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Reliability and economic evaluation of demand side management programming in wind integrated power systems

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ABSTRACT

In this paper, security constrained unit commitment (*SCUC*) is employed for simultaneous clearing of energy and reserve markets. Spinning reserve of generation units and interruptible loads (*IL*) are assumed as system operating reserves. In the proposed method, the unit commitment program is done with considering the wind power uncertainty. So, modeling the wind uncertainty has been done by a two-stage stochastic programming. Also, the economic evaluation of wind power uncertainty is discussed and the impacts of *IL* and wind farm locations have been studied on the system reliability. Expected energy not supplied (*EENS*) is considered as criterion for undesirable load shedding of power system. Finally, the proposed model is applied to the IEEE reliability test system (IEEE-RTS) to demonstrate its effectiveness.

Introduction

In the last thirty years, the demand side management (*DSM*) solutions have been used to reduce energy consumption. Traditionally, *DSM* programs focused on energy efficiency and energy saving programs to improve system reliability, especially during the network fault [1]. Restructuring in power systems changes the objective of consumption management. So, new forms of *DSM* programs are necessary to emphasize a common response to the changes in the electricity prices. Thus, new *DSM* techniques are proposed which are based on the market operations and participation of customers in the market, while the competitive state of the market does not decrease. Also, the overall reliability of the power system is increased with participation of the demand side [2].

In the recent years, power generation based on renewable energies has been important worldwide. The growth of wind power generation is fast due to its environmental and economic benefits. The power output of wind farms cannot be dispatched by conventional methods, because of the wind power generation volatility. Consequently, the efficiency of system operating is reduced caused by the wind power uncertainty. Hence, system operator should use the tools that predict the variable nature of wind power resources to maintain the security and reliability of power system during the system scheduling and operation. The system operator can make more accurate decisions for the market and electrical system with knowledge of future wind power generation.

In the competitive environment, the independent system operator (*ISO*) is responsible for managing and clearing of markets. Generation companies (*GenCos*) submit their offers to *ISO* for supplying the energy. Also, big consumers, distributor companies (*DisCos*) submit their bids to *ISO* for energy purchasing and supplying provisions as *ILs*. The amount and price of the traded energy and reserve are determined based on the received bids. This process called market-clearing. The energy and reserve markets can be cleared by *ISO* in two ways which, are, the sequential dispatch and the simultaneous dispatch [3]. In this paper, the simultaneous dispatch of energy and reserve is considered to prevent the occurrence of price reversals and to reach more optimal values of the problem.

In this paper, *SCUC* has been considered for simultaneous clearing of energy and reserve market. Wind power prediction has been proposed as the uncertain variable. So, a two-stage stochastic mixed integer programming (*SMIP*) is used to include the uncertainty of wind power generation. The purpose of this program is the unit commitments with their energy production and the scheduled spinning reserve for each production unit and *IL* for the next day. Also, the impacts of *ILs* and wind farms locations have been

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Nomenclature

Decision variables

Continuous variables of first-stage

- $C_{it}^{R^U}$ the offer costs of the up-spinning reserve of unit i in the time period t
- $C_{it}^{R^D}$ the offer costs of the down-spinning reserve of unit i in the time period t
- $C_{it}^{R^{NS}}$ the offer costs of the non-spinning reserves of unit i in the time period t
- $C_{jt}^{R^U}$ the offer costs of the up spinning reserve of load j in the time period t
- $C_{jt}^{R^D}$ the offer costs of the down spinning reserve of load j in the time period t
- C_{it}^{SU} the cost due to the scheduled start-up of unit i in the time period t [$]
- P_{it}^{S} the power output scheduled for unit i in the time period t [MW]
- L_{jt}^{S} the power scheduled for load j in the time period t [MW]
- R_{it}^{U} the up-spinning reserve scheduled for unit i in the time period t [MW]. Limited to $R_{it}^{U,max}$
- R_{it}^{D} the down-spinning reserve scheduled for unit i in the time period t [MW]. Limited to $R_{it}^{D,max}$
- R_{it}^{NS} the non-spinning reserve scheduled for unit i in the time period t [MW]. Limited to $R_{it}^{NS,max}$
- R_{jt}^{U} the up-spinning reserve scheduled for load j in the time period t [MW]. Limited to $R_{jt}^{U,max}$
- R_{jt}^{D} the down-spinning reserve scheduled for load j in the time period t [MW]. Limited to $R_{jt}^{D,max}$

