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# Flexible fault ride through strategy for wind farm clusters in power systems with high wind power penetration

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ABSTRACT

This paper investigates a flexible fault ride through strategy for power systems in China with high wind power penetration. The strategy comprises of adaptive fault ride through requirements and maximum power restrictions of the wind farms with weak fault ride through capabilities. The slight faults and moderate faults with high probability are the main defending objective of the strategy. The adaptive fault ride through requirement in the strategy consists of two sub fault ride through requirements, a temporary slight voltage ride through requirement corresponding to a slight fault incident, with a moderate voltage ride through requirement corresponding to a moderate fault. The temporary overloading capability of the wind farm is reflected in both requirements to enhance the capability to defend slight faults and to avoid tripping when the crowbar is disconnected after moderate faults are cleared. For those wind farms that cannot meet the adaptive fault ride through requirement, restrictions are put on the maximum power output. Simulation results show that the flexible fault ride through strategy increases the fault ride through capability of the wind farm clusters and reduces the wind power curtailment during faults.


## 1. Introduction

Fast development of wind power generation brings new requirements for wind turbine integration into the network. By now, wind power accommodation capability is influenced by wind power penetration level and other complicated factors. From the research in Irish power system, the amount of offshore wind, the non-synchronous generation and the transmission constraints can be crucial to the wind power accommodation [1]. As the penetration of the wind farms into the power system increases, voltage stability of the wind farm and voltage control provided by the wind turbines are becoming more significant [2]. To increase renewable energy resources, vehicle-to-grid technique can be applied in smart grid [3], and these electric vehicles can work as loads or energy storage systems [4]. However, from the view point of the fault protection, FRT capability is a key technique used by wind farms to maintain grid connection during voltage dips caused by grid faults [5], and it also has a key influence to the wind power accommodation of the power system [6].

Various studies have been conducted by researchers about FRT capability and regulation. Abbey and Joos [7] reviewed that voltage dips have effect on the operation of wind farms with different wind turbine configurations. Mohammadi et al. [8] proposed an efficient control strategy to improve the FRT capability of the DFIG during the symmetrical and asymmetrical grid faults. Muyeen et al. [9] developed suitable control strategies for the overall system to improve the low voltage ride through capability of variable speed wind generator by considering wind farm grid code. Rahim and Nowicki [10] presented a decoupled P–Q control strategy of a super capacitor energy storage system for low voltage ride through as well as damping enhancement for the DFIG system. Ramirez et al. [11] presented a strategy for the STATCOM to guarantee the grid code compliance when the wind farm faces an extensive series of grid disturbances. Ullah et al. [12] pointed out that the performance of a test system during disturbances is improved when the wind farm is complying with the E.ON code compared to the traditional unity power factor operation. Ling et al. [13] proposed a direct method based on space vector to obtain an accurate expression of rotor currents as a function of time during symmetrical voltage faults in the power system.

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**Nomenclature**

*Abbreviations*
FRT fault ride through
SVRT slight voltage ride through
MVRT moderate voltage ride through
DFIG doubly fed induction generator
SCIG squirrel cage induction generators
RSC rotor side converter

*Parameters*
$U_{nom}$ the normal voltage of the power system
$U_{fal}$ the minimum voltage during fault
$U_{rec}$ the minimum voltage to keep connection with the grid when a wind farm is in normal operation condition
$T_{fal}$ fault duration
$T_{rec}$ duration for voltage restoration after fault occurs
$U_{rcov1}$ temporary low voltage in SVRT requirement
$T_{rcov1}$ overloading duration in SVRT requirement
$U_{rated,m}$ rated voltage of the wind turbine generator in the $m$th wind farm
$I_{rated,m}$ rated current of the RSC in the $m$th wind farm
$I_{max,m}$ maximum over current of the RSC in the $m$th wind farm
$U_{rcov2}$ temporary low voltage after fault clearance in MVRT requirement
$T_{rcov2}$ overloading duration of the RSC in MVRT requirement
$P_{lack,sys}$ the maximum wind power curtailment that system can afford during slight faults and moderate faults
$P_{IImax}$ maximum allowed power of Class II wind farms
$P_{IIImax}$ maximum allowed power of Class III wind farms
$\beta$ the natural frequency characteristic coefficient
$\Delta f_{lack}$ maximum allowed frequency deviation
$K_d$ the distribution coefficient
$C_{II,i}$ capacity of the $i$th wind farm in Class II wind farms
$C_{III,j}$ capacity of the $j$th wind farm in Class III wind farms
$P_{IImax,k}$ maximum allowed power of $k$th wind farm in Class II wind farms
$P_{IIImax,n}$ maximum allowed power of $n$th wind farm in Class III wind farms

