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Wind farms dispatching to manage the activation of frequency support algorithms embedded in connected wind turbines

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ABSTRACT

Wind energy development in power systems and their replacement for conventional generation plants are considered to be a two sided coin. Wind energy penetration process depends on two aspects, namely, the technical and economical impacts on power grid and electricity market. This paper focuses on the technical section and aims to solve a major problem related to the high wind energy penetration levels. This dilemma arises due to the intermittent nature of wind speed which mitigates its capabilities compared to conventional generation, especially in dealing with frequency drops. This research work focuses on a basic sector from this problem, particularly, dispatching the wind turbines, inside wind farms, during frequency drops mitigation. The proposed algorithm integrates several factors to determine the number of wind turbines which should contribute in system frequency recovery. Wind speed nature in the wind farm location, installed wind turbines types and their numbers are examples for these factors. However, this dispatching process is instantaneous and counts on other dynamic factors (e.g. average wind speed at wind turbine and frequency deviation severity). In addition, conventional generation is controlled based on wind farms reactions during frequency drops, likewise at normal operation. Certain zone from the Egyptian grid is integrated in this research work as a benchmark to apply the offered algorithm whereas real data for wind speeds and grid specifications are applied. MATLAB and Simulink are the implemented simulation environments.

1. Introduction

Nowadays, the energy crisis is on the top of either developed countries or third world countries priorities. The excessive fossil fuels consumption rates, their rising prices coupled with their high emissions have alerted many governments and companies to the electrical power production fuzzy future. Presently, renewable energies integration is the seldom solution, especially after recent nuclear reactors catastrophes. The most dominant renewable energies resources are hydro, solar and wind. Hydro power generation requires special geographical nature but it has valuable merit represented in the stable and fully controlled output power. Meanwhile, the major obstacle offending solar energy expansion is the high cost compared to the other two alternatives. Therefore, wind energy is considered as the favorite choice in spite of its fluctuating nature which is still limiting its penetration levels in modern power grids [1,2]. Generally, wind farms (WFs) installation impact on power systems grids' voltage and frequency responses require comprehensive studies [3].

This paper focuses on grid frequency response mutation due to wind energy integration which splits into two branches; normal operation and drop ride thru as well as frequency support operation. However, managing conventional generation capacity according to available wind power [4,5] has a major influence on both branches. Additionally, the determination of suitable number of wind turbines (WTs) contributing in frequency events curtailment (i.e. WF dispatching) is considered as a gray area. Literature offers different approaches to ride WT thru frequency drops and support the power system recovery. In [6] WT power and rotational speed are controlled together leading to active power overproduction where the three offered control modes are classified according to WT rotating speed. In particular, stored kinetic energy in WTs' rotating parts is the major source for system support during frequency recovery. This stored energy is converted into extra active power to support the system during frequency drops elimination [7,8]. Furthermore, de-loaded operation offered in [9,10] is one of the dominant applied methods to store higher amounts of kinetic energy enhancing WTs capability on contributing sufficiently in frequency drop clearance. Hence, at normal frequency WT output power is de-loaded by certain percentage so that the frequency support is insured by the deficit between optimum output and de-loaded one. This method does not cause any reduction for WT rotational speed; on the contrary,

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Nomenclature

WT	wind turbine
WF	wind farm
pu	per unit
TSO	transmission system operator
DFIG	double fed induction generator
K_{droop}	major controller droop constant
$K_{inertia}$	major controller inertia constant
E 101	Enercon wind turbine – model 101 m, 3.4 MW
G 90	Gameza wind turbine – model 90 m, 2.0 MW
N 117	Nordex wind turbine – model 117 m, 2.5 MW
WS	wind speed in m/s
WS(x)	average wake wind speed at distance (x in meters) from the wind turbine in m/s
WS_o	initial wind speed of certain wake wind speed in m/s
R	wind turbine rotor radius in meters
D_{row}	distance between each two successive rows of wind turbines inside a wind farm
k_w	wake decay coefficient
C_t	thrust coefficient
t_{delay}	wind stream propagation delay time in seconds
S_{WF}	aggregated nameplate rating of a wind farm in MW
$\Delta P_{WFs\ total}$	required step rise in active power from the connected WFs in MW
$\Delta P_{WFi\ max}$	maximum allowed required step rise in active power from wind farm "i"
s_f	up scaling factor (dimensionless)
Δf	frequency deviation in Hz or pu
WSi_{inst}	instantaneous approximate wind speed magnitude at wind farm "i"
WSi_{avg}	average free stream wind speed magnitude at wind farm "i"
WFi_{weight}	the estimated contribution of wind farm "i" in the required active power support
$WFi_{total\ weight}$	the summation of WFi_{weight} for all the WTs installed in the considered system
WTi_{rating}	nameplate power rating of wind turbine "i" as mentioned by the vendor
H	generator inertia in seconds
Δf_{max}	maximum frequency deviation occurred in a frequency event in Hz
$\Delta f_{10\ s}$	frequency deviation after 10 s from a frequency event initiation in Hz
T_{SM}	time at which frequency safe margin is reached after a frequency event initiation
Ni_c	number of clusters in wind farm "i"
Ni_{pc}	number of clusters participating in frequency deviation curtailment in wind farm "i"
T_f	time frame in seconds of updating Ni_{pc} value