Continuous variables of second-stage

- $C_{it\omega}^{SU}$ the real time start-up cost of unit i in the time period t and scenario ω
- $P_{Git\omega}(m)$ the power output scheduled from the m-th block of energy offered by unit i in the time period t and scenario ω in MW. Limited to $P_{Git}^{max}(m)$
- $C_{it\omega}^{A}$ the cost due to the change in the start up plan of unit i in the time period t and scenario ω
- $p_{Git\omega}(m)$ the power output of unit i in the time period t and scenario ω [MW]
- $P_{it\omega}^{IL}$ the interruptible load i in the time period t and scenario ω
- $L_{jt\omega}^{C}$ the power consumed by load j in the time period t and scenario ω [MW]
- $r_{it\omega}^{U}$ the up-spinning reserve deployed by unit i in the time period t and scenario ω [MW]
- $r_{it\omega}^{D}$ the down-spinning reserve deployed by unit i in the time period t and scenario ω [MW]
- $r_{it\omega}^{NS}$ the non-spinning reserve deployed by unit i in the time period t and scenario ω [MW]
- $r_{jt\omega}^{U}$ the up-spinning reserve deployed by load j in the time period t and scenario ω [MW]
- $r_{jt\omega}^{D}$ the down-spinning reserve deployed by load j in the time period t and scenario ω [MW]
- $r_{it\omega}^{G}(m)$ the reserve deployed from the m-th block of energy offered by unit i in the time period t and scenario ω [MW]
- $L_{t\omega}^{shed}$ the total load shedding in the time period t and scenario ω [MW]
- $L_{jt\omega}^{shed}$ the load shedding of load j in the time period t and scenario ω [MW]
- $L_{jt\omega}^{shedIL}$ the load shedding in presence of IL imposed on consumer j in the time period t and scenario ω [MW]
- $S_{t\omega}$ the wind power generation spillage in the time period t and scenario ω [MW]
- $f_{t\omega}(n,r)$ the power flow through line (n,r) in the time period t and scenario ω [MW]
- $\delta_{nt\omega}$ the voltage angle at node n in the time period t and scenario ω [MW]

Binary variables of first-stage

- U_{kt}^{ilseg} the binary variable being equal to 1 when interruptible load k is online at period t
- u_{it} the binary variable being equal to 1 when unit i is committed in the time period t at scheduled stage

Binary variables of second-stage

- $U_{kt\omega}^{ilseg}$ the binary variable being equal to 1 when interruptible load k is online at period t and scenario ω
- $v_{it\omega}$ the binary variable being equal to 1 when unit i is committed in the time period t and scenario ω in real time
- $u_{kt\omega}^{il}$ the binary variable being equal to 1 when interruptible load k is committed in the time period t and scenario ω in real time

Random variables

- P_{t}^{WP} random variable modeling the wind power generation in the time period t [MW]
- $P_{t\omega}^{WP}$ represents the amount of the random variable modeling the wind power generation in the time t and scenario ω in real time [MW]

Constants

- d_t the duration of the time period t [h]
- λ_{it}^{SU} the start-up offer cost of unit i in the time period t [$]
- $\lambda_{Git}(m)$ the marginal cost of mth block of energy offered by unit i in the time period t [$/MWh]
- λ_{Ljt} the utility of load j in the time period t [$/MWh]
- λ_{t}^{WP} the marginal cost of the energy offer submitted by the wind producer in the time period t
- V_{jt}^{LOL} the value of loss load for load j in the time period t [$/MWh]
- V_{t}^{S} the cost of wind power spillage in the time period t [$/MWh]
- π_{ω} the probability of occurring scenario ω
- P_{i}^{max} the capacity of unit i [MW]
- P_{i}^{min} minimum power output of unit i [MW]
- $B(n,r)$ absolute value of the imaginary part of the admittance of line (n,r) [p.u.]
- $f_{max}(n,r)$ maximum capacity of line (n,r) [MW]
- $CLOL_{k}^{il}$ the count of Loss of Load of interruptible load k [MW]
- $T_{on,k}^{il,max}$ the max uptime of interruptible load k [MW]
- $T_{off,k}^{il,min}$ the min uptime of interruptible load k [MW]
- $LOLH_{k}^{il}$ the loss of load hour of interruptible load k [MW]

Sets

- $\Lambda(t,\omega)$ the set of transmission lines in the time period t and scenario ω
- R_{it}^{NS} the non-spinning reserve scheduled for unit i in the time period t [MW]. Limited to $R_{it}^{NS,max}$