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Reliability constrained congestion management with uncertain negawatt demand response firms considering repairable advanced metering infrastructures

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ABSTRACT

This paper presents a new framework for congestion management utilizing a reliability model of demand response resources under the smart grid environment. Demand response resources modeling is highly appertaining to uncertainty of customer's behavior. Interval data which is a core deliverable of advanced metering infrastructure, is essential for customers to participate in demand response events. Hence, a systematic method based upon frequency and duration approaches is utilized to present the multi-state model of multiple demand response resources considering repairable advanced metering infrastructures, the so-called demand response firm. Moreover, a new two-step congestion management structure with proposed demand response firm model is introduced for relieving congestion besides diminishing the risk of supplying loads. Firstly, system operator clears the electricity market based on economic and/or reliability-driven issues without considering transmission network limits. Afterwards, he/she will alleviate the existing transmission congestion considering a trade-off between demand response firms and load shedding besides generation rescheduling. In this regard, the impact of several important factors such as demand response firms' maximum achievable potential and forced outage rate of advanced metering infrastructures on the proposed framework are assessed. The simulation results discuss economic- and reliability-driven measures of the proposed demand response model in congestion management.

1. Introduction

In a competitive electricity market environment, all participants including generation companies and consumers compete for earning more profit [1]. Increase in sales of electricity and various contracts make great use of transmission grid. Thus, congestion management is a crucial issue in restructured power system which means transmission lines must not be driven beyond permissible transfer limits [2]. Congestion management strategies are different in various electricity markets according to their structures. In some power markets, congestion management is included into security constrained unit commitment. Indeed, security constrained unit commitment can be considered as a hidden congestion management in which the system is operated without violation of line power flow limits, and in fact no congestion relief tools are utilized [3]. Some other markets implement a two-step congestion management strategy so that at first, electricity markets are cleared with neglecting transmission network security. Then, in case transmission congestion occurs, ISO (Independent System Operator) will relieve the existing transmission congestion close to operation time [4]. From a general perspective, congestion management methods can be also divided into two categories based on before and after congestion occurrence, namely preventive and corrective congestion management methods. In recent years, multifarious studies have utilized different corrective congestion management methods, specially generation rescheduling and load shedding. Pantošuses presented power transfer distribution factors for generation and load redispatching as corrective congestion relief methods to alleviate congestion [5]. In Ref. [6], after determining sensitivity of generators willing to take part in congestion management, deviation of rescheduled power outputs from scheduled levels was minimized. Reference [7] presented a linear programming technique for congestion management using redispatch of generators' output power. Reference [8] described a congestion

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Nomenclature

Constants

N_{step}^{DRR} Total number of approximated states for a DRR
NE Total number of elements constituting the AMI
N_{step}^{DRF} Total number of approximated states for a single DRF
N_{DRR} Total number of demand response resources
N_{AMI} Total number of AMIs
Ng Total number of generators
N_{DRF}^{MC} Total Number of demand response firms in market clearing procedure
NSC Total number of states in capacity outage probability table
NS Total number of scenarios for power curtailment of DRFs in market clearing procedure
NS^{RC} Total number of scenarios for power curtailment of DRFs in relieving congestion procedure
N_{DRF}^{RC} Number of DRFs in relieving congestion procedure

Sets and indices

k Number of approximated states for a DRR
e Index for elements constituting the AMI
ε Number of approximated states for a single DRF
m Number of AMIs that are operable
γ,τ Two states in a DRF which have transition between each other
A_ε Couple of states that result in the identical output power as state ε
j Index for generators
f Index for demand response firms in market clearing procedure
ψ Index for states in capacity outage probability table
ω Set of in service generators
St Index for generator states in market clearing procedure
ζ Index for DRFs' power curtailment scenarios in market clearing procedure
$\Im$ Index for DRFs' power curtailment scenarios in relieving congestion procedure
w Index for involuntary shed loads
r Index for demand response firms in relieving congestion procedure
Ω^{Node} Set of buses
Ω^{Load} Set of loads
Ω^n Set of buses connected to bus n
DRn,wn Index for DRF and shed loads at bus n
SGn Set of generators connected to bus n

