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Optimal scheduling of observable controlled islands in presence of energy hubs

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ABSTRACT

Intentional islanding is becoming an important strategy to improve the reliability of smart distribution systems when the connection between the distribution grid and the upstream network is lost. In addition, the increase penetration of distributed generation and the presence of energy hubs have made intentional islanding a feasible solution. During islanding, an economic energy management is required. This functionality in smart grids is imbedded is smart meters to keep monitoring and controlling the formed islands. In this paper, a three layer optimization algorithm is proposed to determine the optimal islanding configuration of the system in its first layer, the optimal dispatch of distributed generation (DG), combined heat and power (CHP) units and boilers along with the optimal demand side management (DSM) in its second layer and finally, the optimal locations of phasor measurement units (PMU) in its third layer such that each island is completely observable. The proposed algorithm is applied to the distribution system of Alexandria, Egypt.

1. Introduction

Transition to smart grid (SG) has become a must to overcome the weaknesses of some networks and to make use of evolving technologies. These technologies include the penetration of different kinds of distributed generation changing the power system from centralized to decentralized status. In case of loosing connection to the upstream network, DGs help the operator to sectionalize the grid into islands in order to prevent complete blackout [1]. With the expansion in natural gas networks, the evolvement of combined heat and power (CHP) technology brought the multi-carrier energy hub concept into consideration in smart grid applications [2]. Another important specification of SG is the application of demand side management (DSM) programs [3]. To control and schedule different sources along with the application of DSM, the system must be well monitored generally during normal operation and especially during islanding mode. For such purpose, SG must make use of the evolving technology of smart meters and phasor measuring units (PMU) to keep the system observable and controllable [4].

As for intentional islanding, it is an operation mode in which the distribution system is divided into a number of microgrids with the help of DG penetration. Intentional islanding, or sometimes called controlled islanding, is allowed in case of disconnecting the upstream network due to scheduled maintenance or due to an external fault [1]. Many researches have addressed the optimal intentional islanding operation [5–11]. Different methods were applied to find the islanding configuration of distribution system such as branch and bound algorithm [11], Depth First Search (DFS) [12] and Islanding Security Region (ISR) [13]. In addition, many evolutionary computation methods were applied to islanding formation such that particle swarm optimization (PSO) [14,15] and genetic algorithm (GA) [16,17]. The main purpose of these researches was to improve the system reliability indices and reduce the outage cost.

Considering the energy hub (EH) concept and multi-carrier scheduling, many researches were conducted to find the optimal design and schedule of energy hubs. In [18], the concept of EH was introduced as a novel concept. The authors solved the optimal power flow problem for integrated energy systems with multiple energy carriers considering multiple renewables. In [19], a robust optimization problem of an EH operations was presented with the objective of minimizing a cost function. Authors in [20–22] extended the model of EH to include distributed generations, renewables, energy storage, in addition to demand response taking into consideration the operation uncertainty. A comprehensive linearized model was presented in [23] for optimal design and operation of EHs considering reliability constraints. In [24], a charging process of plug-in hybrid electric vehicles (PHEVs) was optimally

