Hierarchical Coordinated Protection with High Penetration of Smart Grid Renewable Resources (2.3)

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Outline

• Current Needs and Study Goals
• Study Focus and Proposed Solutions
• Proposed Approach
• Example: Cascading Events Detection and Mitigation
• Example: Anti-islanding Protection
Needs and Goals

NEEDS:
• Define protection issues and network conditions that current solutions cannot handle well
• Specify new protection requirements associated with high penetration of renewable sources
• Outline criteria for the design of new protection solution that can improve efficiency and reliability

GOALS
• Propose conceptual solution for the hierarchically coordinated protection scheme
• Describe each of the three protection layers and explain how they may be implemented
• Present overall solution using some modeling and simulation, as well as real-life examples
• Assess major benefits of the new solution when compared to the legacy solution
Focus and Proposed Solutions

New Requirements:
- flexibility in the protection principle
- robustness to the system behavior that has not been experienced before
- self correction and verification

Proposed Layout:
- Predictive Protection:
  - provides “breathing time” for protection system to achieve flexibility (adjust bias between dependability and security)
  - conditions leading to major disturbances are anticipated well ahead of the time
  - triggers high computational methods
- Adaptive Protection:
  - Adapts itself to prevailing operating conditions, but NOT through setting changes
  - It implements settingless protection
  - learning from data to recognize prevailing disturbances
- Corrective Protection:
  - Uses disturbance verification tool and modifies the relay action as needed

New Applications:
- Anti-islanding protection
- Cascading event detection and mitigation
Proposed Solution

Power System

Predictive Protection

Adaptive Protection

Corrective Protection

Legacy Solution

Measurements

Forecast

Weather Satellites

Historical

Outage Data

Animal/Bird Migration Patterns

Block/Trip

Control
Cascading Event Detection and Mitigation

Conventional Protection

Hierarchically Coordinated Protection

- Predictive protection: Routine and Event-based Vulnerability Analysis of the system and individual elements

- Adaptive Protection: Neural network based fault detection

- Corrective Protection: Synchronized sampling based fault location
Cascading Event Detection and Mitigation

- **Predictive Protection**
  - Finds the most vulnerable lines
  - Triggers corrective layer to closely monitor relay operation

- **Adaptive Protection**
  - Neural network based fault detection
  - Sends block/trip signal to distance rely

- **Corrective Protection**
  - Synchronized sampling based fault location
  - Verifies fault location or restore line

**Benefits:**
- Make a way for adaptive protection to be accepted as an alternative to conventional protection principle
- Several layers for disturbance verification
- Prevents line tripping due to overloading, swing…
Implementation

**System Monitoring and Control**
- Security Analysis
  - Routine Security Analysis
  - Event-based Security Analysis
- Security Control
  - Steady State Control
  - Transient Stability Control

**Local Monitoring and Control**
- Monitoring Command
- Disturbance Report
- Real-time Fault Analysis
  - Neural Network Based Fault Detection and Classification (NNFDC)
  - Synchronized Sampling Based Fault Location (SSFL)
- Relay Operation Monitoring
- Event Tree Analysis (ETA)

Power System and Protection Relay

**Proposed Solution**
Input-output space mapping

- Short line Model
- Lone line Model

GPS Satellite

Sending end

Receiving end

\[ i(t) \quad \text{Fault Location} \quad \frac{dV}{dt} \quad \frac{di}{dt} \quad V_s(t) \]

\[ d_r \quad d_s \]

\[ R \quad L \quad C \]
Anti-islanding Protection

Conventional Protection

Hierarchically Coordinated Protection

Predictive protection:
- Weather Satellite Data

Adaptive Protection:
- Support Vector Machine based
  Islanding Detection

Corrective Protection:
- Slip Mode Frequency Shift Method

UV/OV and UF/OF Relay
Anti-islanding Protection

- **Predictive Protection**
  - Finds conditions that may lead to islanding
  - Triggers corrective layer to closely monitor system behavior

- **Adaptive Protection**
  - Support Vector Machine based islanding detection sends block/trip signal to OV/UV and OF/UF relays at PCC

- **Corrective Protection**
  - An active islanding method (Sliding Mode Frequency Shift) verifies islanding state

**Benefits:**
- Reduce negative effect of active anti-islanding method to power quality
- Has high accuracy
- Robust to switching events in the grid
- Makes way for adaptive protection to be accepted as an alternative to conventional protection principle
Implementation

Cases | No. of Data Set Samples | Description
---|---|---
Islanding | 300 | ±40 % active power and ±5% reactive power mismatch
Non-islanding | 25 | Load Switching
Non-islanding | 25 | Capacitor Switching
Non-islanding | 25 | Motor Load Switching
Islanding | 225 | Faults
Islanding | 25 | Light load; various power mismatch
Non-islanding | 25 | Faults at different locations
Islanding | 25 | Second DG connected
Non islanding | 25 | Second DG Switching

Cases | Prediction Accuracy on the testing data set (％)
---|---
Fault Event | 100
Capacitor Stitching | 99.04
Static Load Switching | 99.23
Motor Load Switching | 98.87
Islanding | 99.9%
Conclusions

Hierarchically Coordinated Protection paradigm mitigates and manages the effects of increased grid complexity on the protection of the power system is proposed. The new approach:

• has superior performance when compared to the existing solutions
• co-exists with the legacy solutions and only supplements (does not substitute) its operation
• Employs self-corrections and operation verification tools
• makes a way for adaptive protection to be accepted as a alternative to conventional protection principle
• increases penetration of renewable generation by providing adequate protection for new system conditions
• enables detection of cascading outages and offers mitigation approaches
• enables detection of power islands and mitigates negative effect of the active methods on power quality