Power Imbalance Estimation in Distribution Networks with Renewable Energy Resources

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Introduction

Renewable energy policy has a target to reduce CO2 emission in order to protect our environment and to prevent global warming.

At present, in the UK the conventional coal-fired power stations are replaced with nuclear power and renewable energy sources (wind farms, small hydro power generators…)

Target 2020: 32% electricity from wind and small hydro turbines

*Figure:* Future configuration of power generations in the UK.
Introduction

Since a large percentage of renewable energy sources will be connected to distribution networks, future distribution networks will be consisting of conventional consumers and distributed generators, such as small synchronous generators, wind farms and photovoltaic generators.

**How to prevent blackouts** in an isolated distribution network with such a diverse generation mix?

*Figure: A typical distribution network with mixed energy sources.*
Stability Issues in Distribution Networks

1. Voltage Stability.
2. Transient Stability.
3. Frequency Stability (usually associated with active power $P$ balance between generation and consumption).

External networks outage

Generation

Consumption

$?$
Estimation of the Magnitude of Disturbance (EMD) (the basic concept)

\[
\frac{2H_i}{f_n} \frac{df_i}{dt_t} = p_{mi} - p_{ei} = \Delta p_i
\]

- \(H_i\) is the inertia constant of a generator in s,
- \(f_n\) is the rated frequency in Hz,
- \(f_i\) is the actual generator frequency in Hz,
- \(p_{mi}\) is the mechanical turbine power in p.u.,
- \(p_{ei}\) is the electrical power in p.u.,
- \(\Delta p_i\) is the **power imbalance** between generation and consumption in p.u.
Two approaches:

1. Multiple point measurement, based on synchronized Measurement Technology (PMUs, Data Concentrators, Comms.)

2. Single point measurement in a selected point in the network
Multiple Points Measurement

GPS

Data Concentrator

Application

PMU

PMU

PMU
Multi-generator system:

\[ \Delta p_{\text{total}} = \sum_{i=1}^{N} \Delta p_i = \sum_{i=1}^{N} \frac{2H_i}{f_n} \frac{df_i}{dt} = 2H_{\text{ec}} \frac{df_{\text{ec}}}{dt} \]

\[ H_{\text{ec}} = \sum_{i=1}^{N} H_i \]

is the inertia constant of the system equivalent inertia centre

\[ f_{\text{ec}} = \frac{\sum_{i=1}^{N} H_i f_i}{\sum_{i=1}^{N} H_i} \]

is the frequency of the system equivalent inertia centre

The EMD in Distribution Networks (EMDN) can be simplified as follows:

\[ \Delta p_{\text{total}} = \frac{2H_{\text{ec}}}{f_n} \frac{df_{\text{meas}}}{dt} = \frac{2}{f_n} \sum_{i=1}^{x} H_{SG_i} + \sum_{i=1}^{y} H_{FSWF_i} + \sum_{i=1}^{z} H_{DFWF_i} \cdot \frac{df_{\text{meas}}}{dt} \]

\[ f_{\text{meas}} \]

is the frequency measured at a certain point in the distribution network
Test Systems

Two test cases are considered

In both test cases, two synchronous generators were fixed at buses 3 and 4.

At bus 2, a Fixed Speed Wind Farm, or a DFIG based Wind Farm are connected.

In order to compare the simulations results, the same disturbance (the outage of the external grid at bus 1, supplying 2 MW (0.2 p.u.)), was simulated at 0.5 s.

Figure: System structure for all three testing cases
Results

\[
\Delta p_{\text{total}} = \sum_{i=1}^{N} \Delta p_i = \sum_{i=1}^{N} \frac{2H_i}{f_n} \frac{df_i}{dt}
\]

Estimated by EMDN
Load Shedding Based on EMDN

Two adaptive Low Frequency Demand Control schemes (Load Shedding) plans based on the EMDN are implemented:

1) single staged LS with set frequency 49.6 Hz, and $p_1 = p_{est}$
2) two staged LS with set frequency 49.6 Hz and 49.4 Hz $p_i = p_{est}/2$

Frequency Responses during disturbances

Case 1: No Load shedding

Case 2: 1 staged Load shedding

Case 2: 2 staged Load shedding
Conclusions

1) The magnitude of the disturbance can be effectively estimated by using the EMD algorithm.

2) The scheme might be coordinated with the information about the spinning reserve in the system, Demand Side Management and primary response of generators.

3) The prerequisites for the efficient estimation of the power imbalance is an accurate information about the system inertia and precise measurements of the frequency and its rate of the change.
Thank you!

Any questions?

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