What Do We Need to Know for a Comprehensive Post-factum Analysis of Power System Contingencies?

(Can the COMFEDE expand to cover a wider range of event?)

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1. The objectives of the post-factum analyses.
   The objectives of the post-factum analyses of the power system contingencies are to answer the following questions:
   - What were the preconditions before the contingency? Which preconditions contributed to the event?
   - How and why the contingency started?
   - How and why the contingency developed?
   - How was it mitigated?
   - How was the service restored?
   - What to do to prevent such contingencies in the future?

2. Actors, interfaces, and actuators that can impact the conditions for contingency occurrence and development.
   - Personnel
   - Power equipment in Generation, Transmission, and Distribution domains.
   - Relay protection
   - Remedial Action Schemes (distributed and centralized)
   - Automatic devices (controllers, synchronizer, etc.)
   - EMS and DMS applications (for normal and emergency operations). These actors become more critical in the Smart Grid environment providing digital monitoring and control and dynamic optimization [1]
   - Back-office applications (Data Management Systems, Model Processors, Load Management Systems, DER Management Systems, etc.)

The behavior of these components should be recorded in near real-time of the pre-contingency conditions and contingency events. For the post-factum analysis, these records should be combined in a synchronized time frame.

The IEEE C37.239-2010 (COMFEDE) standard [2] is a new IEEE standard for the conveyance of event and associated or Payload data. The XML format enables multiple COMFEDE files to be combined in a time-sequenced format. Its foundation in XML enables future extensions as well as migration into other name spaces [3]. While the standard defines a basic event “…as either a change of state of a binary data value, exceeding or resetting of a measured threshold, or meeting or resetting a rate of change threshold”, it provides the ability to identify different event types such as:
- System event (fault detected; trip issued; breaker operation ...)
- Internal IED Event (event driven by logic state changes, oscillography triggered; ...)
- Setting Change Event (setting changed/edited, new setting group; adaptive setting change; ...)
- Communication event (association lost, buffered report overflow; ...)
- IED Failure event (A/D out of calibration; component failure; memory corrupt; ...)
- Test Event (IED in test mode, protection in test mode; ...)

It also provides the ability to include additional or “payload” data, such as:

- Fault report
- Analog values (e.g., distance to fault, fault currents, fault voltages and a set of other electrical measurements recorded before, during, or after the event)
- File name, e.g., COMTRADE File Names [4], triggered by the event
- Information related to the breaker(s) and line reclosers involved in the event

Although the scope of event covered by the COMFEDE standards is a broad one, it is predominantly focused on events related to faults. While many contingencies are triggered by faults, the development of the contingencies may be dependent on many other factors, which are not directly associated with the faults. Other contingencies may happen without a fault.

The purpose of this paper is to recommend expansion of the definition of the event and of the scope of the COMFEDE standard.

Additional events (causes of contingencies):

- Error in input data
- Defining setup parameters of an EMS or DMS application (objective, operational tolerances…)
- Errors in issued switching orders
- Personnel deviations from switching orders
- Inadequate performance of EMS/DMS applications (inaccurate results, inconsistent timing, …)

Broader scope

The additional events will broaden the scope of COMFEDE. Another expansion of COMFEDE is the inclusion of the Distribution domain. With high penetration of DER/ES, DR, and other controllable variables in the distribution and customer domains, the Active Distribution Network (A.D.N.) becomes a major player in all significant events of the entire power system operations. Therefore, the events happening in A.D.N. should be recorded and analyzed concurrently with the events in the generation and transmission domains.
To apply to distribution in full extent, COMFEDE must be expanded to the aggregated distribution information presented in the Transmission Bus Load Model (TBLM) [5]. The expansion of COMFEDE to the distribution domain will require development of new advanced applications for aggregating the relevant information on distribution operations into the TBLM.

Examples.

1) Local Area contingencies
   a) The Fault Location, Isolation, and Service Restoration DMS application (FLIR) is operational. The initial event is a fault in a section of an automated distribution feeder. The faulted section should be isolated, and the healthy sections should be reconnected to backup sources. The development of the contingency was as follows:
      i. The faulted section was isolated (a correct action)
      ii. The healthy sections were not restored (incorrect actions)

  ➢ Possible causes of the incorrect actions:
    i. Erroneous input data in the DMS database, e.g., a smaller than the actual conductor size. Hence, FLIR did not find a restoration solution without an overload.
    ii. An unloading of a backup feeder was needed, which required preliminary feeder paralleling. The paralleling did not happen due to unacceptable or erroneous voltage vector difference between the adjacent buses, or due to malfunction of a paralleling switch. Hence, the restoration could not be accomplished.
    iii. Incorrect load/DER/Micro-grid forecast by FLIR (or other DMS function) for the time of repair.
    iv. FLIR did not count on Demand Response [6], without which the backup feeder would overload somewhere during the time of repair.
    v. Other.