DRF modeling associated parameters

$\lambda_{k\beta}^{DRR}$ Transition rate from state k to state β for a DRR
$N_{k\beta}$ Total number of observed transitions from state k to state β
D_k^t Duration of state k in the whole period
D^T Entire period of observation
P_k^{DRR} The occurrence probability of state k in a Markov model of a DRR
C_{DRR}^k Output power curtailment associated with approximated state k for a DRR
C_{DRR}^{max} Maximum power curtailment of a DRR
C_{DRR}^{real} Real power curtailment of a DRR
λ^{AMI} Failure rate of AMI
λ_e,r_e Failure rate and repair time of element e constituting the AMI
μ^{AMI}, r^{AMI} Repair rate and repair time of AMI
P_o^{AMI} Probability that AMI is operable
P_f^{AMI} Probability that AMI fails
C_{DRF}^ε Output curtailment associated with approximated state ε for a single DRF
C_{DRF}^{real} Real power curtailment of a single DRF
P_m^k Possible power curtailment of a single DRF
P_i Probability of possible power curtailment state i clustered to approximated state ε for a DRF
Pr_{DRF}^ε Probability of approximated state ε for a DRF
f_k^{DRR} Occurrence frequency of approximated state k in a Markov model of a DRR
$P_\varepsilon f_\varepsilon$ Probability and frequency of the new combined state ε in $COPT^{DRF}$
$f_{+\varepsilon}f_{-\varepsilon}$ Frequency of occurrence from state ε to the higher and lower output power states
$\lambda_{+\varepsilon},\lambda_{-\varepsilon}$ Departure rate from state ε to the higher and lower output power states

$RCCM^{DRF}$ associated parameters

$Prob_{MC}^\zeta$ Probability of scenario ζ for power curtailment of DRFs in market clearing procedure
$\Phi_{DRF,f}^\zeta$ Percentage of power curtailment of DRF f under scenario ζ in market clearing procedure
$price_{DRF,f}^{MC}$ Price of decreasing output power for DRF f in market clearing procedure
$VOLL$ Value of lost load
$P_{G,j}^{Min}$ Lower limit of real power generation of generator j
$P_{G,j}^{Max}$ Upper limit of real power generation of generator j
pr_ψ Probability of state ψ in capacity outage probability table
p_F The fixed load based on demand forecasting
$En_{DRF,f}^{MC}$ Enrolled power curtailment of DRF f in market clearing procedure (capacity of DRF f)
pr_j^{st} Probability of being in each state for in service or out service generators
$B_{G,j}^{Up}$ Bid price of generator j to increase its power
$B_{G,j}^{Down}$ Bid price of generator j to decrease its power
$Prob_{RC}^\Im$ Probability of scenario $\Im$ for power curtailment of DRFs in relieving congestion procedure
$price_{DRF,r}^{RC}$ Price of decreasing power for DRF r in relieving congestion procedure
$\Phi_{DRF,r}^\Im$ Percentage of power curtailment of demand response firm r under scenario $\Im$ in relieving congestion procedure
$VOLL_w^{LS}$ Value of lost load w for involuntary load shedding
$En_{DRF,r}^{RC}$ Enrolled power curtailment of DRF r in relieving congestion procedure (capacity of DRF r)
x_{nq} Reactance of line connected to buses n and q
F_{nq}^{Max} Maximum line flow of the line connected to buses n and q

$RCCM^{DRF}$ associated variables

$I_{G,j}$ Commitment state of generator j
$CF_j(\cdot)$ Production cost function of generator j
$p_{G,j}^\zeta$ Power generation of generator j under scenario ζ in market clearing procedure
$EENS(\cdot)$ Expected energy not supplied
$p_{DRF,f}^{MC}$ Expected Power curtailment of DRF f in market clearing procedure
$p_{DRF,f}^{\zeta,RED}$ Power reduction of DRF f under scenario ζ in market clearing procedure