*Sets*
$G_w^{(q)}$ the $q$th wind farm cluster
$G_w$ set of all the wind farm clusters in the system
$G_{mod}$ set of all operation modes

As China is making regulations to develop sustainable energy, the total installed wind power capacity in China will reach 1600 GW in 2020 [14]. Currently, most installed wind farms are DFIGs, and only a few are SCIGs or other types [15]. As a result, system operators in China enforce strict FRT requirements on wind farms integration [16]. Generally, the crowbar system is essential to avoid the disconnection of DFIG from the network during faults [17]. However, unlike wind farms in Europe, most installed legacy DFIG wind farms in China before 2011 lack crowbar protection and cannot ride through severe voltage dips during faults [18]. Furthermore, most wind farms in China are connected as a centralized cluster via by long distance overhead lines. According to several tripping events of wind farms [18], these legacy wind farms with weak FRT capability are more vulnerable to voltage dips than frequency deviation [19]. At the same time, wind farms in Texas in the US with a similar centralized cluster topology [20], also experience voltage vulnerable FRT problems [21]. Following cascaded events in transmission systems [22], the most worrying problem for a centralized topology is cascading trip events of wind farm clusters caused by short circuit faults, which may propagate over very large areas [23].

Considering that the capacity of the legacy wind farms is very large and their FRT capability is limited, current FRT grid code requirement is very difficult to be adopted for daily operation. Consequently, system operators in China begin to establish new FRT rules to classify the installed legacy wind farms, and enforce power restrictions on those wind farms with very weak FRT capability. Based on the reality that legacy wind farms cannot follow current FRT grid code requirement, new FRT rules allow some legacy wind farms to be tripped when faults occur, which is a new concept for the FRT application of legacy wind farms. Currently, a simple power restriction strategy is already assigned by the Irish grid operators for legacy wind farms connection to the weak parts of the grid [24].

This research focuses on avoiding cascading trip events of wind farm clusters during faults and proposes a flexible FRT strategy for wind farm clusters in power systems with high wind penetration. This flexible FRT strategy fully analyses the influence of faults to the wind farms in the cluster, as well as the temporary overloading capability of the wind turbine converters. Unlike current FRT requirement, which mainly restrain the FRT capability of a single wind farm, this strategy focuses on the FRT capability of the entire wind farm cluster. The key feature of this flexible FRT strategy is that it is not a strict requirement to force wind farms or manufacturers to follow, but a strategy to classify the FRT capability of the legacy wind farms with very large installed capacities. After the classification of the wind farms, power output of some wind farms with weak FRT capability is restricted to avoid large wind power curtailment during faults. The objective of this FRT strategy is to limit the lost wind power of the entire cluster within an acceptable level during faults.

The remainder of this paper is organized in four sections. In Section 2, the existing FRT requirements in China are detailed, and the disadvantages of the current FRT requirement in the operation of the legacy wind farms are analyzed. In Section 3, the requirements of the flexible FRT standard are summarized and the alternative flexible FRT strategy is proposed. In Section 4, several fault scenarios in a typical power system with high wind power penetration in China are presented and the simulation results are examined. Finally in Section 5, the conclusions and discussions are presented.

## 2. Technical and operational consideration of FRT requirements

### 2.1. Parameter settings of the FRT requirement

FRT requirements in most countries are very similar and they are shown in Fig. 1.

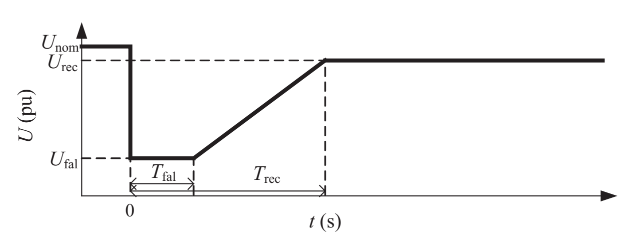


**Fig. 1.** FRT grid code requirement for the wind farm.