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List of symbols

N_b	Number of system buses
m	Number of voltage and current phasors measurements
z	A vector containing the m-measurement phasors
x	State vector containing both measured and unmeasured voltage phasors
H	the design matrix of dimension (m × Nb)
e	A vector of measurement error with dimension (m × 1)
I	The identity matrix
Y_{IM}, Y_{IC}	Sub-matrices containing branches series and shunt admittances
M_{IB}	The (mI × b) current measurement-to-branch incidence matrix.
Y_{BB}	The (b × b) branch admittances diagonal matrix
A_{MB}	Measured node-to-branch incidence sub-matrix with dimension (N_M × b)
A_{CB}	Calculated node-to-branch incidence sub-matrix with dimension (N_C × b)
G	The decoupled gain matrix
C_{con}	The total cost of consumed electrical energy
C_{gen}	The total cost of generated energy
$C_{H\text{-}gas}$	The total cost of consumed gas energy
C_{shed}	The unserved energy cost
C_{loss}	The energy loss cost
C_{PMU}	The cost of installed PMUs
C_D	The diesel energy generation cost
C_{PV}	The PV energy generation cost
C_{wind}	The wind energy generation cost
C_{PHEV}	The PHEV batteries charge/discharge energy cost
C_{HE}	The total cost of energy obtained from energy hubs
N	Simulation period
ND	The number of diesel units in the system
N_{PMU}	The number of phasor measuring units in the system
N_{ZD}	The number of zeroes in the diagonal of matrix D
NG_i	The number of generating units in i^{th} island
t	Time index
$P_{load}(t)$	Demand power at time t
$P_{Di}(t)$	Generated power by i^{th} diesel unit at time t
$P_{PV}(t)$	Output power of PV unit at time t
$P_{wind}(t)$	Output power of wind unit at time t
$P_{ch}(t)$	Charging power of PHEV batteries at time t
$P_{disch}(t)$	Discharging power of PHEV batteries at time t
$P_{HE}(t)$	Electric power input to energy hubs at time t
$P_{H\text{-}gas}(t)$	Gas power input to energy hubs at time t
$P_{shed}(t)$	Unserved power at time t
$P_{loss}(t)$	Power loss at time t
$P_{ec}(t)$	The electricity/cooling power conversion of energy hub at time t
$P_{hc}(t)$	The heat/cooling power conversion of energy hub at time t
$P_g(t)$	The network gas supply at time t
$P_B(t)$	The boiler's output power at time t
a_i, b_i, c_i	Fuel cost coefficients of the i^{th} diesel generator
$Pr_{load}(t)$	Load wholesale price at time t
$Pr_{PV}(t)$	PV energy cost at time t
$Pr_{wind}(t)$	Wind energy cost at time t
$Pr_{PHEV}(t)$	PHEV charge/discharge energy cost at time t
$Pr_E(t)$	The cost of energy imported from energy hubs to the network at time t
$Pr_{gas}(t)$	The cost of gas energy to energy hubs at time t
$Pr_{shed}(t)$	Unserved energy cost at time t
$Pr_{loss}(t)$	Energy loss cost at time t
Pr_{PMU}	The cost of PMU
P^{i}_{gen}	The active power generated at bus i
P^{i}_{load}	The active load power at bus i
Q^{i}_{gen}	The reactive power generated at bus i
Q^{i}_{load}	The reactive load power at bus i
V_i, V_j	The voltages at bus i and bus j, respectively
Y_{ij}	The line admittance between bus i and bus j
δ_i, δ_j	The phase angles of voltages at bus i and bus j, respectively
θ_{ij}	The phase angle of admittance Y_{ij}
P_{Di}^{min}	The minimum power generated by the i^{th} diesel unit
P_{Di}^{max}	The maximum power generated by i^{th} diesel unit
P_{CHP}^{max}	The maximum power input to CHP
P_B^{max}	The maximum power input to boiler
P_g^{max}	The maximum gas supply to the network
$P_k(t)$	The active power flow through k^{th} feeder at time t
$Q_k(t)$	The reactive power flow through k^{th} feeder at time t
S_k^{max}	The maximum power capacity of the k^{th} feeder
$SOC_i(t)$	The state of charge of the i^{th} battery at time t
SOC_{max}	The maximum state of charge of a battery
SOC_{min}	The minimum state of charge of a battery
R_{ch}, R_{disch}	The battery rate of charge and discharge, respectively
$V_i(t)$	The i^{th} bus voltage magnitude at time t
V_i^{max}, V_i^{min}	The maximum and minimum limits of bus voltage magnitude, respectively
$L_e(t)$	The electrical load of an energy hub
$L_h(t)$	The heating load of an energy hub
$L_c(t)$	The cooling load of an energy hub
v(t)	The gas dispatch factor of an energy hub
TR_B	The boiler's turndown ratio
η_{ge}	The electrical efficiency of CHP
η_{gh}	The heating efficiency of CHP
η_B	The heating efficiency of boilers
η_{ec}	The electricity to cooling conversion efficiency of cooling chiller
η_{hc}	The heating to cooling conversion efficiency of cooling chiller

coordinated in the context of EH s. All of the previously mentioned researches focused on dealing with a single hub. On the other hand, many researches addressed the presence of multiple hubs in the system. In [25], optimal power flow problems combined with economic dispatch of multiple energy carriers were presented to cover both energy conversion and transmission between a number of EHs. Demand side management (DSM) was integrated once again in [26] for optimal energy management of EHs. The interaction among a number of EHs in DSM program was considered. An essential part of an energy hub is the combined heat and power (CHP) units. That is why CHP units have attracted the attention of many researchers. In [2,27], the authors proposed a methodology to determine the optimal size of CHP in an EH, while in [28] the authors presented a TLBO based optimization technique to solve the CHP dispatch problem. The objective was to reach power cost saving, loss reduction, reliability enhancement with environmental considerations.

In addition, the application of DSM programs contributes to overcome energy cost problems for consumers. Most importantly, DSM can partially solve the mismatch problem between generation capabilities and load requirements during some intervals either