Sustainable Energy, Grids and Networks 5 (2016) 156–166

Contents lists available at ScienceDirect

Sustainable Energy, Grids and Networks

journal homepage: www.elsevier.com/locate/segan

Islanding in distribution systems considering wind power and storage

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ARTICLE INFO

Article history:
Received 13 April 2015
Received in revised form
4 December 2015
Accepted 5 December 2015
Available online 30 December 2015

Keywords:
Islanding
Distributed generation
Distribution system
Storage devices
Two-stage stochastic programming

ABSTRACT

In modern power systems the penetration of renewable energies has been growing dramatically. The combination of renewable energy and energy storage is seen as an opportunity to better exploit the intermittent and uncertain local generation in distribution systems, especially in the case of islanding. The main goal of this paper is to keep the load and generation units on-line under islanding conditions with respect to the total power imbalance of the isolated area and minimizing the power losses and nodal voltage deviations. A two-stage stochastic linear programming model is introduced to solve the optimization problem and find the best combination of generation, demand and electrical energy storage under islanding conditions. The proposed model has been tested on a 69-bus distribution system and the results obtained in the islanded areas are presented considering two case studies (with and without electrical energy storage), under different levels of generation and demand.

1. Introduction

Currently, regulatory agencies are highly committed to increasing the integration of Renewable Energy Sources (RES) due to their global interest and benefits, including economic and ecological advantages. Likewise, several types of Energy Storage Systems (ESS) are being developed and applied in electrical networks to cope with problems such as smoothing the output power of RES [1], improving power system stability [2,3] and being economically efficient [4]. On the other hand, the penetration of RES, especially wind power, creates several problems regarding their intermittency and uncertainty [5,6]. In particular, to manage and increase the penetration of RES and ESS in electrical networks, an innovative procedure is required for both normal and abnormal conditions. Although having RES and ESS in electrical networks creates challenges to integrate them within Electrical Distribution Systems (EDS), exploiting RES and ESS in abnormal conditions like islanding can be seen as an opportunity to use more generation and demand within the island.

Islanding in power systems may be intentional or unintentional. Due to large frequency perturbations or contingency plans, intentional islanding is planned in advance in power systems to cope with problems in the network. On the other hand, unintentional islanding may occur due to the automatic response of the protection system to a fault happening in radial systems. In this case, it may be more challenging to define the islanded area conditions and guarantee the success of the islanding procedure.

In power systems, especially those with islanding conditions, supply and demand have to be balanced in real-time due to the fact that electrical energy cannot be stored efficiently in large amounts. An imbalance between supply and demand leads to several problems, such as frequency and voltage deviation in the power grid. Therefore, the definition of a predefined procedure able to keep the islanded area energized and avoid complete blackout becomes essential.

Several works have been carried out to deal with the disconnection from the bulk power system creating islands. For example, in [7–9] the configuration and control of islanding in a random way based on the topology of the grid is presented. A two-step algorithm is introduced in [10] using spectral clustering to find suitable islanding. In [11], a time domain simulation is presented to control islanding by dividing a bulk power system into several pre-selected islands. In some works, load shedding is minimized under intentional islanding conditions [12–14]. A review regarding research on planned islanding operation for a rotating type of distributed generation with a particular focus on small hydro generation is presented in [15]. A load shedding and generator tripping logic for proper islanding is developed in [16], based on detailed power system studies. An evolutionary algorithm based on current limiting protectors for controlled islands in distribution systems is presented in [17]. An islanding control approach based

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http://dx.doi.org/10.1016/j.segan.2015.12.002
2352-4677/

Nomenclature

Indexes

i, j, k Bus indexes
r Piecewise linearization (PWL) block index
t Real-time period index on a 10-min basis
ω Scenario index

Parameters

$\hat{C}^{rs}$ Real-time storage cost of the storage unit ($/MWh)
$\hat{C}^{rp}$ Real-time production cost of the storage unit ($/MWh)
C^{sw} Cost of switching
$d_{it\omega}$ Real power demand (MW)
f^{loss} Power losses penalization weight factor
f^{V_dev} Voltage deviation penalization weight factor
C^{W_curt} Wind curtailment cost
C^{d_curt} Real power demand curtailment cost
ini_{ij} Initial state of switches
$\bar{I}_{ij}$ Maximum current flow through branch ij (A)
$m_{ijrt\omega}$ Slope of the rth block of the PWL
N_{loop} Number of buses in a loop
N_B Number of branches of the network
N_N Number of nodes of the network
N_R Number of blocks of the PWL
N_T Number of time intervals
N_W Number of scenarios
$P^{d\_fore}_{it\omega}$ Demand forecast (MW)
$P^{w\_fore}_{it\omega}$ Wind power forecast (MW)
PF^{d}_{i} Power factor of the demand
PF^{wind}_{i} Power factor of the wind turbines
$q_{it\omega}$ Reactive power demand (Mvar)
r^p_i, r^s_i Scheduled power production/storage reserve (MW)
R_{ij} Resistance of branch ij (Ω)
R^{tot} Total number of blocks in the PWL
${V'_{it\omega}}^2$ Approximation of the voltage magnitude of node i (kV)
V_{ref} Nominal voltage of the distribution network (kV)
$\underline{V}, \overline{V}$ Minimum/maximum voltage of the distribution network (kV)
$\overline{W}^2$ Upper bound of variable $W^2_{ijt\omega}$ (kV^2)
x^s_0 Initial energy level of storage (MWh)
$\underline{x}_i, \bar{x}_i$ Minimum/maximum storage capacity at node i (MWh)
X_{ij} Reactance of branch ij (Ω)
Z_{ij} Impedance of branch ij (Ω)
$\Delta S_{ijrt\omega}$ Upper bound of the rth block of the power flow
γ Reactive power control parameter
η^s_i, η^p_i Efficiency rate of the storage units
Δ Real-time period (10 min) (h)