over speeding technique is implemented to de-load WT output. Tracking the same concept, a supplementary controller is integrated in DFIG standard controller was proposed in [11]. This secondary controller gain is proportional to system capacity, WT rating and instantaneous frequency deviation at WT connection point. It adjusts the WT output torque reference signal based on system requirements to overcome the incident frequency excursion. Obtained results were motivating and revealed a positive impact for proposed technique on pitch angle oscillations curtailment but it does not consider the drawbacks at neither high nor medium wind energy penetration levels. However [12], concluded the impact of wind energy replacement for conventional plants as well as highlighting the negative influence of DFIG WTs integration on the overall system inertia. Proposed concept in [13] concentrates on shifting single WT between normal and fault operational modes. Furthermore, an interesting comparison is offered between controlling WT as a conventional generator using droop theory from one side to virtual inertia principle widely applied in literature on the other side. This comparison includes the impact of controllers' parameters variation in case of both techniques. Likewise, the inertial and droop response were discussed in [14] at 20% and 50% wind penetration levels. Additionally, this research work did not highlight the dispatching of all WFs or even a single WF. It only concentrates on riding each variable speed WT independently according to a droop–inertial controller. In [15] the authors have already proposed a relatively advanced methodology merging most of previously mentioned ride thru and support mechanisms, thereupon, this methodology is improved in [16]. Generally, offered methodology integrates the approximate value of instantaneous WS and WT properties including its pitch controller, aerodynamic characteristics and rotor speed limits. For instance, WS decides the suitable operation region whereas each region has two operation modes, namely, normal operation and fault operation (i.e. support algorithm is activated). WT may be de-loaded during normal operation within certain range of WS by pitch angle setting, whereas WT is decelerated at lower WSs to generate higher active power in case of frequency deviations. In addition, this methodology aims to minimize the usual losses in generated wind energy which occur due to output power de-loading by shortening de-loaded operation intervals. Moreover, simplified heuristic dispatching method was integrated with the offered support algorithm. The early experiments in [15,16] proved that switching the whole WF from normal to fault operation causes unfavorable tough oscillations in frequency response during recovery process thus; these oscillations are more dangerous at higher wind energy penetration levels. It is worth mentioning that, the offered dispatching algorithm is very simplified and it was implemented only to provide clearer examination for the proposed support algorithm, such that the obtained results are more significant and not affected by the sudden switching of all WTs integrated in the system, from normal to fault mode and vice versa, at the same time. Findings of [15,16] motivate the authors to perform the research work conducted in this paper. They aim to link between the number of participating WTs in frequency recovery and the other static and dynamic factors so that all WFs are transitioned rapidly and smoothly between normal and fault operational modes. In particular, only certain number of WTs in each WF will contribute in the frequency excursion curtailment through the proposed dispatching technique which estimates and organizes the role of each WF in frequency deviation elimination.

In the light of the previous brief literature survey, most of mentioned research efforts are common from the point of view of examining the WT contribution in frequency events elimination and the assessment of wind energy influence on grid recovery from frequency drops. On the contrary, they do not offer detailed methods to organize (i.e. dispatch) the WTs, inside each WF, between normal and support modes during frequency recuperation. Hence, this paper proposes an algorithm to coordinate WTs switching between normal and fault modes inside one WF as well as estimating