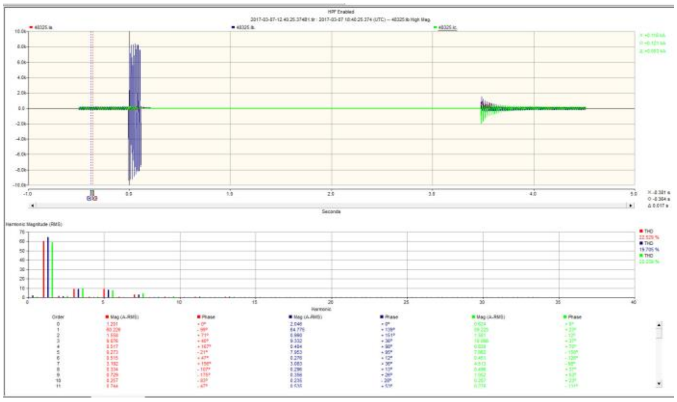

Figure 5. Feeder 325 Current Harmonics

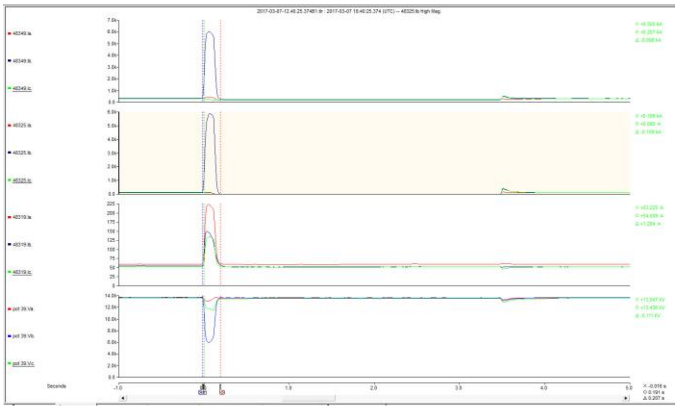

Figure 6. Low Speed RMS Traces

The goal for sharing this (typical) case of a substation equipped with electro-mechanical relays, together with a sampling of DFR collected disturbance data, is not to show how the root-cause of their events was discovered, but instead to highlight the inherent and significant value that high-speed, high-accuracy, and diverse data collection, contributes to the overall operation and maintenance of a distribution system.

V. Some Basic Numbers

What about the economic feasibility of DFR's in the distribution level systems? A typical DFR may cost somewhere in the area of $25K, an apparent first impression, steep investment. However, lets dissect the investment in terms of its functionality versus cost, and its cost per feeder-element basis.

From a Function versus Cost perspective, and assuming the use of all of the device's capabilities listed in section "IV – The Value of DFR's", we arrive at a cost of $25K divided (equally for the sake of simplicity) by 9 capabilities, for an estimated net cost/function of $2,800. Basically, a multi-function device, providing real-time PMU data, high-speed oscillography disturbance data, 61850 GOOSE and MMS capability, standard SCADA DNP3 functionality, Sequence of Events data, Continuous Data Recording, and 90-day RMS Trending data, all in one box. A pretty good value in any estimation.

From a Cost/Feeder perspective, depending of the actual substation's topology/layout, a single DFR could easily monitor ten (10) Feeders and two (2) Buses, a total of 12 elements, resulting in an estimated net cost of about $2,100/element.

Let the user not ignore or minimize the value that DFR data will have when the complexity of the issues that will be experienced in our modern distribution networks starts to reflect the complex nature and variety of its elements.

This engineer and author, believes that the complexity of future Distributions Grids will equal and/or surpass the complexity of the Transmission level systems.

VI. Conclusion

The time has come, for DFR monitoring of Distribution Substations, from a financial, operational, and system analysis perspectives.