Non-negative variables

$I^2_{ijt\omega}$ Square of the current flow through branch ij (A^2)
$P^{wind}_{it\omega}$ Real power of wind turbine at bus i (MW)
$P^{dem}_{it\omega}$ Real power of demand at bus i (MW)
$P^{w\_curt}_{it\omega}$ Real power wind curtailment at bus i (MW)
$P^{d\_curt}_{it\omega}$ Real power demand curtailment at bus i (MW)
$P^{+}_{ijt\omega}$ Real power flow (downstream) (MW)
$P^{-}_{ijt\omega}$ Real power flow (upstream) (MW)
$Q^{+}_{ijt\omega}$ Reactive power flow (downstream) (Mvar)
$Q^{-}_{ijt\omega}$ Reactive power flow (upstream) (Mvar)
$\hat{r}^p_{it\omega}$, $\hat{r}^s_{it\omega}$ Real-time production/storage reserve (MW)
$V^2_{it\omega}$ Square of the voltage magnitude of node i (kV^2)
$W^2_{ijt\omega}$ Variable related to the voltage drop (kV^2)
$\hat{x}_{it\omega}$ Storage level at node i (MWh)
$\Delta P_{ijrt\omega}$ Value of the rth block of real power (MW)
$\Delta Q_{ijrt\omega}$ Value of the rth block of reactive power (Mvar)

Free variables

$Q^{wind}_{it\omega}$ Reactive power of wind generation (Mvar)
$Q^{dem}_{it\omega}$ Reactive power of demand (Mvar)
$Q^{d\_curt}_{it\omega}$ Reactive power demand curtailment (Mvar)
$Q^{wind+}_{it\omega}$ Reactive power upper bound of wind generation (Mvar)
$Q^{wind-}_{it\omega}$ Reactive power lower bound of wind generation (Mvar)

Binary variables

$v^{p+}_{ijt\omega}$ Variable related to real power (upstream)
$v^{p-}_{ijt\omega}$ Variable related to real power (downstream)
$v^{q+}_{ijt\omega}$ Variable related to reactive power (upstream)
$v^{q-}_{ijt\omega}$ Variable related to reactive power (downstream)
$v^s_{it\omega}$, $v^p_{it\omega}$ Variables related to power storage or production
y_{ij} State of the switches in branch ij: 1 if closed, 0 otherwise
$\mu_{ijrt\omega}$ State of the PWL block of real power: 0 if filled, 1 otherwise
$\eta_{ijrt\omega}$ State of the PWL block of reactive power: 0 if filled, 1 otherwise

Functions

ϕ Total switching cost function
$\psi(\omega)$ Total cost of power losses and voltage deviation
$\kappa(\omega)$ Total costs of wind and demand curtailments and ESS operation

on the optimization of a linear DC power flow is presented in [18] and developed in [19] by implementing a piecewise linear approximation of an AC power flow. The main technical issues to develop control techniques for establishing a microgrid, in case of islanding, are addressed in [20]. In distribution systems, an island partition model with distributed generation and a two-stage branch and bound algorithm is designed in [21]. An innovative islanding feasibility function in subtransmission systems based on reactive power and real power is proposed in [22,23], respectively.

In the technical literature, an optimization procedure considering the combination of wind power with energy storage under islanding conditions in distribution systems has not been presented yet. It is worth mentioning that, due to the intermittency and uncertainty of wind power, the combination of RES and ESS is desirable in case of islanding to improve the reliability and reduce the real power imbalance between load and generation. Consequently, the motivation of this paper is to show the benefits of combining RES with ESS to minimize operational storage system costs, wind and generation curtailment, power losses and voltage deviation of buses. In other words, in this paper, a novel algorithm is presented to keep the load and generation units on-line under islanding conditions with respect to the total power imbalance of the isolated area and minimizing the power losses and nodal voltage deviations.