  ➢ Records needed for post-factum analyses:
    i. FLIR (or Data Management Systems) logs with the records of the load/DER/Micro-grid forecast during the time of repair and of overloaded sections; records of the needed switching operations that could not be executed and why; pre-defined list and parameters of resources involved in the restoration of service (e.g., number of levels of backup feeders, DER, DR, emergency loading limits, ride-trough conditions for DER, etc.)
    ii. SCADA logs on switching operations
    iii. Logs of Transmission State Estimation application, which calculates voltage angles, or PMU measurements at the involved transmission buses.

b) The initial event is a fault in a section of an automated distribution feeder. The faulted section should be isolated, and the healthy sections should be reconnected to backup sources. The development of the contingency was as follows:
   i) The faulted section was isolated (a correct action)
ii) The healthy sections were reconnected to other sources, but later, when the load increased some segments of the backup feeder overloaded, and the backup source was disconnected (negative action) or

iii) The healthy sections were reconnected to other sources, including DER and/or involving DR, but later, the DER reduced the generation (e.g., due to cloudiness) or the DR support reduced, and some segments of the backup feeder overloaded, and the backup source was disconnected (negative action)

b) Possible causes of the negative actions:
   i) Erroneous input data in the DMS database, e.g., incorrect data on Demand Response. Hence, FLIR overestimated the support of DR and did not look for another solution.
   ii) Incorrect load/DER/Micro-grid forecast by FLIR (or other DMS function) for the time of repair.
   iii) Other

c) Records needed for post-factum analyses:
   i) FLIR (or Data Management Systems) logs with the records of load/DER/Micro-grid forecast during the time of repair and of the expected power flow in the restoration scheme; pre-defined list and parameters of resources involved in the restoration of service (e.g., number of levels of backup feeders, DER, DR, emergency loading limits, ride-trough conditions for DER, etc.)
   ii) Distribution SCADA logs on measurements
   iii) DOMA logs on power flow/state estimation during the time of restoration.

2) Wide Area contingencies
   a) There is a generation-reach area of the power system and a load-reach area connected by a corridor of long high-voltage transmission lines. If one or more lines of this corridor are disconnected, voltage instability may lead to a blackout of the load-reach area. To prevent this to happened, a predictive load-shedding remedial actions scheme is implemented, and a large dynamic source of reactive power (SVC) is placed in the load-reach area. The predictive load-shedding scheme quickly disconnects a pre-defined portion of the load, when a pre-defined combination of pre-conditions and events happened. The SVC should have a sufficient reserve to quickly boost its reactive power support when the voltage starts declining. The development of the contingency was as follows:
      i) A critical line of the transmission corridor was disconnected by the relay protection (triggering event)
      ii) The predictive load-shedding scheme operated
      iii) The SVC increased the reactive power generation
      iv) A voltage instability situation happened and the load-reach area collapsed.
   b) Possible causes of the collapse:
i) Insufficient load shedding by the predictive load-shedding scheme due to incorrect pre-defined matrix of the preconditions and actions; or due to malfunction of the RAS; or due to too slow communications with the actuators.

ii) Insufficient reactive power support by the SVC, e.g., due to insufficient reserve (the initial loading of the SVC was too high). The unacceptable loading of the SVC could happen due to a low reactive power support from the distribution system, which, in turn, could happen due to the selected objective and setup of the distribution Volt/var optimization.

c) Records needed for post-factum analyses:
   i) Logs of the predictive load-shedding scheme
   ii) Matrix of preconditions and remedial actions
   iii) SCADA/PMU logs on relevant measurements, including the measurements from the SVC, and on switch operations
   iv) IVVO logs, including the objective and the setup parameters of the application, e.g. whether the transmission constraints, like SVC loading, were included in the objective function, and if yes, what are the constraints.

Conclusion.

1. The range and the definitions of events for the post-factum analyses should be expanded to include different kinds of virtual events
2. The EMS and DMS applications should include comprehensive logs (reports), including the preconditions of the events, the setup of the applications, and the data on deriving to the solutions
3. COMFEDE should be expanded to cover the wider range of events.

References.

2. IEEE Standard for Common Format for Event Data Exchange (COMFEDE) for Power Systems, IEEE